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Do green bonds foster economic growth conditional on financial development?

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Abstract

This study examines the relationship between green bond issuance, the financial development index, and economic growth in selected Asian economies over the period 2012–2022. While green bonds have emerged as a key instrument for financing sustainable development, their contribution to macroeconomic performance remains unclear, particularly across countries with varying levels of financial development. To address this gap, the study employs a dynamic panel estimation approach using the Generalized Method of Moments (GMM), incorporating an interaction term between green bonds and the financial development index to capture conditional effects. The findings indicate that green bonds do not exhibit a statistically significant direct effect on economic growth. However, the indirect model shows that the growth benefits of green bonds are conditional on the level of financial development. The results further reveal substantial heterogeneity across countries, where economies with intermediate levels of financial development experience increasing marginal gains, while highly developed financial systems show diminishing returns, and less developed systems face structural constraints that limit the growth-enhancing effects. These findings underscore the importance of financial system maturity in enabling green finance to contribute meaningfully to economic growth. The study provides policy implications by proposing a stage-based framework, suggesting that economies at early stage of financial development should prioritize institutional strengthening, those at an intermediate stage should focus on financial deepening, while financially advanced economies should enhance market quality and transparency. Overall, the study contributes to the literature by offering a mechanism-based understanding of how financial development conditions the effectiveness of green bonds in promoting meaningful economic growth.

Keywords: Green bonds, Financial development, Sustainable growth, Marginal effects, Asia

JEL Classification: D53, G15, O16, P45, Q56

1 Introduction

Financial development refers to the expansion of diverse financial services that address various economic needs, often associated with financial deepening and financial intermediation. Advanced financial development strengthens economic institutions, promotes capital formation, and improves investment efficiency, ultimately laying a solid

foundation for sustainable growth [74]. The International Monetary Fund (IMF) introduced the financial development index to measure financial development by capturing depth, access, efficiency, and stability of financial institutions and markets [97]. A higher financial development index score indicates a more advanced financial system that mobilizes savings and optimizes resource allocation more effectively, thereby supporting inclusive and sustainable economic growth [86, 92].

Within financial markets, green bonds have emerged as a vital instrument for financing environmentally sustainable projects. They serve a dual function by addressing climate challenges and fostering economic development through targeted financing of renewable energy and climate-resilient projects. The dynamics between green bonds and economic growth are primarily driven by green bond supported-technology advancement, an essential component of the neoclassical growth framework [117]. Green bond issuance facilitates investments in environmentally friendly technologies, which can be diffused across economic sectors and promote nation-wide green technology adoption [35]. This circumstance lays technological foundation for productive growth environment, while sustaining economic growth through enhanced resource optimization and improved climate resilience. Empirical evidence suggests that firms issuing green bonds tend to exhibit higher operational efficiency, stronger ESG performance, and greater carbon reduction, thereby boosting competitiveness and economic performance [75].

A distinctive feature that distinguishes green bonds from conventional bonds is the incorporation of a green bond taxonomy [116]. This taxonomy provides a standardized framework to classify eligible projects, ensuring that the proceeds raised are directed exclusively to activities with measurable environmental benefits, such as renewable energy, sustainable infrastructure, and climate-resilient initiatives [72]. These guidelines reduce information asymmetry, mitigates the risk of greenwashing, and strengthens investor confidence [2].

For instance, the ASEAN Green Bond Standards is established to standardize green financing practices across member states, ensuring consistency with global principles while reflecting regional priorities [12]. However, the effectiveness of such frameworks depends on a resilient financial system capable of monitoring compliance, enforcing transparency, and efficiently channeling funds to genuine climate-related projects. Such financial and institutional conditions contribute to a supportive financial environment that lowers financial risks, reduces cost of capital and increases market liquidity [10]. Improved capital allocation and better credit access create a virtuous cycle that promotes productive capital and facilitates green investment, which in turn encourages greater green bond issuance and further investment, ultimately translating into productive green innovation and sustainable economic growth. In this regard, financially developed economies are better equipped to operationalize the taxonomy, safeguard credibility, and fully leverage green bonds to drive sustainable and inclusive economic growth [41, 48, 94].

The relationship between green bonds and economic growth can be understood through several interrelated transmission channels. From a production perspective, green bond issuance primarily facilitates capital accumulation by financing renewable energy, sustainable infrastructure, and climate-resilient projects, thereby expanding the capital input within the economy [52]. However, the effectiveness of this process

depends critically on the efficiency of financial intermediation. In financially developed systems, well-functioning institutions reduce information asymmetry, lower transaction costs, and improve capital allocation, ensuring that green bond proceeds are directed toward highly productive sustainable investments [110]. In contrast, in less developed financial systems, weak regulatory oversight and limited market depth may lead to misallocation of funds, higher financing costs, and greenwashing risks, which can dampen or even reverse the growth impact of green bonds.

Moreover, green bond financing often involves structural reallocation of resources from carbon-intensive sectors to low-carbon industries. While such transitions are essential for long-term sustainability, they may generate short-term adjustment costs, particularly in economies heavily dependent on fossil fuels. Financial development therefore plays a critical moderating role by smoothing this transition, enhancing market efficiency, and strengthening investor confidence. As a result, the impact of green bonds on GDP is not uniform but conditional on the level of financial development, which determines whether green finance acts as a catalyst for growth or imposes transitional economic costs.

Conversely, the benefits of green bonds on GDP may be muted or even reversed in financially weak economies. Countries with weak financial development tend to have insufficient regulatory oversight and weak institutional capacity, which may cause misallocation of green funds, mispricing of capital, crowding out of private investment, and fiscal stress when green financing heavily subsidized by governments. [46] In such contexts, green bonds may constrain sustainable growth by diverting limited capital from more productive sectors [33, 42]. Thus, financial development acts as a moderator, determining whether green bond financing strengthens or undermines economic performance [80].

Nevertheless, green bonds may pose some potential adverse effects on sustainable growth. First, green bonds may undermine economic growth due to increased financial costs emanating from additional issuance and third-party verification costs. Second, if green bond markets expand faster than institutional capacity, risks of greenwashing may arise, reducing investor confidence and weakening financial stability [123]. Third, in the short term, the reallocation of capital toward green sectors may impose adjustment costs, particularly in economies heavily reliant on fossil fuel industries [87]. These transitional frictions may dampen GDP growth in the early stages of green bond adoption [37].

Therefore, the net impact of green bonds on GDP is influenced by the level of financial development. Robust financial institutions can mitigate risks, reduce transaction costs, and ensure that green bond funds are capitalized for productive investments. Weak financial systems, on the other hand, may amplify inefficiencies and expose economies to financial vulnerabilities. These phenomena suggest an intricate connection between financial development and green bonds in shaping the economic landscape.

In Asia, the green bond market has expanded rapidly, with China dominating by issuing more than USD 83 billion worth of green bonds in 2023, while Japan, India, and Saudi Arabia also recorded significant increase in issuance relative to GDP [44]. Globally, Europe leads the market, with issuance surpassing USD 341 billion in 2023 [24]. This scenario underscores the potential of green bonds to finance sustainable

projects and support sustainable growth. However, the potential of green bonds to drive sustainable growth in many developing Asian economies has been constrained by their underdeveloped financial systems, limited financial inclusion, and reliance on external debts [28, 78].

