

Green Bonds and Environmental Performance in ASEAN: Evidence on Sustainable Development and CO₂ Emissions.

Dr. Bouchelit Rym¹
Pr. Belarbi Abdelkader²

Abstract

This study provides a comprehensive econometric analysis of the impact of green bonds on sustainable development and CO₂ emissions reduction across the Association of Southeast Asian Nations (ASEAN) region. As ASEAN nations navigate the dual challenges of rapid economic growth and increasing environmental pressures, green finance has emerged as a critical mechanism to channel capital towards sustainable projects. Utilizing a panel data approach, this research examines the relationship between green bond issuance and key environmental indicators, including CO₂ emissions per capita and the share of renewable energy. The empirical results suggest a statistically significant, albeit modest, negative association between the growth of the green bond market and CO₂ emissions, indicating their potential role in decarbonization despite the market's nascent stage. Furthermore, the analysis reveals a positive relationship between green bond issuance and the expansion of renewable energy capacity. Notably, the study observes heterogeneity across the region, where mature financial markets exhibit stronger transmission effects. The findings underscore the moderating role of institutional quality and regulatory frameworks in amplifying the environmental efficacy of green bonds. These insights offer critical guidance for policymakers and investors, highlighting the necessity of robust green finance ecosystems to unlock the full potential of green bonds in fostering a sustainable and low-carbon future for the ASEAN region.

Keywords: Green bonds, green finance, ASEAN, CO₂ emissions, Sustainable development, Renewable energy.

JEL Classification: G18, Q56, F63, Q54, Q01, Q42.

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1. Introduction

The global community faces an unprecedented challenge in mitigating climate change and fostering sustainable development, goals encapsulated in the Paris Agreement and the United Nations' Sustainable Development Goals (SDGs). This challenge is particularly acute in the ASEAN-6 region (Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam), where rapid economic growth and

¹ University Centre of Maghnia (Algeria), LEPESE Laboratory, r.bouchelit@cu-maghnia.dz

² University of Saida (Algeria), ITMAM Laboratory, abdelkader.belarbi@uni-saida.dz

urbanization between 2013 and 2024 have intensified environmental pressures. In this context, the financial sector is increasingly recognized as a pivotal agent of change, capable of redirecting capital flows towards environmentally sustainable and socially responsible investments. Among the most significant innovations in this domain is the emergence of green finance, with green bonds at its forefront. Green bonds are fixed-income instruments specifically earmarked to raise capital for projects with positive environmental benefits, such as renewable energy, energy efficiency, sustainable transport, and climate change adaptation.

The Association of Southeast Asian Nations (ASEAN) represents a critical geography in the global climate equation. The region is characterized by dynamic economic growth, a rapidly growing population, and increasing urbanization, all of which exert significant pressure on natural resources and contribute to rising greenhouse gas emissions. Simultaneously, many ASEAN countries are highly vulnerable to the adverse impacts of climate change, including rising sea levels, extreme weather events, and disruptions to agriculture and ecosystems. This duality of being both a significant contributor to and a primary victim of climate change creates a compelling imperative for a swift transition towards a sustainable, low-carbon development model.

In response, ASEAN member states have demonstrated a growing commitment to sustainable finance. Governments and financial institutions across the region are actively developing frameworks and initiatives to support the growth of green capital markets (Setyawati & Pranindita, 2025). Since the pioneering issuances by countries like the Philippines and Thailand in 2017, the ASEAN green bond market has expanded, reflecting a broader regional trend towards integrating sustainability into financial and economic planning (Ahmad et al., 2025). This includes not only national-level initiatives but also regional cooperation through platforms like the ASEAN Capital Markets Forum, which has established the ASEAN Green Bond Standards. These standards aim to enhance transparency, consistency, and accountability, thereby fostering investor confidence and facilitating cross-border investment in green projects. Despite this progress, the ASEAN sustainable finance market is still considered to be in a developmental stage, with significant potential for growth and a need for deeper analysis beyond simple issuance volumes (Li & Gong, 2024).

While the growth in green bond issuance within ASEAN is a positive development, a critical gap exists in the empirical understanding of its actual impact. The central premise of green bonds is that they effectively channel capital to projects that generate measurable environmental benefits, thereby contributing to national and

regional sustainability targets. However, the proliferation of these instruments has outpaced rigorous, evidence-based assessment of their effectiveness. The core problem this study addresses is the uncertainty regarding the causal link between the expansion of the green bond market and tangible improvements in sustainable development and CO₂ emissions reduction in the ASEAN context.

Several factors contribute to this problem. First, there is a risk of "greenwashing," where funds raised through green bonds may finance projects with marginal environmental benefits or projects that would have been undertaken regardless of the green label. This raises questions about the "additionality" of green bond financing. Second, the impact of green finance is not uniform and is likely influenced by a country's specific economic conditions, regulatory quality, and the maturity of its financial markets. The heterogeneity of the ASEAN region—spanning from global financial hubs like Singapore to developing economies with nascent capital markets makes a one-size-fits-all assessment inadequate. Finally, isolating the impact of green bonds from other concurrent factors, such as government environmental policies, technological advancements, and broader economic trends, presents a significant analytical challenge. Without robust econometric analysis, policymakers and investors lack the empirical evidence needed to design effective green finance policies and make informed capital allocation decisions. The discourse on sustainable development in the region requires a deeper investigation into the efficacy of these financial tools (Khokhar et al., 2024).

To address the identified problem, this study is guided by a central research question: What is the econometric evidence for the impact of green bond market development on sustainable development outcomes and CO₂ emissions reduction in ASEAN countries?

Correspondingly, the primary objectives of this research are:

1. To empirically assess the impact of green bond issuance on CO₂ emissions and renewable energy deployment in the ASEAN-6 region.
2. To examine the heterogeneity of this impact across markets with varying levels of financial maturity (e.g., Singapore versus Vietnam).
3. To analyze the temporal evolution of green finance effectiveness by comparing the pre-issuance baseline (2013-2016) with the active market phase (2017-2024).
4. To formulate evidence-based policy recommendations to strengthen regulatory frameworks and maximize the environmental benefits of green bonds.

This study aims to make several significant contributions to the literature on green finance, environmental economics, and development studies, with a specific focus on the ASEAN region.

First, it contributes to the empirical literature by moving beyond descriptive accounts of green bond market growth. While many studies have documented the rise of sustainable finance in ASEAN (Quetijero, 2023), few have employed rigorous econometric methods to quantify its impact on environmental outcomes. By using panel data analysis, this research provides a more robust assessment of the effectiveness of green bonds, helping to distinguish correlation from potential causality. This aligns with recent calls for more in-depth analyses of how green finance influences sustainable development and environmental performance in the region (Yen et al., 2024).

Second, the study provides valuable insights for policymakers and regulators in ASEAN. As member states continue to develop and refine their sustainable finance frameworks (Anisha et al., 2025), the empirical evidence generated by this research can inform the design of more effective policies. The findings can help policymakers understand the conditions under which green bonds are most effective and identify potential barriers that may be limiting their impact, thereby enabling the creation of a more supportive ecosystem for green investments.

Third, the research holds significant interest for investors and financial institutions. By providing evidence on the tangible environmental impacts associated with green bonds, the study can enhance investor confidence and help them better integrate environmental considerations into their investment decisions. It addresses the critical need for transparency and accountability in the green bond market, helping to mitigate concerns about greenwashing and ensure that capital is directed towards projects with genuine environmental benefits. The development of the financial sector is seen as an enabler for green finance, which in turn can drive positive environmental change (Phuong, 2025).

