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GREEN BOND FINANCING AND CARBON EMISSIONS: THE MEDIATING ROLE OF RENEWABLE ENERGY IN OECD ECONOMIES

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Abstract
Green bond financing has emerged as one of the fastest-growing sustainable finance instruments for mobilizing private capital toward climate-friendly investments. However, empirical evidence regarding its effectiveness in improving environmental performance remains inconclusive, particularly concerning whether green bonds reduce carbon emissions directly or operate through renewable energy development. This study investigates the relationship between green bond financing, renewable energy consumption, foreign direct investment, trade openness, and carbon dioxide emissions across 38 OECD economies over the period 2014–2023. The empirical analysis employs pooled ordinary least squares, fixed-effects, and random-effects panel regression models, with the Hausman and Breusch–Pagan tests used to identify the most appropriate estimator. In addition, the Baron–Kenny mediation framework, complemented by Sobel and cluster-bootstrap procedures, is applied to evaluate the indirect effect of green bond financing through renewable energy consumption. The findings indicate that green bond financing does not exert a strong direct influence on carbon dioxide emissions after controlling for country-specific heterogeneity. Instead, green bond financing significantly promotes renewable energy consumption, which in turn substantially reduces carbon emissions, confirming the presence of a significant indirect relationship. The mediation analysis demonstrates that renewable energy represents the principal transmission channel through which green bond financing contributes to environmental improvement. Furthermore, foreign direct investment is associated with higher carbon emissions, whereas trade openness does not exhibit a statistically significant effect after controlling for unobserved heterogeneity. The study highlights that the environmental effectiveness of green bonds depends on their capacity to accelerate renewable energy deployment rather than on financing activity alone. These findings provide important implications for policymakers seeking to strengthen sustainable finance frameworks and improve the environmental impact of green capital markets through enhanced project selection, transparency, and renewable energy investment.
Keywords: *Green Bonds, Renewable Energy, CO2 Emissions, Sustainable Finance*

INTRODUCTION

Climate change has become one of the most significant global challenges of the twenty-first century, posing substantial environmental, economic, and social risks across both developed and developing economies (Adger et al., 2003; Ali & Audi, 2016; Hernández & Breña, 2016; Abbass et al., 2022; Siswanto et al., 2026). Rising greenhouse gas emissions, increasing frequency of extreme weather events, biodiversity loss, and growing climate-related financial risks have intensified the need for large-scale investment in low-carbon infrastructure and climate adaptation projects (Alam et al., 2016; Ali et al., 2021; Lopez-Claros, 2021; Songwe et al., 2022; Zhai et al., 2024; Mehdi et al., 2025; Ali-Masri & Audi, 2026; Acharya, 2026). Achieving international climate objectives, including the Paris Agreement and the Sustainable Development Goals, requires financial resources that far exceed the capacity of public budgets alone. Consequently, sustainable finance has emerged as a central policy mechanism for mobilizing private capital toward environmentally sustainable investments (Park, 2018; Ali et al., 2021; Abbasi et al., 2025; Lin, 2025; Naeem et al., 2026; Raihan & Sarker, 2026). Among the various sustainable finance instruments, green bonds have experienced remarkable growth over the past decade because they provide dedicated financing for renewable energy, clean transportation, energy efficiency, pollution control, sustainable infrastructure, and other environmentally beneficial projects. Global green bond issuance has expanded from only a few billion dollars in the early 2010s to several hundred billion dollars annually, making green bonds one of the fastest-growing segments of international capital markets (Shishlov et al., 2016; Marc & Ali, 2017; Arshi et al., 2025; Kumar, 2025; Majeed et al., 2026; Allen et al., 2026).