This study aims to examine the relationship between green bonds, financial development index, and GDP across Asian economies. The objectives are, first, to investigate the direct effects of green bond issuance and financial development on GDP. Second, to evaluate the moderating role of financial development in shaping the impact of green bonds on economic growth.

This study makes several contributions to the existing literature. First, this study provides systematic and regionally grounded empirical evidence on the green bond–growth nexus in Asia, where existing studies remain fragmented and predominantly focused on market development rather than macroeconomic outcomes. While prior research documents the rapid expansion of green bond markets in Asia [24], the literature has largely concentrated on issuance dynamics, regulatory frameworks, and institutional drivers, with limited direct evaluation of how green bond financing translates into aggregate economic performance. For instance, studies such as [13, 99] primarily examine policy frameworks and determinants of green bond issuance, leaving the macroeconomic growth implications underexplored in a unified empirical framework. By explicitly modeling the relationship between green bond issuance and gross domestic product, this study repositions the literature from descriptive and policy-oriented analysis toward a macroeconomic performance perspective, thereby strengthening the empirical foundation of sustainable finance research in the Asian context.

Second, the study introduces a moderating framework that explicitly links green bonds with the financial development index, allowing for conditional and asymmetric effects of green finance on economic growth. Unlike most existing studies that treat green bonds and financial development as independent determinants of growth [59, 86], this study demonstrates that the impact of green bonds is not uniform but depends critically on the level of financial development. In particular, the interaction structure reveals that green bond financing may yield heterogeneous and asymmetric growth outcomes across countries, reflecting differences in financial depth, institutional quality, and market efficiency. This framework provides a clearer identification of the transmission mechanism, showing that financial development shapes how effectively green bond proceeds are allocated into productive investment and translated into economic growth.

Third, the study examines country-specific marginal effects of green bonds across different levels of financial development, rather than relying solely on average or pooled estimates. This approach departs from the conventional assumption of homogeneity and allows the analysis to uncover substantial cross-country heterogeneity in the green bond–growth relationship. By computing marginal effects at country-specific levels of financial development, the study offers granular, policy-relevant insights into how the effectiveness of green bonds varies across financial regimes and development stages. This is particularly important in Asia, where economies differ significantly in financial structure, institutional capacity, and stages of economic

development. Such an approach not only improves empirical precision but also enhances the policy relevance of the findings by identifying where green bonds are most effective and where structural constraints may limit their impact**.**

The remainder of the paper is structured as follows. Section 2 provides an overview of green bond issuance and financial development in Asian countries. Section 3 reviews the existing literature. Section 4 outlines the empirical model, methods, and data sources. Section 5 presents and discusses the empirical findings. Finally, Sect. 6 concludes with policy implications, particularly on how financial development can be leveraged to maximize the economic benefits of green bonds while minimizing their potential adverse effects.

2 Overview of financial development index and green bond in asian countries

This section provides an overview of the financial development index (FD) and green bond in selected Asian countries from 2012 to 2022. It includes countries with different income levels, categorized as lower-middle, upper-middle, and high-income economies. This study compares and shows which countries demonstrate greater effectiveness in promoting sustainable development through the interactive channel between green bonds and financial development index.

Table 1 presents the FD and green bond issuances of the lower-middle income Asian countries between 2012 and 2022. Among the lower-middle income countries, India stands out as the most financially developed economy and the largest player in the green bond market, with FD of 46.85 and green bond issuance worth $13.6569 billion.

India has been leveraging sovereign green bonds to fund sustainable projects and decarbonize railways, carbon-intensive industries, and energy production [25]. To support the development of the green bond market, India introduced a green bond framework in its 2023–2024 federal budget to align domestic green bond practices with the international standards. In parallel, the Securities and Exchange Board of India (SEBI) released the Green Bond Guidelines in 2017, which provide a clear taxonomy to support environmentally friendly projects such as clean energy, transport, and waste management. [53] (India Infrastructure, 2024). These guidelines ensure transparency by requiring detailed reporting on fund use and project goals, while outlining green characteristics for eligible projects [40]. These initiatives have boosted investor confidence and enhance financial credibility of India's green bond market. Through this mechanism, India has successfully raised $2 billion to finance a flagship project aimed at generating

Table 1 Average of financial development index and green bond for lower-middle income in selected Asian Countries from 2012 to 2022

Country	Financial development index (%)	Green bond issuance (Real USD $ in billion)
India	46.85	13.6569
Vietnam	36.36	0.9785
Philippines	35.94	2.7974
Lebanon	29.73	0.0426
Pakistan	21.36	0.3186

Source: international monetary Fund and CEIC database

5 million tonnes of green hydrogen by 2030 and expanding clean energy capacity to 500 GW.

Lebanon exhibits a relatively low FD of 29.73 and the lowest green bond issuance, totaling $0.0426 billion from 2012 to 2022**.** The Philippines and Vietnam manifest moderate FD of 35.94 and 36.36**,** respectively, with green bond issuances recorded at US$2.7974 billion and US$0.9785 billion. Pakistan is the least financially developed economy based on Table 1, with a FD of 21.36. This is mainly due to limited foreign investment, weak global market integration, a slow rate of industrial expansion, and restrictive economic regulations that impede trade and financial development [6]. Nevertheless, Pakistan has issued a modest volume of green bonds within the ten-year period, totalling US$0.3186 billion.

Table 2 shows the FD and green bond issuances of the upper-middle income group in Asia between 2012 and 2022. Thailand has the highest FD of 70.94 and green bond issuance of $1.7748 billion among the income group. In 2020, the Thailand Public Debt Management Office (PDMO) announced the Sustainable funding Framework worth $1.65 billion to facilitate the issuance of green, social, and sustainability bonds. For example, part of the funds raised from the sustainability bond was used to refinance the Mass Rapid Transit Orange Line (East) Project, which aims to modernize Bangkok's clean transportation network. [26, 100].

To improve sustainable financing and advance the green bond sector, the Thailand Ministry of Finance issued Southeast Asia's first sovereign sustainability-linked bond (SLB) in 2024, priced at 30 billion baht. A key feature of the SLB is that its coupon rate is directly linked to the Thai government performance in achieving specific sustainable development goals, such as reducing greenhouse gas emissions by 30% by 2030 and increasing annual registrations of zero-emission vehicles to 440000 [93]. This cornerstone initiative demonstrates Thailand's leadership in sustainable finance in the region and its capacity to establish institutional synergies with the green bond market by integrating sustainability commitments into national fiscal strategies [84].

Malaysia and China are next in line with strong FD of 67.76 and 61.85 respectively, followed by Türkiye (49.48), Indonesia (35.55), Kazakhstan (32.88) and Georgia (28.52), all of which show moderate financial development. Armenia has the lowest FD of 24.27, implying significant room for growth in financial infrastructure and market integration.