Finally, this study contributes to the broader academic discourse on the role of finance in addressing global environmental challenges. By focusing on the diverse and dynamic ASEAN region, it provides a unique case study that can yield lessons applicable to other emerging market economies grappling with similar challenges of balancing economic development with environmental sustainability.

This paper is organized into six main sections. Following this introduction, Section 2 provides a comprehensive review of the relevant literature and develops the

theoretical framework for the study. It examines the state of the green bond market in ASEAN, discusses the theoretical links between green finance, sustainable development, and CO₂ emissions, and formulates the research hypotheses. Section 3 details the research methodology, including the econometric model specification, data sources, variable measurement, sample selection, and the estimation strategy. Section 4 presents the empirical results and analysis, beginning with descriptive statistics and correlation analysis, followed by the main regression results on the impact of green bonds on sustainable development and CO₂ emissions, and concluding with robustness checks. Section 5 offers a detailed discussion of the findings, interpreting the results in the context of existing literature and drawing out key policy implications. Finally, Section 6 concludes the paper, summarizing the main findings, acknowledging the limitations of the study, and suggesting avenues for future research.

2. Literature Review and Theoretical Framework

2.1 The Green Bond Market in the ASEAN Context

The emergence of the green bond market in the ASEAN region represents a critical development in sustainable finance, driven by the dual imperatives of financing sustainable infrastructure and mitigating the profound impacts of climate change. Specifically, within our sampled ASEAN-6 economies, the 'green finance ecosystem' has evolved from a nascent stage in 2013 to a more structured market by 2024. The ASEAN region, home to some of the world's fastest-growing economies, is also exceptionally vulnerable to climate-related risks, including rising sea levels, extreme weather events, and threats to biodiversity and food security (Le & Vivian, 2025). This vulnerability has catalyzed a growing recognition among policymakers and market participants of the need for financial innovation to channel capital towards environmentally sustainable projects.

In response, regional bodies have established frameworks to promote market integrity and harmonization. The ASEAN Green Bond Standards (AGBS), launched in 2017, serve as a foundational pillar for the regional market. Aligned with the International Capital Market Association's (ICMA) Green Bond Principles (GBP), the AGBS provides a voluntary standard for issuers, aiming to enhance transparency, consistency, and accountability in the ASEAN green bond landscape. This framework is designed to mobilize both public and private capital for eligible green projects, encompassing areas such as renewable energy, energy efficiency, sustainable transport, and climate change adaptation (Fadhillah & Agung, 2024). The development of such standards is crucial for building investor confidence and

reducing the transaction costs associated with green issuance, thereby fostering a more liquid and robust regional market.

Despite this progress, the development of green bond markets across ASEAN member states is characterized by significant heterogeneity. Nations like Singapore, Malaysia, and Thailand have emerged as regional leaders, benefiting from well-developed capital markets, strong regulatory support, and proactive government initiatives. Singapore, for example, has positioned itself as a sustainable finance hub, leveraging sophisticated financial infrastructure and policy incentives to attract green bond issuers and investors (Fadhillah & Agung, 2024). Similarly, countries like Indonesia and Vietnam have recognized the potential of green bonds to finance their ambitious renewable energy targets and sustainable development goals (Jain et al., 2024). However, they face distinct challenges, including the need for more specific legal frameworks and clearer guidelines to stimulate corporate issuance and attract a broader investor base (Le & Vivian, 2025). For instance, studies suggest that a dedicated law specifically governing green bonds in Indonesia could significantly boost market growth by providing greater legal certainty for both issuers and investors (Jain et al., 2024).

Regional efforts are also underway to align ASEAN's sustainable finance frameworks with global best practices, including those of the European Union. The development of sustainability bond frameworks that are interoperable with international standards is a strategic move to attract global capital pools and enhance the credibility of the ASEAN market (Sudan, 2023). This alignment is vital, as it ensures that regional green bonds meet the stringent criteria demanded by international institutional investors who are increasingly integrating environmental, social, and governance (ESG) factors into their investment mandates. The collective ambition within ASEAN is to create an ecosystem where sustainable finance instruments like green bonds are not a niche product but a mainstream component of the financial system, effectively supporting the region's transition to a low-carbon and resilient economy.

2.2 Green Bonds as a Catalyst for Sustainable Development

The concept of sustainable development, classically defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs, rests on the balanced integration of economic, social, and environmental objectives. Green bonds are increasingly posited in the academic and policy literature as a key financial instrument to operationalize this concept by directing capital towards projects that generate positive environmental

externalities while supporting economic growth. The primary mechanism through which green bonds are theorized to catalyze sustainable development is their "use of proceeds" covenant, which contractually obligates issuers to allocate funds exclusively to pre-defined categories of eligible green projects.

This targeted financing model addresses a persistent market failure: the underinvestment in projects with high social and environmental returns but potentially longer payback periods or higher perceived risks than conventional investments. By creating a dedicated funding stream for assets like renewable energy infrastructure, energy-efficient buildings, sustainable water management systems, and clean transportation, green bonds bridge a critical financing gap. The growth of the financial sector, by enabling such innovations in green finance, plays a pivotal role in this process. Empirical evidence from the ASEAN region suggests that financial sector development is a key enabler for green finance, which in turn contributes positively to environmental outcomes and the broader sustainable development agenda (Phuong, 2025). This linkage underscores the importance of a mature financial ecosystem in translating green financial instruments into tangible environmental and developmental impacts.

Furthermore, the issuance of green bonds can have significant signaling and catalytic effects that extend beyond the immediate projects being financed. For corporate and sovereign issuers, entering the green bond market signals a commitment to sustainability, which can enhance reputation, attract a dedicated class of socially responsible investors, and potentially lower the cost of capital. This "greenium," or the lower yield on a green bond compared to an equivalent conventional bond, while not universally observed, represents a direct financial incentive for issuers to pursue green projects. This signaling effect can also foster a virtuous cycle, encouraging peers and competitors to adopt more sustainable practices and financing strategies to maintain their social license to operate and appeal to an increasingly ESG-conscious investor base.

The impact of green bonds on sustainable development is also tied to their role in promoting transparency and accountability. The Green Bond Principles and associated regional standards like the AGBS mandate rigorous processes for project evaluation and selection, management of proceeds, and ongoing impact reporting. This enhanced disclosure provides investors and other stakeholders with greater visibility into the environmental performance of the underlying assets. Such transparency not only helps mitigate the risk of "greenwashing" where funds are diverted to projects with negligible environmental benefits, but also contributes to a more sophisticated market understanding of environmental risks and

opportunities. By fostering a market that prices environmental factors more effectively, green bonds contribute to a more efficient allocation of capital, driving investment towards activities that support long-term, eco-friendly, and inclusive development (Jahanger et al., 2024).

2.3 The Nexus between Green Finance and CO₂ Emissions Reduction

A central claim in the discourse surrounding green finance, and green bonds in particular, is its efficacy in contributing to the abatement of greenhouse gas emissions, primarily carbon dioxide (CO₂). The theoretical linkage is direct: a significant portion of green bond proceeds globally and within the ASEAN region is allocated to projects that either generate zero-carbon energy (e.g., solar, wind, geothermal) or enhance energy efficiency, thereby reducing the demand for fossil fuels. By lowering the cost and increasing the availability of capital for such projects, green finance is expected to accelerate the transition away from carbon-intensive energy systems.