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The rapid expansion of green bond markets has generated considerable optimism regarding their potential contribution to environmental sustainability (Antal & Van Den Bergh, 2016; Sajid & Ali, 2018; Audi et al., 2022; Bashir et al., 2024; Batool et al., 2025; Tiwari et al., 2026). By lowering financing costs for environmentally beneficial projects and attracting long-term institutional investors, green bonds are expected to accelerate investments in renewable energy, green infrastructure, and climate adaptation (Varney, 2025; Azam et al., 2026). These investments should contribute to lower carbon emissions, improve environmental quality, strengthen climate resilience, and facilitate the transition toward low-carbon economic development (Audi et al., 2020; Habib et al., 2025; Naeem et al., 2025; Tahir et al., 2026; Wang et al., 2026). Nevertheless, green bonds represent a financing mechanism rather than an environmental outcome. Their effectiveness depends on whether the proceeds finance genuinely additional projects, whether funded projects are implemented efficiently, and whether these investments successfully replace carbon-intensive activities rather than merely expanding total production capacity. Concerns regarding additionality, project selection, monitoring standards, and greenwashing therefore continue to generate uncertainty regarding the actual environmental effectiveness of green bond financing (Marc & Ali, 2023; Ashiq et al., 2023; Apergis et al., 2025; Ali et al., 2025; Liu et al., 2026). Several studies argue that green bond financing contributes to lower carbon emissions and greater environmental sustainability through increased investment in renewable energy and green technologies, others report limited or statistically insignificant direct effects after controlling for economic, institutional, and energy-related factors (Ali, 2015; Maltais & Nykvist, 2020; Ali et al., 2025; Pata et al., 2025; Alcarva et al., 2026). Much of this inconsistency arises because previous studies frequently evaluate only the direct association between green bond financing and environmental performance, overlooking the intermediate mechanisms through which sustainable finance influences environmental outcomes. In particular, renewable energy deployment represents a critical transmission channel through which green bond financing may generate environmental improvements. If green bonds primarily influence environmental quality through accelerating renewable energy investment, policies should emphasize the effective allocation and monitoring of bond proceeds rather than simply expanding green bond issuance (Shishlov et al., 2016; Bhutta et al., 2022; Longston et al., 2025; Nikou, 2025; Daud et al., 2026; Nicolici et al., 2026).

Beyond supporting decarbonization, sustainable finance is increasingly expected to strengthen economies' capacity to withstand and recover from climate-related shocks by promoting resilient infrastructure, technological innovation, and sustainable economic transformation (Fu et al., 2024; Ali et al., 2025; Gabriel & Aung, 2025; Javed et al., 2026; Zhengzheng, 2026). Environmental performance therefore extends beyond carbon emissions alone and encompasses broader structural characteristics associated with sustainable development, including renewable energy utilization, foreign direct investment, and trade openness (Han et al., 2025; Khan et al., 2025; Gillani et al., 2026; Demirtas et al., 2026). These factors influence both environmental quality and climate resilience through technology transfer, international capital flows, diffusion of cleaner production methods, and greater integration into environmentally sustainable global value chains (Javed et al., 2024; Arshad et al., 2025; Abd Alah & Ojekemi, 2025; Soto et al., 2026). However, their environmental effects remain theoretically ambiguous because foreign direct investment and international trade may either facilitate cleaner technologies or increase pollution depending on regulatory quality, production structures, and environmental governance.

The OECD economies provide an appropriate setting for examining these relationships because they possess relatively mature financial systems, well-developed capital markets, stronger regulatory institutions, and the largest green bond markets globally (Lin & Wang, 2025; Kong et al., 2026; Madani et al. 2026). These characteristics enhance the likelihood that green bond financing is efficiently allocated toward environmentally sustainable projects while reducing financial market imperfections that may weaken the transmission of sustainable finance into environmental outcomes (Arampatzi et al., 2025; Jabbour et al., 2026). Consequently, evidence from OECD economies provides valuable insights into the effectiveness of green bond financing under favorable institutional conditions and offers important policy implications for both advanced and emerging economies seeking to expand sustainable finance markets. This study investigates the relationship between green bond financing, climate resilience, and environmental performance across OECD economies during the period 2014–2023.

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LITERATURE REVIEW

GREEN BOND FINANCING AND ENVIRONMENTAL PERFORMANCE

Green bonds have emerged as one of the most important sustainable finance instruments for mobilizing private capital toward environmentally sustainable investments and supporting the transition to low-carbon economic development (Ahmad et al., 2025; Audi et al., 2026). Their primary objective is to finance renewable energy, energy-efficient infrastructure, clean transportation, pollution control, climate adaptation, and other environmentally beneficial projects that contribute to reducing greenhouse gas emissions and improving environmental quality. Since the introduction of the Green Bond Principles, the global green bond market has expanded rapidly, supported by standardized reporting frameworks, greater investor confidence, and increasing policy commitments toward sustainable development (International Capital Market Association, 2022; Sachs et al., 2019; Ali et al., 2025; Audi et al., 2025). Consequently, growing attention has been devoted to determining whether green bond financing produces measurable environmental improvements beyond merely increasing the availability of sustainable capital.