Table 2 Average of financial development index and green bond for upper-middle income in selected Asian Countries from 2012 to 2022

Country	Financial development index (%)	Green bond (Real USD $ in billion)
Thailand	70.94	1.7748
Malaysia	67.76	1.3622
China	61.85	165.4104
Turkiye	49.48	0.3667
Indonesia	35.55	3.8718
Kazakhstan	32.88	0.0002
Georgia	28.52	0.5342
Armenia	24.27	0.0393

Source: international monetary fund and CEIC data

China is the leading green bond issuer among the upper-middle income economies, with a registered issuance volume of $165.4104 billion. To comply with the global standards, China established the Green Bond Endorsed Project Catalogue in 2021, which explicitly prohibits fossil fuel projects such as "clean coal" and specifies appropriate channels for the allocation of green bond funds [107]. This commitment has significantly increased the transparency and strengthened green governance within the country, thereby minimizing greenwashing risks and boosting investor trust [69].

Indonesia, Thailand and Malaysia are the other upper-middle-income countries that have issued over $1 billion worth of green bonds during the ten-year period, recorded at $ 3.8718 billion, $ 1.7748 billion and US$ 1.3622 billion, respectively. These countries have each adopted a tailored green bond framework to guide their green bond markets, such as Sustainable Finance Roadmap in Indonesia 2021–2025, Sustainable Finance Initiatives for Thailand, and Sustainable and Responsible Investment (SRI) Sukuk Framework in Malaysia [18, 109]. These frameworks anchor the development of their green bond markets and reinforce their positions as key participants in the global sustainable finance ecosystem.

Other modest green bond issuers in the upper-middle-income group include Turkey ($ 0.3667 billion), Georgia ($ 0.5342 billion), and Armenia ($ 0.0393 billion). By contrast, Kazakhstan has issued the least green bonds of $ 0.0002 billion, indicating limited emphasis on sustainable finance initiatives.

Table 3 depicts the FD and green bond issuance volumes in the high-income Asian economies between 2012 and 2022. Japan demonstrates the highest FD among the high-income Asian countries, recorded at 87.64, with a relatively substantial green bond issuance amounting to $46.6586 billion. Singapore ranks second among the high-income group in terms of FD, registered at 72.79%, while issuing a total of $23.2640 billion in green bonds from 2012 to 2022. On the other hand, Israel's FD moderates at 58.30%, but it issued the least green bonds during the ten-year period among the high-income group. While the FD of United Arab Emirates (UAE) and Saudi Arabia are on par, at 48.73% and 45.94% respectively, the former has the largest green bond issuance volume of $59.4332 billion, whereas the latter exhibited a marginal issuance of $3.9586 billion.

The UAE aims to achieve 50% clean energy by 2050, comprising 44% renewable and 6% nuclear energy [4]. Major projects supporting this objective include the Barakah Nuclear Energy Plant and the Mohammed bin Rashid Al Maktoum Solar Park. The Dubai Clean Energy Strategy 2050 represents a deepened commitment from the government to

Table 3 Average of financial development index and green bond for high-income in selected Asian Countries from 2012 to 2022

Country	Financial development index (%)	Green bond (Real USD $ in billion)
Japan	87.64	46.6586
Singapore	72.79	23.2640
Israel	58.30	0.5887
United Arab Emirates	48.73	59.4332
Saudi Arabia	45.94	3.9586

Source: international monetary fund and CEIC

promote energy efficiency and sustainable development. For instance, the Dubai Solar Schools initiative aims to achieve decarbonization by installing solar panels in educational institutions [29].

To sum up, advanced financial development tends to promote the growth of green bond market, as evidenced by China, India, and Japan. These countries have well-defined green bond taxonomy, alignment with global standards, and strong institutional commitments underpin their positions at the forefront of the green bond market in their respective income groups in Asia. Contrarily, countries with a weaker financial system, such as Armenia, Kazakhstan, and Pakistan exhibit sluggish green bond market development due to limited investment, poor governance, and weak economic integration.

Apart from that, a higher FD does not automatically translate into greater green bond issuance volume. In the high-income group, Japan has the highest FD but it issued fewer green bonds than the UAE, which has considerably lower FD. The same is observed in the middle-income-group, where China issued substantially more green bonds than Thailand and Malaysia, even though it has lower FD than the other two countries. This could be attributable to factors like investor preferences for traditional investments, less stringent green bond regulations, and a limited number of eligible green projects in some financially advanced countries. On the flip side, China and the United Arab Emirates have emerged as green bond leaders by investing heavily in large-scale renewable energy and climate-resilient projects, demonstrating their strong political determination in energy transition and economic diversification. This contrast suggests that while a strong financial system is vital, supportive government policies and strong political will are critical to the successful development of green bond markets.

As aforementioned, there is a pronounced correlation between FD and green bonds, underpinned by financial preparedness, institutional capacity, and regulatory clarity. These factors determine how effectively countries can leverage their financial development to enhance the positive impact of green bond issuance on GDP. By analyzing the interactive effects of FD and green bonds on GDP, this study offers new insights and improves the existing financial policies in achieving sustainable growth.

The classification by income group is intended for descriptive benchmarking rather than formal statistical comparison. The substantial variation observed across countries and income groups motivates the empirical specification adopted in this study, particularly the inclusion of an.

interaction term between green bonds and the financial development index, as well as the country-specific marginal effect analysis.

3 Literature review

Green bonds and financial development have become increasingly interconnected in driving GDP growth in recent years. [32, 98] emphasize that integrating environmental considerations into financial systems through instruments such as green bonds is essential for aligning economic growth with sustainability objectives. This linkage supports economic expansion while simultaneously addressing environmental challenges, reinforcing the concept of sustainable growth. The relationship among GDP, financial development, and green bonds is therefore inherently complex, reflecting the interdependence between financial system evolution, investment structures, and sustainability

goals. Accordingly, this section synthesizes recent findings to examine how financial transformation, particularly through green initiatives, influences economic performance.

Green bonds, defined as debt instruments used to finance projects with positive environmental impacts, play a central role in transforming the financial landscape, while fostering environmental sustainability [59]. The Green Bond Principles enhance transparency and investor confidence by ensuring that proceeds are allocated to clearly defined green purposes [39]. Although green bonds typically offer yields that are 15–20 basis points lower than conventional bonds, they remain attractive to investors due to their environmental benefits and reputational value [71]. Evidently, corporate green bond issuance is associated to stock value appreciation as the incorporation of ESG in corporate practice is essentially part of the corporate social responsibility that would enhance company reputation [70, 119].

The effectiveness of green bonds also depends on the level of financial development. [118] show that in countries with advanced financial systems, such as the Netherlands and Belgium, green bonds are more closely integrated with broader financial markets, implying stronger linkages and greater exposure to volatility transmission. This highlights the importance of well-developed financial infrastructure in supporting green finance and enabling green bonds to serve as tools for risk management in mature markets. At the institutional level, [108] underscores the role of central banks in promoting financial development through sustainable financial frameworks, climate-related regulations, and strategic capital allocation toward green sectors. In addition, non-bank financial institutions, including insurance companies and pension funds, are increasingly investing in green financial instruments, while fintech developments—particularly in China and Hong Kong—are improving transparency and operational efficiency. Complemented by incentive mechanisms and public awareness initiatives, these developments strengthen financial resilience, support environmental sustainability, and contribute to long-term economic growth.