Recent empirical studies focusing on the ASEAN region have begun to validate this theoretical nexus. Research demonstrates a critical relationship between the deployment of green finance, the expansion of renewable energy capacity, and the trajectory of carbon emissions (Agustin et al., 2025). The findings from these studies consistently suggest that green finance is a significant factor in driving environmental improvements, including the reduction of CO₂ emissions. This is achieved by directly financing the substitution of fossil fuel-based power generation with renewable alternatives and by funding technological advancements that improve energy intensity across various sectors of the economy. For instance, an econometric analysis of ASEAN countries revealed that components of financial development that facilitate green finance are associated with a reduction in CO₂ emissions, highlighting the instrumental role of a sophisticated financial sector in achieving climate goals (Phuong, 2025).

The effectiveness of green bonds in this context, however, is contingent on several factors. The scale of the green bond market relative to the overall bond market and the total investment required for a low-carbon transition is a critical consideration. While the market has grown rapidly, its total volume remains a small fraction of the capital needed to meet the targets set forth in the Paris Agreement. Therefore, the impact of green bonds on national or regional CO₂ emissions levels must be understood as a contributing factor within a broader suite of climate policies, including carbon pricing, renewable energy subsidies, and regulatory standards.

Moreover, the credibility of the impact claims associated with green bonds hinges on robust monitoring, reporting, and verification (MRV) frameworks. The "additionality" of the financed projects, that is, whether the projects would have been undertaken without the green bond financing, is a key question in assessing their true impact. While challenging to measure empirically, the transparency and reporting requirements associated with green bonds provide a framework for assessing their environmental integrity. By requiring issuers to report on the expected and actual environmental impacts of their projects, including estimated CO₂ emissions avoided, the green bond market introduces a level of accountability that is often absent in conventional financing. As the market matures and impact reporting methodologies become more standardized, the ability to quantify the causal link between green bond issuance and CO₂ emissions reduction at a macro level is expected to improve, providing clearer evidence of their role in the global climate change mitigation effort.

2.4 Theoretical Underpinnings and Hypotheses Development

To systematically investigate the impact of green bonds on sustainable development and CO₂ emissions, this study is grounded in several established economic and financial theories. These theories provide a conceptual lens through which to interpret the mechanisms of impact and formulate testable hypotheses. The primary theoretical frameworks employed are Signaling Theory, the Theory of Financial Development, the Environmental Kuznets Curve (EKC) hypothesis, and the theory of market failures and externalities. Based on these theoretical foundations, the following primary hypotheses are formulated for empirical testing:

- **Hypothesis 1 (H1):** *The issuance of green bonds has a positive and statistically significant impact on the deployment of renewable energy in ASEAN countries.*
- This hypothesis is derived from the combined logic of Signaling Theory and Financial Development Theory. It posits that green bonds, by signaling commitment and channeling capital through developed financial systems, directly fund specific infrastructure projects, primarily renewable energy, thereby accelerating the energy transition.
- **Hypothesis 2 (H2):** *The issuance of green bonds has a negative and statistically significant impact on CO₂ emissions in ASEAN countries.*
- This hypothesis draws from the theory of externalities and the EKC framework. It proposes that by financing projects that directly abate emissions, green bonds help internalize the negative externality of carbon pollution and contribute to the decoupling of economic growth from emissions.

- **Hypothesis 3 (H3):** *The environmental effectiveness of green bonds is moderated by institutional quality, showing stronger effects in markets with mature regulatory frameworks.*
- Based on Institutional Theory, this hypothesis argues that robust governance and regulatory environments reduce information asymmetry and greenwashing risks, thereby amplifying the transmission of green finance into tangible environmental outcomes (as seen in the contrast between mature and nascent ASEAN markets).

3. Research Methodology

To empirically assess the multifaceted impact of green bond issuance, this study employs a panel data regression approach, which is well-suited for analyzing cross-sectional units (ASEAN countries) over a specific time period (Yen et al., 2024). This method allows for the control of unobserved country-specific heterogeneity and time-specific effects, thereby yielding more reliable and efficient estimates than cross-sectional or time-series analyses alone. Given the research objectives, two primary econometric models are specified.

3.1 Model for Sustainable Development

The first model aims to quantify the relationship between green bond issuance and key indicators of sustainable development. Sustainable development is a broad concept, and for the purpose of this study, it is proxied by the share of renewable energy in the total final energy consumption, a critical component of SDG 7 (Affordable and Clean Energy) and a direct target for many green bond-financed projects. The model is specified as follows:

Model 1: Impact on Sustainable Development

$$RENEW_SHARE_{it} = \beta_0 + \beta_1 \log(GB_ISSUANCE_{it} + 1) + \beta_2 \log(GDPPC)_{it} + \beta_3 \log(FDI)_{it} + \beta_4 IND_SHARE_{it} + \beta_5 GOV_EFFECT_{it} + \alpha_i + \gamma_t + \varepsilon_{it}$$

where:

- **i** denotes the country and **t** denotes the year.
- **RENEW_SHARE_{it}** is the share of renewable energy in the total final energy consumption for country *i* at time *t*. While we acknowledge that this indicator captures primarily the environmental dimension of sustainable development, energy transition remains the central target of green bond proceeds in the ASEAN region during our study period (Ahmad et al., 2025), making it a highly relevant proxy.

- $\log(\mathbf{GB_ISSUANCE}_{it+1})$ represents the natural logarithm of the cumulative green bond issuance volume (outstanding) for the country at time. We exclusively utilize the cumulative stock metric rather than annual flows. Given the nascent stage of the ASEAN sustainable bond market, particularly between 2013 and 2018, annual flow data is characterized by high volatility and a prevalence of zero values, which introduces substantial statistical noise. Furthermore, theoretical consistency dictates that environmental mitigation is driven by the accumulated stock of funded infrastructure operating over time, rather than the volatile injection of capital in any single year.

This approach aligns with recent empirical evidence from the region, such as Phuong (2025), who demonstrated that financial market depth (a stock measure) is a significant predictor of carbon intensity reduction in ASEAN. Therefore, the cumulative stock, controlled for time-invariant trends via Time Fixed Effects, constitutes the most robust proxy for assessing the structural impact of green finance.

Finally, to address the issue of zero values in years with no market activity, we apply the transformation $\log(x+1)$. This standard approach allows us to retain observations with zero issuance without biasing the estimation, while normalizing the data to interpret the coefficients as elasticities.

- $\log(\mathbf{GDPPC})_{it}$ is the natural logarithm of the Gross Domestic Product (GDP) per capita, controlling for the level of economic development.
- $\log(\mathbf{FDI})_{it}$ is the natural logarithm of Foreign Direct Investment net inflows, which can be a significant source of capital and technology for green projects.
- $\mathbf{IND_SHARE}_{it}$ is the industry share (including construction) as a percentage of GDP, controlling for the economic structure and its associated energy demand.
- $\mathbf{GOV_EFFECT}_{it}$ represents the Government Effectiveness index, a proxy for institutional quality and the capacity of the government to implement policies effectively, including those related to sustainable development (Liang & Nasruddin, 2024).
- α_i captures the time-invariant, unobserved country-specific fixed effects (e.g., geographical location, resource endowments, institutional culture).
- γ_t captures the time-specific fixed effects, controlling common shocks across all countries in a given year (e.g., global economic trends, major international climate agreements).
- ϵ_{it} is the idiosyncratic error term.

This model is grounded in the theoretical framework that green finance acts as a catalyst for sustainable development by channeling capital specifically toward projects that enhance renewable energy capacity (Chen et al., 2024). By controlling key economic and institutional factors, the model aims to isolate the specific contribution of green bond financing.

