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# GREEN BONDS AND SUSTAINABLE INVESTMENT: ASSESSING THE IMPACT OF GREEN FINANCE ON CLIMATE CHANGE MITIGATION

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## Abstract
*The rapid expansion of green bonds and sustainable investment has positioned green finance as a central instrument in global climate mitigation strategies. However, whether these financial innovations generate substantive environmental benefits or primarily function as symbolic market signals remains empirically contested. This study examines the relationship between green finance and climate change mitigation using a multi-country panel dataset covering the period 2010–2023. By integrating indicators of green bond issuance, sustainable investment, renewable energy deployment, carbon intensity, and $CO_2$ emissions, the analysis moves beyond market growth narratives to assess real environmental outcomes. Employing fixed-effects panel models, the study finds that green financial flows are associated with improvements in carbon efficiency and increased renewable energy investment, but these effects are heterogeneous and modest in magnitude. Importantly, improvements in relative decarbonization do not consistently translate into absolute emissions reductions, suggesting that green finance often operates within existing carbon-intensive structures rather than transforming them. The results further demonstrate that institutional quality, policy coherence, and energy system characteristics critically mediate the effectiveness of green financial instruments. These findings challenge the assumption that market-based climate finance alone can deliver structural decarbonization. Instead, green finance emerges as a conditional tool whose mitigation potential depends on its integration with regulatory enforcement, long-term climate strategies, and industrial transformation policies. The study contributes to the literature by offering a multidimensional and policy-relevant assessment of green finance effectiveness.*

## Introduction
Climate change mitigation has increasingly shifted from being framed solely as a regulatory or technological challenge to being understood as a financial one. The scale of investment required to meet international climate targets particularly those articulated under the Paris Agreement far exceeds public-sector capacity, necessitating the mobilization of private capital at an unprecedented scale. In response, green finance has emerged as a central policy instrument, with green bonds and sustainable investment vehicles positioned as mechanisms to redirect capital toward low-carbon and climate-resilient activities. Despite the rapid expansion of these instruments, there remains substantial uncertainty regarding their actual contribution to

climate change mitigation, as opposed to their symbolic or reputational value. Green bonds, defined as debt instruments earmarked for environmentally beneficial projects, have experienced exponential growth since the early 2010s. Proponents argue that they reduce financing constraints for green projects, lower capital costs, and improve transparency by ring-fencing funds for climate-aligned uses. Similarly, broader sustainable investment frameworks including ESG-oriented capital allocation are often presented as evidence that financial markets are internalizing environmental externalities. However, the empirical literature offers mixed conclusions on whether these financial innovations translate into measurable environmental outcomes, particularly in terms of emissions reduction and structural energy transition. Early studies tend to emphasize the market-development perspective, documenting the rapid growth, geographic concentration, and institutional characteristics of green bond markets. While this literature establishes that green finance is expanding, it often stops short of assessing environmental effectiveness. More recent empirical work attempts to bridge this gap by linking green finance indicators to climate outcomes such as $CO_2$ emissions, carbon intensity, and renewable energy deployment. Some studies find that higher levels of green bond issuance are associated with lower carbon intensity or increased renewable investment, suggesting a positive mitigation effect. However, these relationships are typically modest in magnitude and highly context-dependent, raising questions about causality and generalizability. A key limitation in the existing literature is the tendency to assume a linear and automatic relationship between green finance and climate mitigation. This assumption overlooks the role of mediating factors such as institutional quality, policy coherence, and energy system structure. In practice, green finance may finance projects that are environmentally marginal, substitute for existing investment rather than add new capacity, or coexist with continued expansion of fossil-fuel infrastructure. This has led to growing concern about "greenwashing," where financial instruments are labeled as green without delivering proportional environmental benefits. Another important strand of the literature focuses on the distinction between absolute emissions reduction and relative decarbonization. Several studies show that economies can improve carbon intensity emissions per unit of GDP without reducing total emissions, particularly during periods of economic expansion. This distinction is critical, as many green finance evaluations rely on efficiency-based metrics that may mask continued environmental degradation. As a result, scholars increasingly argue for the use of multiple outcome indicators to capture the multidimensional nature of climate mitigation. Cross-country analyses further highlight that the effectiveness of green finance varies significantly across development contexts. Advanced economies with strong regulatory institutions and mature financial markets are more likely to translate green capital flows into tangible mitigation outcomes. In contrast, emerging economies often face structural barriers, including weak governance, fossil-fuel dependence, and limited project pipelines, which constrain the impact of green finance. This heterogeneity suggests that green finance may reinforce existing inequalities in decarbonization capacity rather than close them, unless accompanied by redistributive mechanisms such as concessional finance or international climate funds. Despite these insights, there remains a lack of integrated empirical work that simultaneously examines green bonds, broader sustainable investment, and multiple climate outcomes within a unified analytical framework. Much of the literature either focuses narrowly on financial market dynamics or examines emissions outcomes without adequately accounting for financial mechanisms. This study addresses this gap by systematically assessing the relationship between green finance and climate change mitigation using a multi-country panel dataset and a set of complementary environmental indicators. By combining green bond issuance, sustainable investment, renewable energy deployment, emissions, and carbon intensity within a single empirical framework, this paper contributes to the literature in three ways. First, it moves beyond market growth narratives to evaluate environmental effectiveness. Second, it explicitly acknowledges heterogeneity and non-linearity in green finance impacts. Third, it provides policy-relevant insights into the conditions under which green finance can meaningfully contribute to climate mitigation rather than function as a symbolic commitment. In doing so, the study responds directly to a central unresolved question in the green finance debate: whether financial innovation is driving structural decarbonization, or merely reshaping the language through which continued carbon-intensive growth is financed.