Recent empirical studies generally report a positive relationship between green bond financing and environmental sustainability. Ahmed et al. (2024) found that green bond issuance generates positive market responses while supporting investments aligned with the Sustainable Development Goals, particularly climate action. Similarly, Dai et al. (2024) examined twenty European countries and reported that green bond financing significantly promotes sustainable development by facilitating investments in environmentally friendly projects, although the magnitude of the effect varies according to countries' economic structures. Using panel econometric techniques, Ahsan et al. (2025) likewise concluded that green finance improves carbon efficiency and supports environmental sustainability, although the effectiveness of these instruments depends on institutional quality and policy consistency. These findings collectively indicate that green bonds can contribute to environmental improvement when supported by effective governance and appropriate policy frameworks. Comparable evidence is provided by Flammer (2021), who demonstrated that corporate green bond issuance encourages environmentally responsible investment while improving firms' environmental performance. Likewise, Zhou and Cui (2019) found that green bond financing enhances corporate environmental responsibility and sustainable performance by directing financial resources toward environmentally beneficial activities. Tolliver et al. (2020) further argued that the expansion of green bond markets is strongly associated with national climate commitments under the Paris Agreement, emphasizing the importance of policy support in accelerating sustainable finance.

Despite these encouraging findings, empirical evidence remains far from conclusive. Zhou and Kytherotis (2024) found no statistically significant direct relationship between green bond issuance and national carbon emissions following the implementation of net-zero policies. Their results suggest that firms issuing exclusively green bonds exhibit stronger environmental performance and lower financing costs, whereas issuers combining conventional and green bonds may engage in greenwashing, limiting environmental gains. Similar concerns regarding the effectiveness of green bonds have been highlighted by Jian (2023), who reported that although green bonds positively influence several environmental indicators, their direct contribution to reducing carbon emissions remains relatively modest. Likewise, Nanayakkara and Colombage (2019) and Fatica et al. (2021) reported that investors are willing to accept a pricing premium for certified green bonds, indicating strong market demand; however, favorable financing conditions alone do not necessarily guarantee measurable environmental improvements unless the proceeds are allocated efficiently to genuinely sustainable projects. Reboredo (2018) also argued that although green bonds strengthen sustainable financial markets through diversification and improved capital allocation, their environmental effectiveness ultimately depends on the quality and implementation of financed projects.

The broader environmental economics literature further suggests that financial instruments alone cannot ensure environmental improvement without complementary structural changes. The Porter Hypothesis argues that environmentally oriented financial and regulatory policies stimulate innovation and improve environmental performance by encouraging cleaner technologies (Porter & van der Linde, 1995). Similarly, the Environmental Kuznets Curve proposes that environmental degradation declines only after economies achieve higher levels of development and technological progress (Grossman & Krueger, 1995). Furthermore, international trade and investment may either improve or deteriorate environmental quality depending on technology transfer and production structures (Copeland & Taylor, 1994). These theoretical perspectives indicate that the environmental

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effectiveness of green bond financing is likely to depend on complementary factors such as renewable energy deployment, institutional quality, and broader economic conditions rather than on sustainable finance alone. Therefore, additional cross-country evidence remains necessary to evaluate whether expanding green bond markets produces meaningful improvements in environmental performance across OECD economies.

GREEN BONDS, RENEWABLE ENERGY, AND CLIMATE RESILIENCE

An emerging body of literature suggests that the environmental effectiveness of green bonds depends not only on the volume of sustainable financing but also on whether financial resources are successfully translated into renewable energy development and other low-carbon investments. Rather than generating immediate reductions in carbon emissions, green bonds are expected to improve environmental performance indirectly by expanding renewable energy capacity, reducing reliance on fossil fuels, and strengthening climate resilience. Consequently, renewable energy investment is increasingly recognized as the principal transmission mechanism through which sustainable finance contributes to long-term environmental sustainability.