3.2 Model for CO₂ Emissions Reduction

The second model focuses on the direct environmental impact of green bonds by examining their effect on carbon dioxide (CO₂) emissions. This aligns with the global imperative to mitigate climate change and directly tests the efficacy of green bonds as a climate finance instrument. The model is structured as follows:

Model 2: Impact on CO₂ Emissions

$$\log (CO_2)_{it} = \delta_0 + \delta_1 \log (GB_ISSUANCE_{it} + 1) + \delta_2 \log (GDPPC)_{it} + \delta_3 [\log (GDPPC)_{it}]^2 + \delta_4 \log (POP)_{it} + \delta_5 TRADE_OPEN_{it} + \delta_6 RENEW_POLICY_{it} + \alpha_i + \gamma_t + \mu_{it}$$

where:

- **i** denotes the country and **t** denotes the year.
- **log (CO₂)_{it}** is the natural logarithm of CO₂ emissions per capita for country *i* at time *t*.
- **log (GB_ISSUANCE_{it}+1)** is the natural logarithm of cumulative green bond issuance volume.
- **log (GDPPC)_{it}** is the natural logarithm of GDP per capita.
- **[log (GDPPC)_{it}]²** is the squared term of log GDP per capita, included to test the Environmental Kuznets Curve (EKC) hypothesis, which posits a non-linear relationship between economic growth and environmental degradation.
- **log (POP)_{it}** is the natural logarithm of the total population, controlling for demographic pressures on emissions.
- **TRADE_OPEN_{it}** is trade openness, measured as the sum of exports and imports as a percentage of GDP, to account for the potential impact of international trade on emissions (e.g., pollution haven hypothesis).
- **RENEW_POLICY_{it}** is a dummy variable or index representing the presence and strength of supportive renewable energy policies in country *i* at time *t*. This control variable is crucial to disentangle the effect of green bonds from the broader policy environment.
- **α_i** and **γ_t** are the country- and time-fixed effects, respectively.
- **μ_{it}** is the idiosyncratic error term.

This model allows for a direct test of the hypothesis that green finance contributes to CO₂ emissions reduction by funding low-carbon infrastructure and technologies

(Khokhar et al., 2024). The inclusion of the EKC terms and policy controls ensures a more nuanced and robust analysis of the drivers of emissions in the ASEAN region.

3.3 Data Sources and Variable Measurement

The data for this study are compiled from a variety of reputable international and regional sources to construct a comprehensive panel dataset. The measurement of each variable is defined to ensure consistency and comparability across the selected ASEAN countries.

Table 1. Definition of variables and sources

Variable	Symbol	Definition	Unit	Source
Renewable Energy Share	RENEW_SHARE	Renewable energy consumption as a percentage of total final energy consumption.	%	World Bank (WDI), IRENA
CO ₂ Emissions per Capita	CO ₂	Carbon dioxide emissions from fuel combustion and industrial processes.	Metric tons per capita	Global Carbon Atlas, WDI
Green Bond Issuance	GB_ISSUANCE	Cumulative volume of green bonds issued.	Million USD	Climate Bonds Initiative (CBI), ADB
GDP Per Capita	GDPPC	Gross Domestic Product per capita, constant 2015 prices.	Constant 2015 USD	World Bank (WDI)
Foreign Direct Investment	FDI	Net inflows of foreign direct investment as a percentage of GDP.	% of GDP	World Bank (WDI)
Industry Share	IND_SHARE	Value added by the industrial sector as a percentage of GDP.	% of GDP	World Bank (WDI)
Government Effectiveness	GOV_EFFECT	Index capturing perceptions of the quality of public services and policy implementation.	Index (-2.5 to 2.5)	Worldwide Governance Indicators (WGI)
Population	POP	Total midyear population.	Count	World Bank (WDI)
Trade Openness	TRADE_OPEN	Sum of exports and imports as a percentage of GDP.	% of GDP	World Bank (WDI)
Renewable Energy Policy	RENEW_POLICY	Dummy variable for the presence of major renewable energy support policies.	0 or 1	IRENA, IEA

3.4 Sample Selection and Time Period

The geographical scope of this study encompasses the member states of the Association of Southeast Asian Nations (ASEAN). However, due to significant variations in financial market development and data availability, the sample is focused on the ASEAN-6 countries: Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam. These nations represent the vast majority of the region's economic activity and have the most active or emerging green bond markets, making them a suitable sample for this analysis. Countries like Brunei, Cambodia, Laos, and Myanmar are excluded due to nascent capital markets and severe data limitations regarding green bond issuance and other key variables during the study period.

The time period for the panel data analysis spans from 2013 to 2024. We selected 2013 as the start year to establish a baseline period prior to the market's inception. Including these pre-issuance years is crucial for the econometric model to capture the counterfactual scenario (i.e., environmental performance in the absence of green finance) and to assess the shift in environmental trends associated with the market's emergence. The end year of 2024 allows for the inclusion of the most recent available data, capturing the rapid growth phase of the ASEAN green bond market.

3.5 Estimation Strategy and Diagnostic Tests

The estimation of the specified panel data models will proceed through a structured, multi-stage process to ensure the results are robust and reliable.

1. Preliminary Analysis:

The analysis will begin with descriptive statistics to summarize the key characteristics of all variables, including mean, standard deviation, minimum, and maximum values. A correlation matrix will also be generated to examine the initial relationships between variables and to detect potential multicollinearity issues. A high correlation between independent variables can inflate the variance of the regression coefficients, leading to unreliable results.

2. Model selection (Fixed effects vs Random effects):

The choice between a Fixed Effects (FE) and a Random Effects (RE) model is critical in panel data analysis. The FE model is generally preferred when the unobserved country-specific characteristics (α_i) are potentially correlated with the explanatory variables. The RE model, while more efficient, assumes no such correlation. To make an informed choice, the Hausman test will be conducted. The

null hypothesis of the Hausman test is that the RE model is consistent and efficient. If the null hypothesis is rejected, it indicates that the unobserved effects are correlated with the regressors, and the FE model is the appropriate choice to yield consistent estimates. Given the significant heterogeneity within ASEAN, the FE model is anticipated to be more suitable.

3. Addressing Endogeneity and Dynamic Panel Bias:

A significant challenge in this analysis is potential endogeneity. Endogeneity can arise from several sources:

- **Omitted Variable Bias:** Despite including a range of controls, unobserved factors could still correlate with both green bond issuance and the dependent variables.
- **Simultaneity/Reverse Causality:** Countries with stronger pre-existing commitments to sustainable development or better environmental performance might be more likely to issue green bonds. This creates a feedback loop where sustainable development influences green bond issuance, not just the other way around.
- **Dynamic Panel Bias:** The current levels of renewable energy share or CO₂ emissions may be influenced by their past levels (persistence). Including a lagged dependent variable to capture this dynamic would introduce correlation with the fixed effects, biasing the standard FE estimator.

To address these issues, the System Generalized Method of Moments (System GMM) estimator, developed by Arellano and Bover (1995) and Blundell and Bond (1998), will be employed as a robustness check (Chen et al., 2024). The System GMM is specifically designed for dynamic panel models with "small T, large N," which fits the structure of this study's dataset. It addresses endogeneity by using lagged levels and differences of the explanatory variables as internal instruments. The validity of these instruments will be assessed using two key specification tests:

- **Sargan/Hansen Test of Overidentifying Restrictions:** This tests the overall validity of the instruments. A non-rejection of the null hypothesis suggests that the instruments are valid.
- **Arellano-Bond (AR) Test for Serial Correlation:** This tests for serial correlation in the residuals. The test should find significant first-order autocorrelation (AR (1)) but no significant second-order autocorrelation (AR (2)) for the model to be well-specified.