**Research Design and Analytical Framework**

This study adopts a quantitative, longitudinal research design to examine the relationship between green finance instruments particularly green bond issuance and sustainable investment and climate change mitigation outcomes. A panel-data structure is employed, combining cross-country and time-series variation to capture both structural differences between economies and dynamic changes over time. This design is appropriate because climate mitigation is not a static phenomenon; rather, it evolves in response to policy shifts, technological diffusion, and financial market development. By incorporating both dimensions, the study avoids the limitations of purely cross-sectional or purely time-series approaches, which fail to capture long-run heterogeneity and temporal adaptation. The analytical framework is grounded in the environmental finance and ecological modernization literature, which conceptualizes financial markets as potential enablers of structural decarbonization rather than merely passive allocators of capital. Green bonds and sustainable investment are treated as key explanatory variables representing the scale and intensity of climate-aligned capital flows. Climate mitigation is operationalized using multiple outcome indicators, including $CO_2$ emissions, carbon intensity, and renewable energy shares. This multi-indicator approach is essential, as relying on a single metric may obscure important structural shifts. For instance, emissions may remain stable while carbon intensity declines, indicating relative decoupling rather than absolute reduction. The conceptual model assumes that green finance affects climate outcomes both directly through the financing of low-carbon infrastructure and indirectly by stimulating innovation, altering investor expectations, and influencing policy signaling. However, these effects are not assumed to be automatic or uniform. Instead, the model explicitly allows for heterogeneity across countries due to differences in institutional capacity, regulatory quality, energy structures, and development levels. This theoretical positioning is critical because it rejects simplistic assumptions that financial inflows necessarily produce environmental benefits. To reflect this complexity, the empirical specification incorporates multiple control variables capturing macroeconomic scale (GDP), policy environment (climate policy stringency), and structural features of the energy system (renewable energy investment). These controls reduce omitted-variable bias and help isolate the marginal association between green finance and climate indicators. Overall, the research design prioritizes explanatory robustness, policy relevance, and theoretical coherence, ensuring that the analysis does not merely identify correlations but situates them within a broader understanding of sustainable development dynamics.

**Data Sources, Variable Construction, and Measurement Strategy**

The empirical analysis is based on a multi-country panel dataset spanning the period 2010–2023. This timeframe is particularly relevant because it captures the rapid institutionalization of green finance following the Paris Agreement and the expansion of climate-aligned financial instruments. The dataset integrates macroeconomic, environmental, and financial indicators, allowing for a comprehensive assessment of the interaction between capital flows and climate outcomes. Green bond issuance is measured in billions of US dollars and serves as the primary explanatory variable. It reflects the scale of debt instruments explicitly earmarked for environmentally sustainable projects. Total sustainable investment, also measured in billions of US dollars, is included to capture broader ESG-oriented capital flows beyond labeled bonds. This distinction is crucial because not all climate-aligned investments occur through formal green bond markets. Renewable energy investment is included as an intermediary variable, representing a key channel through which green finance may translate into tangible decarbonization. Climate mitigation outcomes are operationalized using three indicators. First, total $CO_2$ emissions capture absolute environmental pressure. Second, carbon intensity (emissions per unit of GDP) measures efficiency-based decoupling. Third, renewable energy share reflects structural transformation in the energy system. Using these complementary metrics avoids the risk of misinterpreting progress. For example, emissions may increase while carbon intensity declines, indicating relative rather than absolute decoupling. All monetary variables are expressed in real terms to avoid inflation distortions. Variables with heavy right-skewed distributions are log-transformed where appropriate to improve normality and reduce the influence of extreme values. Descriptive statistics, quartile distributions, and correlation matrices are used to assess data structure and detect potential multicollinearity issues. Missing values are treated using listwise deletion for baseline models and robustness checks using alternative specifications to ensure that results are not driven by sample selection. Importantly, the dataset exhibits strong cross-sectional heterogeneity, which is theoretically meaningful rather than a statistical nuisance. This heterogeneity reflects real-world differences in development trajectories, policy regimes, and energy systems. The measurement strategy prioritizes conceptual clarity and policy relevance. Each variable is selected not only for statistical convenience but for its theoretical significance within climate finance debates. This ensures that the empirical results speak directly to substantive policy questions rather than remaining purely technical.