Hu and Jin (2023) demonstrated that green bonds significantly facilitate renewable energy investment in China by improving access to long-term capital for renewable energy projects. Their findings indicate that financial, environmental, and regulatory factors jointly determine the effectiveness of green bond financing. Similarly, Wang et al. (2022) argued that green bonds accelerate low-carbon energy transitions by improving capital allocation, strengthening cooperation between governments and firms, and promoting standardized evaluation of environmentally sustainable projects. Extending this perspective, Zhou (2026) emphasized that the environmental effectiveness of green bonds depends on coordinated financing mechanisms, efficient allocation of capital, and stronger institutional collaboration between governments and financial markets. Supporting these findings, Tolliver et al. (2020) reported that countries with stronger climate commitments and supportive policy environments experience more rapid growth in green bond markets, thereby facilitating greater investment in renewable energy and sustainable infrastructure. Likewise, Flammer (2021) found that green bond issuance enables firms to finance environmentally beneficial projects that enhance long-term environmental performance. Collectively, these studies indicate that renewable energy investment constitutes the primary transmission channel linking green bond financing with improved environmental performance and enhanced climate resilience, while emphasizing that supportive institutional and regulatory frameworks remain essential for maximizing the environmental benefits of sustainable finance.

SUSTAINABLE FINANCE AND CLIMATE POLICY

Beyond renewable energy investment, green bonds have increasingly become an integral component of broader sustainable finance strategies aimed at accelerating climate adaptation, strengthening environmental governance, and mobilizing private capital for sustainable development. Rather than functioning as standalone financing instruments, green bonds are now embedded within comprehensive sustainable finance frameworks that encourage environmentally responsible investment, facilitate low-carbon economic transitions, and support the achievement of global climate objectives. Consequently, recent literature increasingly evaluates green bonds within the broader context of sustainable finance, emphasizing their interaction with institutional quality, regulatory frameworks, and financial market development.

Danish et al. (2024) argued that green bonds have become a central mechanism for financing environmentally sustainable projects while encouraging responsible investment practices across financial markets. Likewise, Raman et al. (2025) demonstrated that sustainable finance instruments—including green bonds, green fintech, and sustainable lending—substantially contribute to achieving climate-related Sustainable Development Goals by promoting renewable energy investment and reducing environmental degradation. Arora and Veeralakshmi (2023) further highlighted that green bonds facilitate sustainable infrastructure development and generate measurable environmental benefits when supported by appropriate regulatory frameworks. Similar conclusions were reached by Sachs et al. (2019), who emphasized that sustainable finance plays a pivotal role in mobilizing private capital to bridge the global climate financing gap, while Khan et al. (2024) argued that expanding green bond markets improves resource allocation toward environmentally sustainable investments. Nevertheless, these studies consistently acknowledge that high transaction costs, inconsistent regulatory standards, limited institutional capacity, and inadequate monitoring mechanisms continue to constrain the effectiveness of sustainable finance, particularly in developing and emerging economies. These findings suggest that the environmental benefits of green bonds depend not only on increased financing but also on robust governance structures, transparent reporting

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standards, and supportive policy environments that ensure the efficient allocation of sustainable financial resources.

Accordingly, this study addresses these gaps by examining the effectiveness of green bond financing in improving environmental performance across 38 OECD economies during 2014–2023. Unlike previous studies, it simultaneously investigates the direct effect of green bond financing on environmental performance and the indirect role of renewable energy while accounting for foreign direct investment, trade openness, and climate resilience within a comprehensive panel econometric framework.

THEORETICAL FRAMEWORK

Achieving sustainable economic development requires substantial financial resources to support low-carbon technologies, renewable energy projects, and climate-resilient infrastructure. However, environmental investments often face financing constraints because their long-term social benefits exceed the private returns received by investors. As a result, capital markets tend to allocate insufficient resources to environmentally sustainable projects, slowing the transition toward a low-carbon economy (Songwe et al., 2022; Sachs et al., 2019; Lopez-Claros, 2021). In response, green bonds have emerged as an important sustainable finance instrument that mobilizes capital specifically for environmentally beneficial investments while encouraging greater participation from institutional and private investors (Flammer, 2021; Tolliver et al., 2020; International Capital Market Association, 2022; Bhutta et al., 2022; Ahmed et al., 2024). This study is grounded in Market Failure Theory, which argues that environmental degradation results from negative externalities that are not fully incorporated into market prices (Grossman & Krueger, 1995; Porter & van der Linde, 1995). Since greenhouse gas emissions impose social costs that are largely excluded from production and investment decisions, markets naturally underinvest in activities that generate environmental benefits (Abbass et al., 2022; Antal & Van den Bergh, 2016). Green bond financing seeks to correct this market failure by reducing financing constraints and directing capital toward renewable energy, energy efficiency, clean transportation, and other environmentally sustainable projects (Dai et al., 2024; Wang et al., 2022; Jian, 2023; Raihan & Sarker, 2026). Through increased investment in these sectors, green bonds are expected to improve environmental performance by reducing carbon emissions and strengthening climate resilience (Hu & Jin, 2023; Ahsan et al., 2025; Habib et al., 2025; Lin & Wang, 2025). Within this framework, renewable energy consumption represents the primary transmission mechanism through which green bond financing influences environmental outcomes, while foreign direct investment and trade openness are incorporated as complementary determinants that may facilitate technology diffusion, capital allocation, and structural transformation (Copeland & Taylor, 1994; Tahir et al., 2026; Al-Masri & Audi, 2026; Soto et al., 2026). Accordingly, Market Failure Theory provides the conceptual foundation for examining the effectiveness of green bond financing in promoting environmental sustainability across OECD economies (Ali et al., 2025; Ali et al., 2021; Gabriel & Aung, 2025). The functional form of the model become as:

$$CO2_{it}=f(GB_{it}, RE_{it}, FDI_{it}, TO_{it}) \quad (1)$$

The econometric model can be written as:

$$CO2_{it}=\alpha+\beta_1 GB_{it}+\beta_2 RE_{it}+\beta_3 FDI_{it}+\beta_4 TO_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (2)$$

Mediator equation:

$$RE_{it}=\alpha+\delta_1 GB_{it}+\delta_2 FDI_{it}+\delta_3 TO_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (3)$$

Outcome equation:

$$CO2it=\alpha+\theta_1 GB_{it}+\theta_2 RE_{it}+\theta_3 FDI_{it}+\theta_4 TO_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (4)$$

where *CO2* denotes carbon emissions per capita, *GB* represents green bond financing, *RE* is renewable energy consumption, *FDI* denotes foreign direct investment, *TO* represents trade openness, μ_i captures country-specific effects, λ_t represents time effects, and ε_{it} is the stochastic error term. This framework enables the direct and indirect effects of green bond financing on environmental performance to be evaluated within a panel data setting.

Table 1: Measurement and Definitions of Variables

Variables	Definitions	Measurements
CO_2 Emissions per Capita (CO_2)	Carbon dioxide emissions released per person, used as the proxy for environmental performance.	Metric tons per capita
Green Bond Financing (GB)	Total annual green bond issuance, transformed as ln(GB + 1) to account for zero and highly skewed observations.	Natural logarithm

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Renewable Energy Consumption (RE)	Share of renewable energy in total final energy consumption, reflecting the extent of clean energy utilization.	Percentage (%)
Foreign Direct Investment (FDI)	Net foreign direct investment inflows as a percentage of gross domestic product, representing international capital inflows.	% of GDP
Trade Openness (TO)	Degree of economic openness measured as the sum of exports and imports divided by gross domestic product.	% of GDP

This study employs a quantitative panel data research design to examine the effectiveness of green bond financing in improving environmental performance across 38 OECD economies over the period 2014–2023. Carbon dioxide emissions per capita, renewable energy consumption, foreign direct investment (net inflows as a percentage of GDP), and trade openness (exports plus imports as a percentage of GDP) are obtained from the World Bank's World Development Indicators (WDI) database. Data on green bond financing are collected from the International Monetary Fund (IMF) Climate Change Indicators Dashboard, which compiles information from Refinitiv/LSEG on annual green bond issuance. To address the presence of zero and highly skewed green bond issuance values, the variable is transformed using ln(GB + 1). Carbon dioxide emissions per capita serve as the dependent variable, while green bond financing represents the principal explanatory variable. Renewable energy consumption is incorporated as the mediating variable, whereas foreign direct investment and trade openness are included as control variables.

RESULTS AND DISCUSSION

Table 2 presents the descriptive statistics for the variables included in the analysis. The results indicate carbon dioxide emissions per capita have moderate dispersion, suggesting that while OECD countries generally maintain relatively high living standards, they differ substantially in their emissions intensity because of variations in energy structures, industrial composition, and environmental policies. Renewable energy consumption also demonstrates considerable heterogeneity, indicating that some economies rely extensively on renewable energy sources whereas others remain more dependent on conventional fossil fuels. Green bond financing displays the highest degree of positive skewness, implying that green bond issuance is concentrated in a relatively small number of countries with well-developed sustainable finance markets, while many countries recorded limited or no issuance during the sample period. This justifies the logarithmic transformation of the green bond variable, which reduces distributional asymmetry and improves its suitability for panel regression analysis. Foreign direct investment exhibits substantial variability together with pronounced negative skewness, reflecting the presence of exceptionally large capital inflows and outflows in certain country-year observations, a common feature of international investment data. Trade openness likewise shows wide dispersion and positive skewness, indicating considerable differences in the degree of international economic integration among OECD economies.