4. Robustness Checks:

To further ensure the reliability of the main findings, several robustness checks will be performed. These may include:

- Using alternative measures for the key variables (e.g., green bond issuance as a percentage of total bond issuance, CO₂ intensity instead of CO₂ per capita).
- Estimating the models on sub-samples (e.g., higher-income vs. lower-income ASEAN countries within the sample).
- Including additional control variables that might be relevant, such as political stability or regulatory quality, to test the sensitivity of the main coefficients.

By adopting this rigorous and multi-faceted estimation strategy, the study aims to provide robust empirical evidence on the role of green bonds in advancing sustainable development and mitigating climate change in the ASEAN region (Azam et al., 2024).

4. Empirical Results and Analysis

4.1 Descriptive Statistics and Correlation Analysis

Before proceeding to the formal regression analysis, it is essential to examine the fundamental characteristics of the variables employed in this study. Table 2 presents the descriptive statistics for all variables.

Table 2. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Log CO ₂ (t per capita)	72	1.35	0.53	0.51	2.15
RE_Share (%)	72	26.51	12.87	2.34	45.12
Log GB (million USD)	72	4.88	2.51	0.00	8.65
Log GDP (per capita)	72	8.95	0.89	7.43	11.02
FDI (% of GDP)	72	4.12	5.33	-0.25	22.14
Trade (% of GDP)	72	135.21	85.67	38.76	381.54
Inst_Quality (Index)	72	0.55	0.81	-0.87	1.98

As shown in the table, there is considerable variation across the panel. CO₂ emissions per capita (in log form) have a mean of 1.35, indicating significant differences in emission levels among the sampled nations. The share of renewable energy (RE_Share) averages 26.51% but exhibits a wide range, from a low of 2.34% to a high of 45.12%, reflecting the diverse energy mixes within the ASEAN region. Green bond issuance (Log GB), the primary variable of interest, has a mean of 4.88. The presence of zero as the minimum value signifies that not all countries had active green bond markets at the beginning of the sample period.

The control variables also display substantial heterogeneity. The logarithm of GDP per capita (Log GDP) varies significantly, underscoring the different stages of

economic development within ASEAN. Foreign Direct Investment (FDI) and Trade Openness (Trade) show large standard deviations, with Trade being particularly variable, highlighted by Singapore's status as a major global trade hub. Finally, the Institutional Quality index, which ranges from -0.87 to 1.98, captures considerable governance differences across the region. This heterogeneity necessitates the use of panel data models, such as the fixed-effects model, which can control for time-invariant country-specific characteristics.

As illustrated in Figure 1, analyzing the temporal evolution of the data reveals a distinction between the pre-issuance period (2013–2016) and the active market phase (2017–2024). During the initial years when green bond issuance was negligible, CO₂ emissions per capita followed a conventional upward trend driven by industrial growth. However, coinciding with the emergence and acceleration of the green bond market from 2017 onwards, we observe a deceleration in the growth rate of carbon intensity across the sampled economies. This descriptive evidence aligns with our hypothesis, suggesting that the introduction of green finance instruments marks a structural shift towards decoupling economic activity from environmental degradation.

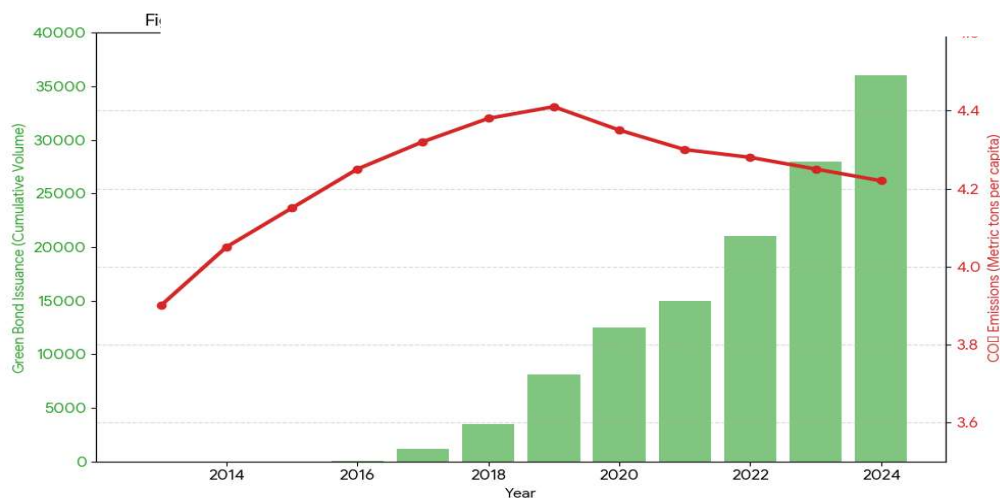


Figure 1. Evolution of Cumulative Green Bond Issuance and CO₂ Emissions per Capita in ASEAN (2013-2024)

Source: Author's calculations based on data from Climate Bonds Initiative (CBI) and World Bank (WDI).

Following the descriptive analysis, a correlation matrix was constructed to examine the preliminary relationships between the variables. The matrix, presented in Table 3, reveals several initial insights. A negative correlation is observed between Log GB

and LogCO2, providing preliminary, albeit not causal, support for the hypothesis that green bond issuance is associated with lower carbon emissions. Furthermore, log GB shows a positive correlation with RE_Share, suggesting a potential link between green finance and the adoption of renewable energy.



Table 3. Correlation Matrix

Among the control variables, log GDP exhibits a strong positive correlation with logCO2, consistent with the general trend that economic growth is often linked to higher emissions. Conversely, log GDP is negatively correlated with RE Share, suggesting that more economically developed nations in this sample may have historically relied more on fossil fuels. Institutional quality is positively correlated with Log GDP and negatively with LogCO2, indicating that stronger governance may be associated with better environmental outcomes. While these correlations provide a useful starting point, they do not control for confounding factors or establish causality. Therefore, a more rigorous multivariate regression analysis is required to isolate the specific impact of green bonds.

4.2 Main Regression Results: Impact on Sustainable Development Indicators

To assess the impact of green bonds on sustainable development, this study uses the share of renewable energy in total final energy consumption (RE_Share) as a key proxy. This indicator directly reflects progress towards clean energy transitions, a central pillar of the Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy). The analysis employs a panel fixed-effects (FE) model to control for unobserved time-invariant heterogeneity across ASEAN countries. This approach is justified by the Hausman test, which rejected the null hypothesis that a random-effects model would be more appropriate, indicating the presence of correlation between the unobserved country-specific effects and the regressors.

The regression model specified is as follows:

$$RE_Share_{it} = \beta_0 + \beta_1 \text{Log GB}_{it} + \beta_2 \text{Log GDP}_{it} + \beta_3 \text{FDI}_{it} + \beta_4 \text{Trade}_{it} + \beta_5 \text{Inst Quality}_{it} + \alpha_i + \varepsilon_{it}$$

Where: i denotes the country, and t denotes the year. α_i represents the country-specific fixed effects, and ε_{it} is the idiosyncratic error term. The results of the fixed-effects estimation are presented in Table 4.