Empirical findings on the relationship between green bonds and GDP growth is mixed. One strand of the literature argues that green bond issuance promotes GDP growth, mainly through job generation, investment expansion, and technological development, supporting the neoclassical growth theory [59, 117] suggests that green bond issuance can stimulate GDP growth, particularly in Asia and Europe, by financing green infrastructure and creating jobs opportunities in ESG-integrated financial sector. Both [7, 110] explain that green infrastructure like renewable energy facilities expand sustainable energy access for businesses and households in South Asian countries, thereby stimulating economic growth. In line with that, [79] emphasize that green financing helps mobilize private capital for renewable energy, waste management, and other sustainable sectors. On one hand, reliable and sustainable channeling of investment funds into these sectors facilitate relevant technological improvement that spill over across domestic industries holistically [35]. On the other hand, green bond-financed investments significantly create more employments across the broader economy. Essentially, green bond issuance fosters overall economic expansion through their multiplier effects across economic sectors, which corroborates the argument of [17].

In contrast to the proposition of [17, 35, 50] found that more than half of the green capital allocation is directed towards energy sector development. This implies

that the growth-enhancing effect of green finance may be limited as technological advancement and job generation are largely concentrated at specific sectors, thus, hampering economic diversification and constraining aggregate returns [106]. In the same vein, [15] reveals that green bond-supported investment exhibits diminishing returns in the long run, especially when the green bond market is still immature and inefficient. [49] claim that green bond issuance alone is insufficient to drive GDP growth although it can improve the investment climate and contribute to sustainable development by encouraging innovation and supporting environmentally beneficial projects. They highlight that the growth-enhancing effect of green bond issuance contingent upon institutional robustness and a sound financial system.

Besides that, [99] informs that the effect of green bond issuance on GDP growth varies across Asian economies of different income levels. In higher and upper-middle income countries, increased green bond issuance reinforces GDP growth. Conversely, in low and lower-middle-income nations, green bond issuance often trends similarly with GDP, while financial development has a minimal feedback effect on growth. While foreign direct investment contributes to financial development, governance quality and institutional strength remain key drivers of green bond issuance. In essence, existing literature suggests that while green bond issuance catalyzes GDP growth through job creation, increased investment, and technological innovation, the extent to which these channels translate into sustainable GDP growth largely depends on the diversity of domestic green projects, financial market development, and institutional quality, all of which differ significantly across countries with different economic sizes.

Meanwhile, [82] argue that green bonds are essential for sustainable development in low and middle-income countries. However, robust GDP growth alone does not guarantee a thriving green finance sector. For example, despite strong economic performance, Vietnam green bond market remains underdeveloped due to weak financial infrastructure and the absence of ESG standards. The development of the green bond market can only be accelerated by enhancing regulations, building market capacity, and offering financial incentives. According to [58], the Green Finance Development (GFD) shows that stronger green finance systems are associated with better economic outcomes, including higher GDP and reduced poverty. Investments in clean energy and sustainable infrastructure not only raise living standards but also create employment opportunities and stimulate long-term economic growth.

According to [120], green bonds in developed economies are less sensitive to financial stress due to investor preference for sustainable investments, contributing to greater price stability during economic uncertainty. This suggests that the role of green bonds as a stabilizing instrument is amplified by financial development. A well-functioned financial system fosters investment in sustainable practices, which is positively associated with GDP growth [104]. However, the link between finance and sustainability is conditional upon the presence of strong governance and ESG alignment. Research further shows that the development of the banking sector significantly influences the ability of green bonds to channel capital into renewable energy and sustainable infrastructure [22]. In countries with advanced banking systems, green bonds support green investments more effectively, indirectly stimulating GDP

growth and supporting the transition to a low-carbon economy through mechanisms like carbon pricing and green credit lines.

While a strong financial development facilitates access to credit and fosters a supportive investment climate, excessive financial deepening may hinder GDP growth. [8] demonstrate that financial depth exhibits diminishing returns on GDP growth when private credit exceeds 80% of GDP, which affirms the threshold analysis findings of [63]. This is a typical scenario whereby an economy is overleveraged, exposing it to high credit risk. Similarly, [21] found a U-shaped relationship between financial development and GDP growth. They explained that rapid financial development may cause overinvestment and overvaluation of stocks when not accompanied by proportionate returns. Besides, they added that uneven sectoral development, in which financial development significantly outpaces other economic sectors, can lead to concentration of resources, such as capital and labour, in the financial sector, potentially undermining the development of productive real sectors. In the same vein, [105] reveal differentiated finance-GDP relation between developed and developing economies. Particularly, financially advanced countries tend to create a variety of complex financial products which could result in increased vulnerabilities in the financial system. In countries with less developed financial systems, financial development facilitates the mobilization of private credit toward fundamental sectoral development.

Although the literature on green bonds, financial development index, and economic growth is expanding, there remain several gaps. First, most existing research in Asia tends to examine these variables either in aggregate or within limited country samples, without systematically comparing their dynamics across income groups [59, 82, 99]. This study categorizes the sample countries into lower-middle, upper-middle, and high-income Asian economies to capture country-specific differences in green bond market maturity, policy situations, and overall financial adoption. Second, while panel models are widely used, prior studies often rely on relatively short time frames, limiting the ability to observe long-term structural relationships [17, 55]. The 10-year timeframe used in this study better captures the structural changes and long-lasting consequences in the relationship between green bonds, FD, and GDP. Third, while many studies assess the relationship between the three variables separately, few look at their sophistication through a moderating channel [79, 98]. This study focuses on the interaction between green bond and FD in affecting GDP, especially in the Asian context, which can provide deeper insights for policy design and sustainable development.

4 Model and methodology

To examine the impact of green bonds and the financial development index on GDP, we adopt the Cobb–Douglas production function as the base model, which has been widely used in previous studies, such as Husaini and Lean (2022) [51] and Lean and Smyth (2014) [64], as shown in Eq. (1):

$$GDP_{it} = \beta_0 + \beta_1 GB_{it} + \beta_2 FD_{it} + \beta_3 K_{it} + \beta_4 L_{it} + \beta_5 GLO_{it} + \varepsilon_{It} \quad (1)$$

where:

GDP-Gross Domestic Product in USD constant at the year 2015.

GB-Amount issued of green bond in USD constant at the year 2015.

FD-Financial development.

K-Gross Capital Formation in USD constant at the year 2015.

L-Numbers of Employment.

GLO-Globalization Index.

The inclusion of green bond issuance and the financial development index in the augmented production function should be interpreted within a reduced-form framework. Green bond issuance does not directly represent a traditional factor of production but serves as a proxy for green-oriented capital formation, as it finances investments in renewable energy, sustainable infrastructure, and environmentally efficient technologies [1]. Through this channel, it contributes to the expansion and reallocation of the capital stock.

Meanwhile, the financial development index captures the efficiency of financial intermediation, influencing how effectively financial resources are mobilized and allocated across sectors. In this context, financial development enhances the productivity of investment by reducing information asymmetry and improving capital allocation [111]. Additionally, green bond financing may facilitate structural transformation, shifting resources from carbon-intensive activities toward more sustainable sectors. Accordingly, the estimated coefficients should be interpreted as reflecting the combined effects of capital accumulation, allocation efficiency, and structural change, rather than a purely structural production function relationship.