Table 2: Descriptive Statistics

Variables	Mean	Std. Dev.	Min	Max	Skewness
CO2 emissions per capita (metric tons)	7.453	3.718	1.425	17.889	0.986
Green bond financing (GB, level)	6.102	12.211	0	97.63	2.55*
Renewable energy consumption (% of total)	23.623	16.359	2.6	82.9	1.494
Foreign direct investment (net inflow, % GDP)	2.675	26.99	-391.555	234.311	-6.547
Trade openness (% of GDP)	103.946	65.091	23.402	412.177	2.078

Table 3 reports the Pearson correlation matrix among the study variables and provides preliminary evidence regarding the direction and strength of their pairwise relationships. Carbon dioxide emissions per capita exhibit a weak positive correlation with green bond financing, indicating that countries with more developed green bond markets do not necessarily experience lower emissions at the descriptive level. This finding suggests that the environmental benefits of green bonds may not be immediate and could operate indirectly through other channels, such as renewable energy investment. In contrast, renewable energy consumption is negatively correlated with carbon dioxide emissions, providing initial evidence that greater reliance on renewable energy is associated with improved environmental performance through lower emission levels. Green bond financing is weakly and negatively associated with renewable energy consumption, foreign direct investment, and trade openness, indicating that simple bivariate relationships may not fully capture the complex interactions among these variables.

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Foreign direct investment exhibits virtually no correlation with carbon dioxide emissions and only very weak correlations with the remaining variables, suggesting that its environmental effects are likely to depend on country-specific characteristics and investment composition rather than overall capital inflows. Similarly, trade openness displays only a weak positive relationship with carbon dioxide emissions and negligible correlations with green bond financing, renewable energy consumption, and foreign direct investment. Overall, the relatively low correlation coefficients indicate the absence of serious pairwise linear associations among the explanatory variables, suggesting that multicollinearity is unlikely to pose a significant concern in the subsequent panel regression analysis. Moreover, the modest correlations imply that each variable captures a distinct dimension of environmental performance and sustainable finance, justifying their simultaneous inclusion in the empirical models.

Table 3: Correlation Matrix

Variables	CO2	ln(GB)	RE	FDI	TO
CO2	1.000				
ln(GB)	0.177	1.000			
RE	-0.208	-0.138	1.000		
FDI	0.000	-0.092	-0.033	1.000	
TO	0.150	-0.027	-0.068	-0.061	1.000

The Table 4 presents, the panel regression, fixed effects, and random effects estimators to examine the determinants of carbon dioxide emissions across OECD economies. Green bond financing exhibits an insignificant relationship with carbon dioxide emissions under the pooled ordinary least squares model, indicating that ignoring country-specific heterogeneity masks the environmental contribution of green finance. However, after controlling for unobserved country characteristics through the fixed-effects and random-effects estimators, green bond financing demonstrates a negative relationship with emissions, with the random-effects specification indicating statistical significance. These findings suggest that expanding green bond markets contributes to improving environmental quality by supporting investments in low-carbon infrastructure, renewable energy, and climate-friendly technologies, although the direct environmental impact remains relatively modest. The results support the argument that green bonds function primarily as financing mechanisms whose effectiveness depends on project implementation and complementary environmental policies rather than immediate emission reductions. This finding is consistent with Ahmed et al. (2024), Dai et al. (2024), Hu and Jin (2023), Jian (2023), Wang et al. (2022), Ahsan et al. (2025), Zhou (2026), Flammer (2021), Tolliver et al. (2020), Sachs et al. (2019), Ali et al. (2025), and Habib et al. (2025), who argue that green finance supports environmental improvement through financing sustainable investments. The comparatively weak direct effect also agrees with Zhou and Kytherotis (2024), who reported that the environmental benefits of green bonds are often indirect and materialize through complementary climate policies and renewable energy expansion.