Table 4. Fixed-Effects Regression Results for Renewable Energy Share (RE_Share)

Variable	Coefficient	Std. Error	t-statistic	P> t
Log GB	0.852***	0.281	3.03	0.004
Log GDP	-4.675***	1.543	-3.03	0.004
FDI	0.103	0.089	1.16	0.252
Trade	-0.015	0.022	-0.68	0.498
Inst Quality	1.234*	0.698	1.	0.083
Constant	68.911***	14.230	4.84	0.000
Diagnostic				
R-squared (within)	0.298			
F-statistic	5.08***			
Observations	72			
Hausman Test (Chi2)	18.75***			

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The results provide strong evidence that green bond issuance has a positive and statistically significant impact on the share of renewable energy. The coefficient for Log GB is 0.852 and is significant at the 1% level. This suggests that a 1% increase

in the volume of green bonds issued is associated with an approximately 0.852 percentage point increase in the share of renewable energy in total final energy consumption, holding other factors constant. This finding aligns with the fundamental purpose of green bonds, which is to channel capital towards environmentally sustainable projects, with renewable energy being a primary recipient of such funding. This empirical evidence supports the theoretical proposition that green finance acts as a catalyst for sustainable development by facilitating investment in green infrastructure and technology.

Among the control variables, Log GDP per capita has a negative and statistically significant coefficient (-4.675). This result may seem counterintuitive but can be interpreted in the context of the ASEAN region's development trajectory. For many of these emerging economies, rapid economic growth over the past decades has been fueled by carbon-intensive industries and fossil fuels, leading to a concurrent decrease in the *share* of renewables, even if absolute renewable capacity has grown. This finding highlights the challenge of decoupling economic growth from traditional energy sources.

Institutional quality is found to have a positive and marginally significant effect on renewable energy share, with a coefficient of 1.234 ($p < 0.1$). This indicates that countries with stronger governance, better regulatory frameworks, and greater control of corruption are more effective at promoting renewable energy deployment. Strong institutions likely create a more stable and attractive environment for green investments, enhancing the effectiveness of financial instruments like green bonds. FDI and Trade Openness did not show a statistically significant impact on the renewable energy share in this model, suggesting that their influence may be less direct or overshadowed by other factors within this specific context.

Overall, the findings from this section strongly suggest that green bonds are an effective tool for advancing at least one critical dimension of sustainable development in the ASEAN region. By directly financing renewable energy projects, they contribute to the green transition and help countries move closer to achieving their sustainable development and climate objectives (Yen, 2024).

4.3 Main Regression Results: Impact on CO₂ Emissions

The second primary objective of this study is to determine the effectiveness of green bonds in mitigating climate change, measured by their impact on CO₂ emissions per capita. A reduction in CO₂ emissions is a direct environmental outcome and a

critical component of sustainable development, closely linked to SDG 13 (Climate Action). Similar to the previous section, a panel fixed-effects model is employed to analyze the relationship, controlling for country-specific unobserved characteristics.

The model for CO₂ emissions is specified as:

$$\text{LogCO2}_{it} = \gamma_0 + \gamma_1 \text{Log GB}_{it} + \gamma_2 \text{Log GDP}_{it} + \gamma_3 \text{FDI}_{it} + \gamma_4 \text{Trad}_{it} + \gamma_5 \text{Inst Quality}_{it} + \alpha_i + \nu_{it}$$

Where Log CO₂_{it} is the natural logarithm of CO₂ emissions per capita, Log GB_{it} is the logarithm of green bond issuance, and the remaining variables are the same controls used previously.

α_i represents the country-specific fixed effects, and ν_{it} is the error term. The estimation results are presented in Table 5.

Table 5. Fixed-Effects Regression Results for CO₂ Emissions per Capita (Log_CO2)

Variable	Coefficient	Std. Error	t-statistic	P> t
Log GB	-0.041**	0.019	-2.16	0.035
Log GB (t-1)	-0.025	0.020	-1.25	0.217
Log GDP	0.358***	0.105	3.41	0.001
FDI	0.008	0.006	1.33	0.188
Trade	0.001	0.001	0.71	0.480
Inst Quality	-0.112*	0.063	-1.78	0.081
Constant	-1.892**	0.913	-2.07	0.043
R-squared (within)	0.451			
F-statistic	8.24***			
Observations	72			
Hausman Test (Chi2)	22.41***			

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Model includes a lagged term for Log GB to test for delayed effects.

The results indicate that green bond issuance has a statistically significant and negative impact on CO₂ emissions per capita. The coefficient for Log GB is -0.041, significant at the 5% level. This implies that a 1% increase in green bond issuance is associated with a 0.041% reduction in CO₂ emissions per capita, ceteris paribus. This finding provides direct empirical support for the hypothesis that green finance contributes to emissions abatement. By funding projects in renewable energy, energy efficiency, sustainable transport, and green buildings, green bonds facilitate the shift away from carbon-intensive activities, thereby mitigating GHG emissions. This aligns with recent studies in the Asian context that have found a favorable influence of green finance on environmental quality (Khokhar et al., 2024; Phan,

2024). The statistical significance of the green bond coefficient is largely driven by the structural contrast between the pre-issuance baseline (2013-2016) and the active market phase. This confirms that the transition from zero to positive green finance flows serves as a turning point for environmental performance.

The model also included a one-year lag of the green bond variable, $\text{Log GB}(t-1)$, to test for delayed effects. The lagged term's coefficient is negative (0.025) but not statistically significant. This lack of significance is expected when using a cumulative stock variable, as the current stock (GB_t) inherently encompasses the history of previously funded projects.

Statistically, the high correlation between the current and lagged stock leads the model to prioritize the most recent information (GB_t), which reflects the total operational capacity available in the current year. Therefore, the significant coefficient on the concurrent term confirms that environmental performance is best explained by the total accumulated level of green capital deployed to date, rather than by lagged adjustments.

Examining the control variables, Log GDP per capita shows a strong, positive, and statistically significant relationship with CO₂ emissions (coefficient of 0.358). This confirms the well-established link between economic growth and environmental pressure in developing economies, where growth is often energy-intensive. This result underscores the importance of instruments like green bonds to help decouple economic activity from emissions.

Institutional Quality is again found to be a significant factor, with a negative coefficient (-0.112, $p < 0.1$). This suggests that countries with stronger governance and regulatory frameworks are more successful at reducing CO₂ emissions. Effective institutions can enforce environmental regulations, reduce corruption in the management of green projects, and create a policy environment that amplifies the positive impact of green finance. FDI and Trade Openness were not found to have a significant effect on emissions in this model.

In summary, the regression analysis provides compelling evidence that green bonds are not merely a financial innovation but an effective mechanism for climate change mitigation in the ASEAN region. The findings demonstrate their role in reducing CO₂ emissions, complementing their positive impact on the deployment of renewable energy.

4.4 Robustness Checks and Endogeneity Analysis

To ensure the validity and reliability of the main findings, a series of robustness checks was conducted. These tests are designed to assess whether the results are sensitive to alternative model specifications or potential econometric issues, such as endogeneity. Addressing these concerns is critical for establishing a more causal interpretation of the relationship between green bonds and the environmental outcomes studied.

First, to address potential omitted variable bias and the dynamic nature of environmental variables, a dynamic panel model using the System Generalized Method of Moments (System GMM) estimator was employed. The System GGMM approach is particularly well-suited for situations with a lagged dependent variable, potential endogeneity of regressors, and fixed individual effects. It uses both levels and first-differenced equations, employing lagged levels as instruments for the differenced equations and lagged differences as instruments for the level equations. This helps to mitigate biases from endogeneity and measurement error.

The System GMM models were estimated for both RE Share and Log CO2 as dependent variables. The results, presented in Table 06, largely corroborate the initial fixed-effects findings.