Financial development is a key driver of economic growth, reflecting the depth, efficiency, and accessibility of a country's financial system [27]. Research indicates that financial development supports growth by encouraging capital accumulation, productivity, and innovation [57, 62]. However, crises and inequalities can result from unbridled financial liberalisation [89]. In that regard, the coupling of appropriate regulation and financial development is necessary for achieving sustainable [19]. Through technological investment, employment creation, and green infrastructure development, green bonds foster economic growth and support sustainable development initiatives [38, 81].

Gross capital formation includes actual investments in fixed assets, machinery, and infrastructure. Gross capital formation can boost production capacity and stimulate associated economic sectors, conventionally seen as a major driver of economic growth [101](Topçu et al., 2020). Employment serves as a proxy for labor input in the production process. Increased household income and heightened demand for spending are two indirect effects of higher employment rates on output growth [14, 61]. Labor productivity rises in economies that invest in human capital, leading to long-term economic growth. According to [45], the Globalisation Index measures how integrated a nation is with the world economy through trade, finance, and information flows. Increased globalisation makes it easier to transfer technology, attract foreign direct investment, and improve access to global markets [56, 95]. These variables serve as fundamental driving forces for innovation and competition, which boost GDP growth.

The second objective to evaluate the indirect impact of financial development and green bonds on economic growth. The empirical framework is expanded by introducing the interaction term FD*GB into the empirical model. This approach enables a comprehensive analysis of how financial development index influences the effectiveness of green bonds in driving economic growth. The empirical model is expressed as follows:

$$GDP_{It} = \beta_0 + \beta_1 GB_{It} + \beta_2 FD_{It} + \beta_3 (GB * FD)_{It} + \beta_4 K_{It} + \beta_5 L_{It} + \beta_6 GLO_{It} + \varepsilon_{It} \tag{2}$$

where *GB*FD* represents the interaction term between the FD and green bonds. According to [43], the presence of an interaction term suggests that the impact may be influenced differently depending on the value of another independent variable. By employing an interaction term, the model may investigate whether the impact of green bonds on GDP fluctuates in response to shifts in FD. The study derives the partial derivatives using an interaction term in order to quantify the marginal effects of FD and GB on GDP:

$$\frac{\partial GDP_{it}}{\partial GB_{it}} = \beta_1 + \beta_3 FD \tag{3}$$

The interaction effect of FD and GB on GDP is reflected in the coefficients β_1 and β_3. If $\beta_1 > 0$ and $\beta_3 < 0$, the promoting effect of green bonds on GDP becomes less pronounced as FD rises. Green bonds pose a negative impact on GDP if $\beta_1 < 0$ and $\beta_3 > 0$, while FD mitigates this negative effect. Coefficients with $\beta_1 < 0$ and $\beta_3 < 0$ suggest that increased green bond issuance deteriorate GDP growth, while the adverse effect is enhanced by higher FD. If $\beta_1 > 0$ and $\beta_3 > 0$, the facilitating effect of green bonds on GDP is amplified as FD rises.

The Generalized Method of Moments (GMM) is used in this study to handle possible endogeneity, ensuring more accurate and efficient parameter estimates [9, 20]. GMM is particularly suitable for dynamic panel data models, as it allows for potential correlations between explanatory variables and error terms. The system GMM approach incorporates level and difference equations to increase efficiency while accounting for unobserved heterogeneity, endogeneity, and omitted variable bias. The general form of the dynamic panel model estimated using GMM is as follows:

$$Y_{It} = \alpha Y_{it-1} + \beta' X_{it} + \mu_i + \varepsilon_{It} \tag{4}$$

where Y_{it} is dependent variable (gross domestic product in case), Y_{it-1} is its one-period lag, X_{it} is the vector of independent variable, μ_i captures unobserved country-specific effects, and ε_{it} is idiosyncratic error term. To generate accurate and consistent estimates when endogeneity is present, the GMM approach uses internal instruments, specifically the lagged values and differences of the endogenous variables.

4.1 Data

The sources of the data employed are obtained from World bank, World Economic Forum, CEIC database, International Monetary Fund (IMF) and KOF Globalization Index data, involving 18 Asian countries. The sample period of the study spans from 2012 to 2022. Details about the data employed are presented in Table 4.

Table 5 represent 18 Asian countries grouped by income level based on the World Bank. Although the 18 countries were selected based on data availability, they provide broad regional representation across Asia. The sample includes countries from different income groups within each region to ensure diversity in economic and financial development levels, thereby reducing potential sample bias. In particular, China and Japan represent East Asia; India and Pakistan represent South Asia; Indonesia, Malaysia, the

Table 4 Description data of the study

Variables	Symbol	Measurement	Description	Data sources	Expected sign
Gross domestic product	GDP	Gross domestic product per capita constant at 2015	Measures the average economic output per person, adjusted for inflation to reflect real economic growth over time	World Bank Development Indicator [112]	
Green bond	GB	Amount issued of green bonds in USD by country	Gauges a country's investment in environmentally friendly projects and sustainable finance by calculating the inflation-adjusted value of green bonds issued	CEIC Data	-/+
Financial development index	FD	Financial development index	Measures the efficiency, depth, and accessibility of a country financial institutions and markets, reflecting the overall development of its financial system	International Monetary Fund	+
Gross capital formation	K	Gross capital formation constant 2015	Calculates the whole worth of investments made in fixed assets, like machinery, equipment, and infrastructure, while accounting for inflation to reflect actual economic growth over time	World Bank Development Indicator [113]	+
Employment	L	Number of employment	Calculates the total number of people working for pay or working for themselves within an economy, making it a crucial gauge of economic activity and labor market conditions	World Bank Development Indicator [114]	+
Globalization index	GLO	Globalization index	Gauges how much a nation has integrated economically, socially, and politically with the rest of the globe, taking into account cross-border investment, commerce, information flows, and cross-cultural interactions	KOF Globalisation Index	+

Philippines, Singapore, Thailand, and Viet Nam represent Southeast Asia; Kazakhstan represents Central Asia; Lebanon, Israel, Saudi Arabia, and the United Arab Emirates represent the Middle East; whereas Armenia, Georgia, and Turkiye represent West Asia.

Table 5 Income classification of selected Asian Economies

Income level		
Lower-middle income economies		
India	**Lebanon**	**Pakistan**
Philippines	Viet Nam	
Upper-middle-income economies		
Armenia	China	Georgia
Kazakhstan	Indonesia	Malaysia
Thailand	Turkiye	
High-income economies		
Israel	Japan	Singapore
Saudi Arabia	United Arab Emirates	

Source: World Bank, 2024 [115]

Table 6 Descriptive statistic on selected Asian Countries

	GDP	GB	FD	K	L	GLO
Mean	26.6384	9.1993	3.7830	25.2598	16.8029	4.2263
Median	26.6003	4.6052	3.7954	25.1479	16.8381	4.2126
Maximum	30.4237	20.2179	4.5326	29.5474	20.4288	4.4321
Minimum	22.9804	4.6052	2.9957	21.4151	14.0064	3.9712
Std. dev	1.6919	5.7091	0.3997	1.8471	1.8171	0.0108
Observations	198	198	198	198	198	198

All values are in natural log except N (observation)

Source: author own calculation

4.2 Empirical results

Table 6 depicts the descriptive statistics of the variables. Table 7 reports the findings of the direct and indirect relationships between green bonds, FD and economic growth. All variables are transformed into natural logarithms to address normality issues, stabilize variance, and facilitate interpretation. For direct effect, both green bonds and FD are statistically insignificant. On the other hand, control variables including K, L, and GI exhibit positive influence on GDP, statistically significant at 1% significance level. The Sargan test result is not significant, suggesting the model is free from overidentification problem.