Renewable energy consumption demonstrates a strong and statistically significant negative relationship with carbon dioxide emissions under both the fixed-effects and random-effects models, indicating that greater reliance on renewable energy substantially improves environmental performance across OECD economies. The result confirms that replacing fossil fuel-based energy sources with renewable alternatives remains one of the most effective mechanisms for reducing greenhouse gas emissions and achieving long-term climate sustainability. Since renewable energy directly substitutes carbon-intensive energy production, its environmental contribution is considerably stronger than that of financial instruments alone. The finding strongly supports the environmental transition literature and is consistent with Hu and Jin (2023), Wang et al. (2022), Zhou (2026), Han et al. (2025), Demirtas et al. (2026), Javed et al. (2024), Tiwari et al. (2026), Ali et al. (2021), Batool et al. (2025), and Audi et al. (2026), all of whom conclude that expanding renewable energy is essential for reducing emissions and improving environmental sustainability.

Foreign direct investment exhibits a positive and statistically significant relationship with carbon dioxide emissions under both panel estimators, suggesting that increased capital inflows are associated with higher

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emission levels in OECD countries. This finding indicates that although foreign investment promotes economic activity and technological development, it may also increase industrial production, energy demand, transportation activity, and resource utilization, thereby raising carbon emissions. The results provide greater support for the pollution-haven argument than the pollution-halo hypothesis within the study period, implying that environmentally beneficial technology transfers are insufficient to offset the environmental costs associated with increased economic activity. These findings are consistent with Abd Alah and Ojekemi (2025), Tahir et al. (2026), Khan et al. (2025), Ali et al. (2022), Audi et al. (2025), and Marc and Ali (2017), which report that foreign investment can intensify environmental degradation when expansion in production outweighs improvements in environmental efficiency. However, the results differ from Soto et al. (2026), who argue that strong environmental governance can transform foreign investment into a cleaner source of economic development.

Trade openness displays a positive but statistically insignificant relationship with carbon dioxide emissions across all estimation techniques, indicating that greater international trade neither significantly increases nor decreases environmental degradation within the OECD sample. This finding suggests that the positive scale effects associated with increased production and transportation are broadly offset by the technique effects arising from technology diffusion, cleaner production methods, and stricter environmental standards among highly integrated economies. Consequently, trade openness alone does not appear to be a decisive determinant of environmental performance once green finance, renewable energy consumption, and foreign direct investment are taken into account. The findings are consistent with Grossman and Krueger (1995) and Copeland and Taylor (1994), who argue that trade generates both environmental costs and technological benefits, causing the overall effect to remain ambiguous. Similar conclusions are reported by Al-Masri and Audi (2026), Gillani et al. (2026), Ali and Audi (2016), and Marc and Ali (2023), which emphasize that the environmental consequences of trade depend largely on accompanying environmental regulations, technological innovation, and the composition of traded goods rather than trade openness itself.

Table 4: Panel Regression Results

Dependent Variable: CO2 Emissions per Capita

Variables	Pooled OLS	Fixed Effects	Random Effects
Constant	6.977*** (1.601)	14.355*** (1.636)	13.501*** (1.866)
ln(Green Bond Financing + 1)	0.495 (0.366)	-0.106 (0.104)	-0.163* (0.095)
Renewable Energy Consumption	-0.040 (0.036)	-0.304*** (0.084)	-0.252*** (0.076)
FDI (net inflow, % GDP)	0.002 (0.004)	0.004*** (0.001)	0.004*** (0.001)
Trade Openness (% GDP)	0.008 (0.009)	0.004 (0.007)	0.001 (0.005)

The mediation analysis provides strong evidence that renewable energy consumption constitutes the principal transmission mechanism through which green bond financing improves environmental performance. The first stage of the Baron–Kenny framework demonstrates that green bond financing has a positive and statistically significant effect on renewable energy consumption, indicating that greater green bond issuance successfully mobilizes financial resources toward renewable energy development. This finding supports the theoretical argument that green bonds primarily function by lowering financing constraints for environmentally sustainable projects rather than directly reducing carbon emissions. The result is consistent with Hu and Jin (2023), Wang et al. (2022), Zhou (2026), Ahmed et al. (2024), and Dai et al. (2024), who argue that green bonds stimulate renewable energy investment by facilitating long-term capital allocation to clean energy infrastructure.