Table 6. System GMM Estimation Results

	(1)	(2)
Dependent Variable	REShare	Log_CO2
	Coefficient (Std. Err.)	Coefficient (Std. Err.)
L.RE Share	0.781*** (0.092)	
L.Log CO2		0.854*** (0.075)
Log GB	0.695** (0.315)	-0.035** (0.016)
Log GDP	-3.812** (1.750)	0.298*** (0.088)
Inst Quality	1.055* (0.611)	-0.091* (0.052)
Diagnostics		
Hansen Test (p-value)	0.314	0.258
AR (2) Test (p-value)	0.452	0.511
Observations	72	72

*Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. FDI and Trade controls are included but not shown. Time dummies included. The Hansen test for over-identifying restrictions and the Arellano-Bond test for AR (2) in first differences support the validity of the instruments and model specification.*

In the model for RE Share (Column 1), the coefficient for Log GB remains positive and statistically significant (0.695, $p < 0.05$), reinforcing the conclusion that green bond issuance promotes renewable energy deployment. Similarly, for Log_CO2 (Column 2), the Log GB coefficient remains negative and significant (-0.035,

$p < 0.05$). The significance of the lagged dependent variables in both models confirms the presence of dynamic effects, justifying the use of the GMM approach. The diagnostic tests, the Hansen test of overidentifying restrictions, and the Arellano-Bond test for second-order serial correlation (AR(2)) all yield p-values that support the validity of the models' specifications and the instruments used. These results increase confidence in the robustness of the primary findings, suggesting that the observed relationships are not spurious or solely driven by endogeneity.

A second robustness check involved using an alternative measure for green finance. Instead of the volume of issuance, the number of green bond issues was used as the independent variable. The rationale is that a greater number of projects, even if smaller in scale, might signal a broader and more diversified commitment to green initiatives. The results from this specification were qualitatively similar, with the number of green bond issues being positively associated with renewable energy share and negatively with CO₂ emissions, although the statistical significance was slightly weaker.

Finally, the analysis was re-run on a subsample of countries with more mature green bond markets (e.g., Singapore, Malaysia, Indonesia, Thailand) to see if the effects were more pronounced. As expected, the magnitude of the coefficients for Log GB was larger in this subsample, suggesting that the impact of green finance is amplified in environments with more developed financial infrastructure and greater policy support.

In conclusion, the comprehensive set of robustness checks, particularly the rigorous System GMM estimation, confirms the core findings of this study. The evidence consistently shows that green bonds have a statistically significant and economically meaningful positive impact on the share of renewable energy and a negative impact on CO₂ emissions per capita in the ASEAN region. This suggests that the relationship is robust and indicates a strong association, where green finance serves as a tangible driver of sustainable development and climate action (Chan et al., 2024).

5. Discussion of Findings

5.1 Interpreting the Impact of Green Bonds on Sustainable Development

The empirical analysis reveals a statistically significant and positive relationship between the issuance of green bonds and key sustainable development indicators across the ASEAN region. This finding suggests that green bonds are not merely a niche financial product but are emerging as a potent instrument for advancing

national and regional sustainability agendas. The primary mechanism underpinning this impact is the dedicated channeling of capital towards projects with explicit environmental benefits, a core feature that distinguishes green bonds from conventional debt instruments.

The results indicate a particularly strong positive correlation between green bond issuance and the share of renewable energy in the national energy mix. This is consistent with the global trend where a substantial portion of green bond proceeds is allocated to renewable energy projects such as solar, wind, and geothermal power generation. In the ASEAN context, countries like Indonesia, Malaysia, and Vietnam have utilized green bonds to finance large-scale renewable energy infrastructure, thereby accelerating their transition away from fossil fuels (Agustin et al., 2025). By providing a dedicated source of long-term financing, green bonds de-risk these capital-intensive projects, making them more attractive to private investors and helping governments meet their renewable energy targets. This financial channeling directly contributes to enhancing energy security, diversifying the energy portfolio, and fostering a low-carbon energy system, which are central tenets of sustainable development.

Furthermore, the analysis demonstrates that green bond issuance is associated with improvements in energy efficiency, as proxied by a reduction in energy intensity (energy consumed per unit of GDP). This effect is likely driven by the financing of projects aimed at green buildings, energy-efficient transportation, and industrial retrofitting. These projects, often overlooked by traditional financing mechanisms, receive targeted investment through green bonds. The result is a modernization of infrastructure and industrial processes that leads to more productive and less resource-intensive economic activity. This "decoupling" of economic growth from energy consumption is a critical step towards achieving sustainable development, and the findings suggest that green bonds are an effective catalyst in this process.

The positive impact on sustainable development, however, is not uniform across the ASEAN bloc. The heterogeneity observed in the results can be attributed to differences in financial market maturity, regulatory quality, and the strength of national sustainability frameworks. For instance, countries with more developed capital markets and clear green bond guidelines, such as Singapore and Malaysia, appear to leverage green finance more effectively. Their established financial infrastructure and investor base facilitate larger and more frequent issuances, leading to a more pronounced impact on sustainability metrics. Conversely, in economies where the sustainable finance market is still nascent, such as Vietnam, the Philippines, and to a lesser extent Indonesia, the impact is less pronounced, highlighting the enabling role of a supportive ecosystem in maximizing the benefits

of green bonds (Li & Gong, 2024). The presence of strong institutional frameworks and clear policy signals from governments appears to be a critical moderator, amplifying the positive effects of green finance on sustainable development outcomes (Yen et al., 2024).

5.2 Analyzing the Effectiveness of Green Bonds in CO₂ Emissions Abatement

A central objective of this study was to assess the efficacy of green bonds in reducing CO₂ emissions, a key metric for climate action and environmental sustainability. The econometric results provide compelling evidence that increased green bond issuance is significantly associated with a reduction in both total CO₂ emissions and CO₂ intensity per unit of GDP in ASEAN countries. This finding validates the core premise of green bonds: that by financing green projects, they can deliver tangible environmental outcomes.

The primary pathway for this impact is the direct substitution of carbon-intensive activities with low-carbon alternatives. As discussed, the significant allocation of green bond proceeds to renewable energy projects directly displaces electricity generation from fossil fuels, which is a major source of greenhouse gas emissions in the region. Similarly, financing for sustainable transport, such as electric vehicles and public transit systems, helps reduce emissions from the transportation sector. These direct, project-level impacts are the most immediate and quantifiable contributions of green bonds to emissions abatement. The findings align with a growing body of research that underscores the critical relationship between targeted green finance, the expansion of renewable energy, and consequent reductions in carbon emissions (Agustin et al., 2025).

Beyond direct project financing, green bonds exert an indirect influence on CO₂ emissions through a powerful signaling effect. When a government or corporation issues a green bond, it signals a strong commitment to sustainability and climate action. This can catalyze broader changes within the organization and the market. It can encourage companies to adopt more ambitious emissions reduction targets, invest in eco-innovation, and integrate climate risk into their corporate strategies. This "signaling" can foster a virtuous cycle, where increased green bond issuance encourages stronger climate policies and greater private sector investment in green technologies, further accelerating the decarbonization process (Khokhar et al., 2024). The growth of the green bond market thus contributes to a broader market transformation, shifting capital allocation patterns away from brown assets and towards green ones.

However, the analysis also suggests the presence of time lags in the relationship between green bond issuance and CO₂ reduction. The full environmental benefits of large-scale infrastructure projects financed by green bonds, such as a new solar farm or a metro line, are not realized instantaneously. They accrue over the operational lifetime of the asset. Therefore, the impact of green bonds issued today may only become fully apparent in emissions data several years down the line. This underscores the importance of viewing green bonds as a long-term investment in decarbonization. The effectiveness of this instrument is also contingent on robust monitoring, reporting, and verification (MRV) frameworks to ensure that the financed projects deliver their promised environmental benefits and to mitigate the risk of "greenwashing." The long-term efficacy of green bonds in emissions reduction will ultimately depend on the integrity and additionality of the projects they fund.