For indirect effect, GB is statistically significant at the 5% significance level, with a negative sign. In contrast, the interaction coefficient (GB*FD) is statistically significant at 1% significance level, with a positive sign. These results indicate that the green bonds negatively affect GDP, however, the effect is mitigated by financial development. The Sargan test result is not significant, suggesting the model is free from overidentification problem.

Since GMM results indicate that green bonds pose behavioral change on GDP, conditional on financial development, it is necessary to compute the marginal effects of the interaction term for a country-specific analysis.

It is important to note that the direct coefficient of green bonds is statistically insignificant, and therefore does not provide sufficient evidence of a standalone growth

Table 7 Results of panel data analysis

Model	Direct Model	Indirect Model
Constant	0.6384*** [0.0459]	0.6456 *** [0.0451]
ln GB	− 0.0001 [0.0003]	− 0.0006** [0.0003]
ln FD	− 0.0346 [0.0327]	− 0.0106 [0.0259]
ln K	0.1415 *** [0.0172]	0.1413 *** [0.0185]
ln L	0.5488 *** [0.0551]	0.5261 *** [0.04665]
ln GI	0.5399 *** [0.2549]	0.5760 ** [0.2427]
ln GB*FD	–	0.0062*** [0.0007]
N	162	162
T	18	18
Sargan Test	14.527	15.790
AR1	0.0195	0.0096
AR2	0.6072	0.4768

***, ** and * represent significance at the 1%, 5%, and 10% significance levels, respectively. [] report the standard error statistics

effect. The economic interpretation of the results is primarily derived from the interaction term, which captures how the impact of green bonds on GDP is conditional on the level of financial development.

Table 8 reports the marginal effects of GB on GDP at the country level, computed using the estimated GB and GB*FD coefficients with the equation below:

$GDP = -0.0006 + 0.0062(FD)$

The Table 8 presents the results at the minimum, median, and maximum levels of FD, alongside the percentage change in the GB coefficients across these levels. The countries are ranked according to the magnitude of their GB coefficients, providing a comparative picture of how financial development conditions the growth impact of green bonds.

The results in Table 8 reveal significant heterogeneity in the marginal effects of the interaction between financial development and green bonds on GDP growth. The reported country-specific marginal effects are derived from the estimated regression coefficients and represent conditional effects evaluated at each country's level of financial development. While the underlying coefficients are statistically tested within the model, the cross-country comparison of marginal effects is intended to provide descriptive insights into heterogeneity rather than formal statistical inference. Accordingly, the observed patterns, such as increasing or flattening effects across financial development levels, should be interpreted as indicative rather than definitive group differences.

According to Table 8, advanced financial development economies such as Japan, Singapore, and Thailand exhibit significant changes in the marginal effects as their respective financial development levels rise. To be specific, the growth-enhancing effects of GB improve for Japan, Singapore, and Thailand as their FD increase from minimum to median level, with growth rates estimated at 8.03, 4.29, and 10.95%

Table 8 Marginal effect by country

No	Country	Financial development index		
		Minimum	Median	Maximum
1	Japan			
	GB coefficient	0.5016	0.5419	0.576
	% change		8.03%	6.29%
2	Singapore			
	GB coefficient	0.4334	0.452	0.4706
	% change		4.29%	4.12%
3	Thailand			
	GB coefficient	0.3962	0.4396	0.4582
	% change		10.95%	4.23%
4	Malaysia			
	GB coefficient	0.4024	0.4117	0.452
	% change		2.31%	9.79%
5	China			
	GB coefficient	0.3404	0.39	0.4148
	% change		14.57%	6.36%
6	Israel			
	GB coefficient	0.3466	0.359	0.3714
	% change		3.58%	3.45%
7	United Arab Emirates			
	GB coefficient	0.2598	0.3032	0.359
	% change		16.71%	18.40%
8	India			
	GB coefficient	0.2598	0.2815	0.3342
	% change		8.35%	18.72%
9	Saudi Arabia			
	GB coefficient	0.2474	0.2877	0.3218
	% change		16.29%	11.85%
10	Turkey			
	GB coefficient	0.2908	0.3094	0.3156
	% change		6.40%	2.00%
11	Vietnam			
	GB coefficient	0.1978	0.2257	0.2412
	% change		14.11%	6.87%
12	Philippines			
	GB coefficient	0.2102	0.2195	0.235
	% change		4.42%	7.06%
13	Indonesia			
	GB coefficient	0.204	0.2164	0.2226
	% change		6.08%	2.87%
14	Kazakhstan			
	GB coefficient	0.1854	0.2009	0.2226
	% change		8.36%	10.80%
15	Georgia			
	GB coefficient	0.1358	0.1854	0.204
	% change		36.52%	10.03%
16	Lebanon			
	GB coefficient	0.1792	0.1854	0.1916
	% change		3.46%	3.34%

Table 8 (continued)

No	Country	Financial development index		
		Minimum	Median	Maximum
17	Armenia			
	GB coefficient	0.1296	0.1482	0.1606
	% change		14.35%	8.37%
18	Pakistan			
	GB coefficient	0.1234	0.1296	0.1358
	% change		5.02%	4.78%

respectively. However, the growth-enhancing effects of GB begin to diminish as their FD reaches the maximum level, with computed growth rates of 6.29, 4.12, and 4.23% respectively.

These results confirm that while increased green issuance may undermine GDP growth, this effect is mitigated by financial development, eventually resulting in a positive effect on GDP in the presence of a sound financial system. Green bond-funded projects are usually associated with long lock-in periods which may increase exposure to financial risk [85]. A mature financial system can improve fund mobilization, capital allocation, and risk management, thereby mitigating long-term risks associated with green projects [10]. However, the incremental benefits diminish at higher FD levels, suggesting the presence of threshold dynamics, whereby highly developed financial systems experience diminishing marginal returns in positive green bond-output relation from additional financial deepening, consistent with the findings of [21]. Financially developed countries with high ESG demand tend to issue more corporate green bonds, which are more prone to greenwashing than sovereign green bonds [68]. Particularly, greenwashing identification becomes increasingly difficult as more sophisticated "green" labeled instruments are introduced [105]. This phenomenon not only erodes investors' confidence, but also heightens financial vulnerabilities, thus weakening the growth-enhancing potential of green bonds. At this stage, the policy challenge shifts from expanding depth to safeguarding quality, transparency, and resilience, particularly to mitigate greenwashing and sustain investor confidence, which require a strong regulatory environment in the green bond market.