The second stage confirms that renewable energy consumption exerts a significant negative effect on carbon dioxide emissions after controlling for green bond financing. This finding indicates that expanding renewable energy generation effectively substitutes fossil fuel consumption and improves environmental quality. The result supports the environmental transition literature, which identifies renewable energy as one of the primary drivers of long-term decarbonization. Similar conclusions have been reported by Han et al. (2025), Demirtas et al. (2026), Javed et al. (2024), Tiwari et al. (2026), Ali et al. (2021), and Batool et al. (2025).

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The comparison between the total and direct effects provides clear evidence of mediation. Green bond financing exhibits a significant total negative effect on carbon dioxide emissions when renewable energy consumption is excluded from the model. However, once renewable energy is introduced as the mediator, the direct effect of green bond financing declines substantially and becomes statistically weak under the cluster-robust specification, indicating that much of the environmental benefit associated with green bonds operates indirectly through renewable energy expansion rather than through a direct reduction in emissions. This finding reinforces the view that green bonds should be regarded as financing instruments whose effectiveness depends on the successful implementation of renewable energy projects rather than as stand-alone environmental policy tools. Similar arguments have been advanced by Ahsan et al. (2025), Zhou and Kytherotis (2024), Flammer (2021), Tolliver et al. (2020), Sachs et al. (2019), Lin and Wang (2025), and Habib et al. (2025).

Finally, both the Sobel test and the bootstrap confidence interval confirm that the indirect effect is statistically significant, providing robust evidence that renewable energy consumption significantly mediates the relationship between green bond financing and carbon dioxide emissions. The bootstrap confidence interval excludes zero, confirming that the mediation effect is stable even after accounting for country-level clustering. Overall, these findings validate the proposed theoretical framework and demonstrate that the environmental effectiveness of green bond financing is realized primarily through its ability to accelerate renewable energy deployment, thereby strengthening climate resilience and reducing carbon emissions across OECD economies.

Table 5: Baron-Kenny Mediation Analysis: Green Bond Financing -> Renewable Energy -> CO2 Emissions

Path	Coefficient	p-value
Path a: GB -> RE	1.369	<0.001
Path b: RE -> CO2 (controlling for GB)	-0.304	<0.001
Total effect c: GB -> CO2 (no mediator)	-0.440	<0.001
Direct effect c': GB -> CO2 (with RE)	-0.106	0.316 (cluster) / 0.023 (classical)
Indirect effect (a x b)	-0.416	Sobel p<0.001
Bootstrap 95% CI for indirect effect (2,000 reps, clustered by country)	[-0.642, -0.180]	--

CONCLUSIONS

This study examines whether green bond financing improves environmental performance directly or indirectly through renewable energy consumption across 38 OECD economies during 2014–2023. For empirical analysis, we have used panel ordinary least squares, fixed-effects, random-effects, and Baron–Kenny mediation analysis. The empirical findings provide four important conclusions. First, green bond financing does not exert a strong and consistent direct effect on carbon dioxide emissions once unobserved country-specific characteristics are controlled for, indicating that green bonds alone are insufficient to generate immediate environmental improvements. Second, green bond financing significantly promotes renewable energy consumption, confirming that sustainable finance effectively mobilizes capital toward low-carbon energy investments. Third, renewable energy consumption significantly reduces carbon dioxide emissions, demonstrating that the environmental effectiveness of green bond financing operates primarily through expanding clean energy deployment rather than through direct emission reductions. The mediation analysis further confirms that renewable energy serves as the principal transmission mechanism linking green bond financing with improved environmental performance, with the indirect effect remaining statistically robust under both Sobel and bootstrap procedures. Fourth, foreign direct investment exhibits a positive association with carbon emissions, suggesting that economic expansion through external capital may increase environmental pressure unless accompanied by cleaner technologies and stronger environmental governance, while trade openness does not exert a significant independent influence on environmental performance after controlling for country-specific characteristics. These findings carry important policy implications for governments, financial regulators, and international institutions. Expanding green bond markets should remain a priority, but greater emphasis should be placed on ensuring that mobilized capital is effectively directed toward renewable energy infrastructure capable of delivering measurable environmental

outcomes. Strengthening project selection standards, improving post-issuance monitoring and impact reporting, and enhancing transparency under internationally recognized green bond frameworks can increase the environmental credibility and effectiveness of sustainable finance instruments. Complementary investments in renewable energy infrastructure, grid modernization, and supportive regulatory frameworks are equally essential for translating financial resources into meaningful carbon reductions.

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