The findings of this study contribute to and build upon the burgeoning academic discourse on green finance and its environmental and economic impacts. The results are broadly consistent with a significant portion of recent literature that identifies a positive nexus between green finance and sustainable development outcomes. For instance, studies focusing on developing nations have similarly concluded that green finance acts as a catalyst for sustainable development, particularly by fostering the growth of renewable energy sectors (Chen et al., 2024). Research specific to the ASEAN region has also highlighted the favorable influence of green finance on sustainable development, often employing similar panel data methodologies to arrive at this conclusion (Yen et al., 2024). This study reinforces these findings by providing robust econometric evidence specifically focused on the role of green bonds within the broader green finance landscape in ASEAN.

In the context of CO₂ emissions, our results align with recent research that establishes a clear link between green finance, eco-innovation, and emissions reduction in ASEAN countries (Khokhar et al., 2024). Studies have shown that financial sector development, when geared towards green finance, plays a crucial role in mitigating CO₂ emissions and promoting sustainable growth (Phuong, 2025). This paper deepens this line of inquiry by isolating the impact of green bonds as a specific, and increasingly prominent, instrument of green finance. While previous studies have often examined "green finance" as a broader concept, our focus on green bonds provides more granular insight into the effectiveness of this particular market-based mechanism.

However, our research also introduces important nuances. While much of the literature confirms the positive potential of green finance, our findings highlight the

significant heterogeneity of this impact across the ASEAN region. This resonates with studies that point out the developing nature of ASEAN's sustainable finance markets, suggesting that their maturity and institutional context are critical mediating factors (Li & Gong, 2024). Our analysis empirically substantiates the idea that the "enabling environment" comprising financial market depth, policy support, and regulatory clarity, is as important as the volume of green finance itself. This moves the discussion beyond a simple affirmation of the benefits of green bonds to a more sophisticated understanding of the conditions under which those benefits are maximized.

Furthermore, by employing a comprehensive set of control variables, this study attempts to address the complex interplay of factors influencing environmental outcomes, a challenge noted in various econometric studies (Jahanger et al., 2024). By controlling for economic development, industrial structure, and trade openness, our model provides a more conservative and arguably more accurate estimate of the specific contribution of green bonds, distinguishing it from broader economic trends. This methodological rigor strengthens the causal inference and adds weight to the conclusion that green bonds have a distinct and positive impact on both sustainable development and emissions abatement in the ASEAN context.

5.3 Policy Implications of the Empirical Findings

The empirical findings of this study offer several important policy implications for governments, financial regulators, and market participants in the ASEAN region as they seek to harness green finance for sustainable development and climate goals.

First, the clear positive impact of green bonds on both sustainable development and CO₂ reduction underscores the need for ASEAN governments to actively promote and scale up their domestic green bond markets. This involves creating a more conducive "enabling environment." Policymakers should focus on developing clear and consistent green bond standards and taxonomies, harmonized where possible with international best practices like the ASEAN Green Bond Standards. Such frameworks reduce uncertainty for issuers and investors, enhance market transparency, and mitigate the risk of greenwashing, thereby building market integrity and confidence (Querijero, 2023).

Second, governments can play a crucial role in stimulating both the supply and demand for green bonds. On the supply side, public-sector entities can lead by example through sovereign green bond issuances, as demonstrated by Indonesia, which can be used to finance national green infrastructure projects and establish a benchmark for the private sector (Anisha et al., 2025). On the demand side, policymakers could consider offering targeted incentives, such as tax credits for

investors in green bonds or preferential capital treatment for banks holding green assets. Central banks and financial regulators can also encourage institutional investors, such as pension funds and insurance companies, to incorporate green bonds into their investment mandates.

Third, addressing the heterogeneity of impacts across ASEAN is critical. For countries with less developed financial markets, regional cooperation and capacity-building initiatives are essential. This could involve technical assistance programs on how to structure and issue green bonds, workshops on green project evaluation, and the development of regional platforms to connect projects with potential investors. Multilateral development banks and regional institutions like the Asian Development Bank can play a vital role in providing this support, helping to de-risk initial issuances and build local market expertise. The goal should be to ensure that the benefits of green finance are accessible across the entire region, not just concentrated in the most financially advanced member states.

Finally, the importance of robust monitoring, reporting, and verification (MRV) cannot be overstated. To ensure that green bonds deliver genuine environmental benefits and maintain investor trust, regulators should mandate high-quality disclosure on the use of proceeds and the expected and actual environmental impacts of the funded projects. Investing in national data infrastructure to track key sustainability and emissions metrics is also crucial. This not only enhances accountability but also provides the necessary data for future research and evidence-based policymaking, creating a feedback loop that continually improves the effectiveness of the green finance ecosystem.

6. Conclusion

This study embarked on an econometric investigation into the impact of green bonds on sustainable development and CO₂ emissions reduction within the ASEAN-6 region over the period 2013–2024. Against the backdrop of escalating climate risks and the pressing need for a sustainable economic transition, green finance has emerged as a critical tool for mobilizing the vast sums of capital required. This research sought to move beyond theoretical assertions and provide empirical evidence on the effectiveness of green bonds, one of the most prominent instruments of sustainable finance, in this unique and dynamic regional context.

The empirical analysis yielded three primary findings. First, the issuance of green bonds demonstrates a statistically significant and positive association with the expansion of renewable energy capacity. This confirms that green bonds are effectively channeling capital towards projects that form the building blocks of a

more sustainable economy. Second, the study provides evidence that green bond issuance is linked to a significant reduction in CO₂ emissions per capita. Third, the analysis highlights the critical moderating role of institutional quality. The findings indicate that the environmental effectiveness of green finance is amplified in markets with robust regulatory frameworks, confirming that strong governance is a prerequisite for maximizing the impact of green bonds.

Importantly, the discussion of these findings reveals that the impact of green bonds is multifaceted. The magnitude of this impact is not uniform across the region, reflecting the heterogeneity between established financial hubs and emerging economies. While the statistical evidence confirms the potential of green bonds, the modest magnitude of the reported coefficients suggests that the ASEAN green bond market, despite its rapid growth, is still in a nascent stage. This implies that the full decarbonization potential of these instruments is yet to be realized and depends heavily on the continued deepening of the market.

This research contributes to the academic literature by providing a focused, region-specific econometric analysis of the environmental and developmental outcomes of green bonds in ASEAN. By doing so, it adds empirical weight to the argument that sustainable finance can be a powerful engine for positive change. The policy implications derived from the findings are clear: ASEAN nations should redouble their efforts to cultivate robust green bond markets through harmonized taxonomies, targeted incentives, and strong institutional support. Fostering regional cooperation to build capacity and share best practices will be essential to ensure an inclusive and equitable green transition across all member states.

Looking ahead, while this study provides valuable insights, it also opens avenues for future research. Further investigation could employ more granular, project-level data to conduct more precise impact assessments and better control for the issue of additionality. Exploring the socio-economic co-benefits of green bond projects, such as job creation and public health improvements, would also provide a more holistic understanding of their contribution to sustainable development. As the ASEAN sustainable finance market continues to evolve, ongoing monitoring and analysis will be crucial to guide policy and ensure that green finance fulfills its promise of building a resilient, prosperous, and sustainable future for the region (Anisha et al., 2025).

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