Despite possessing robust financial system, the capacity of green bond issuance to promote greater economic growth faces certain constraints. For instance, Japan faces major structural obstacles in transitioning to a low-carbon economy, largely because of its heavy reliance on fossil fuel imports to meet its increasing energy demands arising from ongoing economic expansion [76]. Recognizing this, the government launched the Green Transformation (GX) framework, with a plan to issue 20 trillion yen in climate transition bonds over the next decade for strategic investments in renewable energy, hydrogen, and battery technology [83]. In parallel, the Ministry of the Environment revised the Green Bond and Sustainability-Linked Bond Guidelines (2017–2024) to align with international standards, strengthen disclosure requirements, and combat greenwashing [11]. These reforms reflect the need for quality- and transparency-focused measures once economies reach the threshold where financial deepening alone is insufficient.

Similarly, Singapore's advanced green finance sector illustrates the same shift in emphasis. The country's main challenge is no longer market depth, but the risk of greenwashing and the need to maintain investor trust [66]. In response, the Monetary Authority of Singapore (MAS) introduced the Singapore-Asia Taxonomy, a detailed classification framework that defines what counts as "green". This initiative enhances market confidence, provides regulatory clarity, and consolidates Singapore's status as a regional hub for sustainable finance [36].

In Thailand, the policy initiative has focused on scaling issuance while ensuring credibility. As one of ASEAN's leading issuers of green and sustainable bonds, Thailand issued its first sovereign sustainable bond in 2020 (30 billion Baht), which was oversubscribed and funds were allocated to both social and green infrastructure projects [16]. By 2022, the country's outstanding stock of Green, Social, and Sustainability (GSS) bonds had reached approximately USD 9.5 billion, supported by both government and corporate issuers [96]. This rapid development demonstrates how middle-to-advanced economies can leverage strong investor demand and institutional frameworks to consolidate leadership in the sustainable debt market.

In contrast, economies with moderate financial development level including Malaysia, the UAE, India, the Philippines, and Kazakhstan appear to be in the "sweet spot." GB coefficients increase consistently from the minimum to maximum levels of FD without signs of flattening. For example, Malaysia progresses steadily from 0.4024 to 0.4117 (2.31% growth) and then to 0.452 (9.79% growth), while the UAE records one of the strongest upward trajectories, moving from 0.2598 to 0.3032 (16.71% growth) and then to 0.359 (18.40% growth). India and Kazakhstan follow similar paths, while the Philippines shows smaller but still progressive gains. These economies show that further financial development continues to amplify the growth benefits of green bonds. Suggesting that the promoting effect of green bonds on sustainable growth is most pronounced in financially emerging countries with improving institutional quality and infrastructure support [23]. These countries possess high financial development capacity and are capable to extensively leverage green bond instruments to mobilize capital for sustainable development, especially during the expansion phase of financial deepening.

The policy frameworks adopted in these countries imply how this dynamic plays out in practice. Malaysia and the UAE demonstrate how targeted strategies can harness green bonds as central financing tools. Malaysia pioneered Islamic green finance with its Green Sukuk Framework in 2014 and ASEAN's first Green Sukuk in 2017, albeit having relatively limited market size and shallow market liquidity [60, 88]. On the other hand, the UAE has integrated green and sustainable bond issuance into its broader clean energy transition, financing large-scale projects such as the Barakah Nuclear Plant and the Mohammed bin Rashid Solar Park, supported by the Dubai Clean Energy Strategy 2050 [4, 29].

The financial situations in India and the Philippines reflect the scale of financing challenges in rapidly growing economies. India continues to grapple with a large financing gap but has responded with a sovereign green bond framework, while aligning SEBI's Green Bond Guidelines aligned with international standards to mobilize resources for its ambitious renewable energy and hydrogen targets [25]. The Philippines, meanwhile, has laid a regulatory foundation through the Renewable Energy Act and the NREP to

finance solar projects such as the Calatagan Solar Farm [31]. Yet, its USD 72 billion climate finance gap shows the limits of green bond markets in smaller economies where investor confidence and market depth remain constrained [91].

Kazakhstan illustrates a different dimension of the "sweet spot." The establishment of the Astana International Financial Centre (AIFC) has facilitated the introduction of sustainable finance regulations and incentives, such as loan interest subsidies [30]. However, structural dependence on fossil fuels and limited diversification of financial markets mean that while marginal effects rise, they remain more modest compared to other emerging peers [121].

Other economies demonstrate a non-linear, inverted pattern. In these cases, financial development initially unlocks substantial positive effects from green bonds, but the pace of gains slows as FD rises further. China, for instance, records a strong improvement from 0.3404 to 0.39 (14.57%), but the incremental change declines to 6.36% at the maximum. Vietnam follows a similar trajectory, with early gains of 14.11% that slow to 6.87%. Saudi Arabia and Armenia also show this inverted shape, where financial deepening produces strong effects up to the median level, with drastically weaker returns thereafter. These patterns suggest that some economies may face a saturation point, where further financial deepening produces limited additional gains, perhaps due to institutional bottlenecks, inefficient allocation of capital, or limited diversification in green projects [49].

These inverted trajectories stem from institutional and structural factors, particularly in China, Vietnam, Saudi Arabia, and Armenia. In China, the green bond market has expanded rapidly, but over 83% of the proceeds continue to flow to state-owned enterprises (SOEs), crowding out private innovation and constraining allocative efficiency [67]. Recognizing this imbalance, China has cooperated with the European Union to establish the Common Ground (CGT), which seeks to harmonize standards and attract more diversified international investments [102]. The inverted effect observed in the results therefore reflects how an initially strong green bond market faces limitation when capital allocation remains skewed and private sector participation is restricted. A similar scenario emerges in Vietnam, where the financial system is still immature. The absence of an independent credit rating agency, combined with limited financial incentives for green investments, has resulted in inefficient capital allocation and weak investor confidence47. These market deficiencies explain why Vietnam's marginal effects rise strongly at early stages but taper off over the course of financial development.

Saudi Arabia highlights a different structural constraint. While the country has introduced ambitious programs such as the Saudi Green Initiative and Vision 2030 to diversify beyond hydrocarbons, its strong dependence on oil remains a fundamental limitation. The issuance of USD 8.5 billion in sovereign green bonds by the Public Investment Fund (PIF) reflects an effort to finance new infrastructure and accelerate diversification [3, 5, 103]. Yet, the inverted pattern in Saudi Arabia suggests that without deeper institutional reforms and diversification of project pipelines, financial deepening alone cannot sustain the growth effect of green bonds.

In Armenia, the problem lies in weak institutional capacity and persistent delays in public investments. A fragile legal system and limited accountability mechanisms undermine the efficiency of capital use [54]. Recent efforts, including the Finance Ministry's establishment of a Monitoring and Evaluation (M&E) Unit and the development of a 2050

climate-neutrality strategy, aim to improve transparency and investment effectiveness [122]. These initiatives reflect the role of institutional commitments in realizing the growth potential of the green bond market, although the impact is still gradually unfolding.

Finally, economies with low FD, such as Georgia, Lebanon, and Pakistan register smaller overall coefficients but striking relative increases at the early stage. Georgia, for example, improves from 0.1358 to 0.1854, a remarkable 36.52% increase before slowing sharply to 10.03% when moving from the median and maximum level of FD. Meanwhile, the coefficient changes of GB in Pakistan and Lebanon are relatively marginal than the other Asian peers from the minimum to the maximum level of FD. These findings imply that early financial development disproportionately boosts the effectiveness of green bonds, but shallow capital markets, weak institutions, and limited enforcement capacity constrain their ability to sustain these gains over time. For such economies, expanding green bond issuance alone will not be sufficient; strengthening institutional credibility, ensuring market stability, and enhancing governance must precede large-scale expansion of green bond markets [49].

The experiences of these countries reveal common structural barriers. Underdeveloped financial infrastructure and weak enforcement capacity are the common challenges that prevail across Asian countries with weaker financial systems. In Georgia, corporate financing remains constrained, the bond market is still in its infancy stage, and development relies heavily on external assistance. Even with strategies such as the Vision 2030 Sustainable Economic Development Plan, gaps between policy design and actual market outcomes persist because of lax regulatory enforcement [34]. This is consistent with the argument of [90] that in low-income nations, financial systems contribute more to capital accumulation than to the capital markets, limiting the role of instruments such as green bonds.

A second constraint is political and macroeconomic instability, which undermines institutional credibility and investor confidence. Lebanon exemplifies this, where long-standing political unrest, debt crises, and currency devaluation have severely weakened financial institutions. As [65] argues, financial development cannot be separated from institutional quality, while [92] emphasize that market stability depends critically on the rule of law and effective regulation. In such contexts, green bonds face an uphill battle where policies may exist on paper, but poor governance and fragile institutions make it difficult to attract investors, thereby hindering the scaling up of issuances.

A third limitation is shallow markets that struggle to translate policy actions into scalable growth, which is exemplified by Pakistan. Despite progress through made in the 2019 Renewable Energy Policy and the issuance of its first Sovereign Green Bond in 2021, weak regulatory enforcement and shallow markets continue to restrict capital mobilization in the country [77]. As [73] observed, achieving scalable finance and sustained growth requires crossing a critical threshold of financial development of which this particular group of economies may not have reached yet.

4.3 Robustness test

For robustness, we replace gross capital formation with gross fixed capital formation in Eqs. (1) and (2). The results, reported in Table 9, remain consistent in both direction and magnitude with the baseline estimates.

4.4 Conclusion

This research aims to examine the direct and indirect relationships between green bonds, financial development, and economic growth across 18 selected Asian economies. The findings suggest that while green bonds and financial development do not directly influence economic growth, financial development exerts indirect influence by mitigating the negative impact of green bonds on economic growth. At the country-specific level, it is found that financial development level of a country determines how much growth impact green bonds can have. Green bonds show significant positive marginal effects in advanced financial development economies like Thailand, Singapore, and Japan, but these effects waned as financial systems matured. This implies the existence of threshold dynamics, whereby diminishing returns emerge beyond a certain financial development level.

On the other hand, it is discovered that upper-middle-income economies, such as Malaysia, the United Arab Emirates, India, the Philippines, and Kazakhstan, are in a "sweet spot" where additional financial deepening continuously increases the growth impact of green bonds. These countries serve as examples of how crucial it is to maximize sustainable finance by bolstering capital markets, investor confidence, and regulatory enforcement. Lastly, economies with low financial development indexes, like Georgia, Lebanon, and Pakistan, show disproportionately large relative gains but small overall economic returns. The sustainability of these gains was constrained by their weak institutions, shallow markets, and inadequate governance, highlighting the necessity of institutional strengthening before scaling green bond issuances.

Based on the findings obtained, this study provides several policy implications. First, for advanced economies with well-developed financial system, green bond development should remain a key agenda to foster sustainability-driven economic growth.

Table 9 Robustness checks

Model	Direct model	Indirect model
Constant	0.9332*** [0.0250]	0.9135*** [0.0607]
ln GB	− 0.0002 [0.0002]	− 0.0021** [0.0011]
ln FD	− 0.0081 [− 0.0231]	− 0.0998 [0.0611]
ln K	0.6401*** [0.0291]	0.0130*** [0.0021]
ln L	0.6651*** [0.0719]	0.2373 [0.1150]
ln GI	0.7241** [0.3033]	0.2443 [0.1527]
ln GB*FD	–	0.0091** [0.037]
N	162	162
T	18	18
Sargan Test	10.1842	10.2371
AR1	0.0492	0.0139
AR2	0.3856	0.8142

***, ** and * represent significance at the 1%, 5%, and 10% significance levels, respectively. [] report the standard error statistics. AR1 and AR2 report the p-value

Nevertheless, these countries should carefully monitor the pace of green bond development, since increased financial deepening leads to the emergence of more corporate issuers and increasingly complex green bond instruments, potentially complicating monitoring process and increasing greenwashing risk. At this stage, priority should shift toward enhancing transparency, tightening disclosure standards, and safeguarding investor trust, which are essential for sustaining confidence in sustainable finance. This requires the formulation of law-binding regulations and implementation of standardized reporting mandate to reduce greenwashing behavior, especially across corporate issuers. Besides, policymakers should ensure that financial instruments labeled as "green" are not excessively complex and adhere to stringent disclosure and external verification requirements.

Second, upper-middle-income economies stand at a critical juncture where further financial deepening can yield the largest gains. These economies should therefore pursue capital market development and regulatory harmonization more aggressively. Measures such as improving secondary market liquidity, standardizing disclosure practices, and aligning national taxonomies with international frameworks will not only attract global investors but also ensure that green finance remains efficient, transparent, and scalable. Sovereign green bond issuance can play a catalytic role in encouraging corporate participation in the green bond market. The issuance process of sovereign green bonds, including impact reporting, disclosure standards, and third-party verification, can provide a benchmark framework for corporate issuers and signal the government's commitment to green finance development to the private sector. This will foster a supportive financial environment to drive the development momentum of the green bond market.

Third, lower-middle-income countries may pursue a transient expansion in the green bond market at early financial development. At this stage, these countries should prioritize sovereign green bond issuance to stimulate economic growth through capital investment and job generation, as private participation tends to be relatively limited in a shallow financial system. However, as financial development takes pace, green bond market development should be stabilized and priority should be shifted to improving institutional frameworks and strengthening governance instead. Thus, as financial development accelerates, these countries should focus on developing effective enforcement mechanisms, fostering an open regulatory environment, and strengthening institutional capacity. These initiatives lay a robust institutional foundation for green bonds to effectively mobilize long-term capital toward sustainable development projects, while minimizing risks of misallocation and subpar economic returns.

Overall, there is no one-size-fits-all approach to optimizing the growth advantages of green bonds. Instead, the stage of financial development of each economy must be taken into consideration when designing policies. Quality assurance is critical for advanced economies, with an emphasis on avoiding "greenwashing" and preserving the market's long-term credibility. To take full advantage of its "sweet spot" effects, market deepening and regulatory coordination are essential for mid-stage economies. Additionally, large-scale issuance must be subordinated to institutional building and governance reforms in less financially developed economies. Financial development is not just a contextual condition, but an important moderating factor that determines whether green bonds could dampen the growth potential or become a significant driver of sustainable growth. The

potential of financial development and green bonds to accelerate Asian economies' transition toward a low-carbon, resilient, and inclusive economic future can only be realized through the coordination and enhancement of institutional quality, regulatory capacity, and financial market development.

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Data availability
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Declarations

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