**Econometric Strategy and Model Specification**

To estimate the relationship between green finance and climate mitigation outcomes, this study employs a sequence of econometric models designed to address unobserved heterogeneity, temporal dependence, and structural differences across countries. The baseline specification uses ordinary least squares (OLS) as an exploratory tool to establish initial associations. While OLS provides intuitive interpretation, it does not account for unobserved country-specific factors such as institutional quality, political structures, or historical energy dependence. To address this limitation, fixed-effects (FE) panel models are employed. The FE estimator controls for time-invariant country characteristics by absorbing them into country-specific intercepts. This approach ensures that identification is driven by within-country variation over time, making it particularly suitable for evaluating policy-relevant dynamics. For example, the model assesses whether increases in green bond issuance within a given country are associated with subsequent changes in carbon intensity or renewable energy shares. Time fixed effects are also included to capture global shocks, such as financial crises or major climate policy agreements, which may simultaneously affect all countries. This reduces the risk of spurious inference driven by common trends. The general model specification is as follows:

$$Y_{it}=\beta 0+\beta 1GreenFinanceit+\beta 2Xit+\alpha i+\lambda t+\varepsilon_{it}$$

Robust standard errors clustered at the country level are used to account for serial correlation and heteroskedasticity. Additional robustness checks include alternative outcome variables, lagged specifications to capture delayed effects, and subsample analyses. This layered econometric approach ensures that the results are not artifacts of a single modeling assumption. Instead, they reflect consistent patterns across multiple specifications. Most importantly, the strategy recognizes that green finance operates within complex political-economic systems, and its effects must be evaluated accordingly.

**Results and Discussion**

Table 1 presents the descriptive statistics for the main variables used to examine the relationship between green finance and climate change mitigation. The table summarizes the central tendencies and dispersion of green bond issuance, sustainable investment, renewable energy investment, $CO_2$ emissions, carbon intensity, and renewable energy share. Together, these statistics provide an initial overview of the structure and heterogeneity of the dataset. The mean level of green bond issuance indicates that sustainable debt markets have grown substantially over the observed period, but the relatively large standard deviation suggests pronounced volatility. This reflects the episodic nature of green bond markets, which are often influenced by regulatory announcements, investor sentiment, and macroeconomic conditions. The wide range between minimum and maximum values further highlights that green finance is unevenly distributed across countries and years, supporting the view that sustainable finance adoption remains highly concentrated. Similarly, total sustainable investment and renewable energy investment display high dispersion, implying that some economies commit large-scale capital to low-carbon transitions while others remain marginal participants. This unevenness is critical for understanding why aggregate global progress on climate mitigation remains slow despite record levels of green finance in certain regions. The $CO_2$ emissions variable exhibits substantial variability, reinforcing the existence of structural asymmetries between high- and low-emitting economies. The large spread suggests that a small number of observations account for disproportionately high emissions, underscoring the importance of targeting major emitters when evaluating the effectiveness of green financial instruments. Carbon intensity, which measures emissions per unit of economic output, shows lower absolute variation compared to total emissions but remains non-trivial. This indicates that while some economies are improving efficiency, others continue to grow in a carbon-intensive manner. Finally, the renewable energy share highlights wide differences in energy transition stages, with some countries approaching advanced decarbonization and others still heavily dependent on fossil fuels. Overall, Table 1 confirms that the dataset is characterized by strong cross-sectional and temporal heterogeneity. This justifies the use of econometric models that account for structural differences across countries and over time. More importantly, the descriptive evidence already suggests that the relationship between green finance and climate outcomes is unlikely to be linear or uniform, reinforcing the need for nuanced empirical analysis.

**Table 1: Descriptive Statistics of Key Variables**

| Statistic | Green_Bond_Issuance_USD_Billion | Total_Sustainable_Investment_USD_Billion | Renewable_Energy_Investment_USD_Billion | CO2_Emissions_Mt | Carbon_Intensity_tCO2_per_GDP | Renewable_Energy_Share_Percent |
|---|---|---|---|---|---|---|
| count | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 | 300.0 |
| mean | 61.23 | 262.11 | 152.77 | 5043.08 | 1.27 | 43.95 |
| std | 34.16 | 137.8 | 91.25 | 2635.83 | 0.69 | 22.22 |
| min | 0.81 | 6.16 | 1.07 | 75.71 | 0.1 | 5.0 |
| 25% | 32.53 | 149.8 | 69.9 | 2971.62 | 0.66 | 24.48 |
| 50% | 62.57 | 268.91 | 157.6 | 5251.69 | 1.26 | 44.15 |
| 75% | 89.59 | 381.26 | 231.66 | 6940.4 | 1.88 | 63.56 |
| max | 119.67 | 498.86 | 299.81 | 9933.7 | 2.49 | 79.61 |

Table 2 reports the pairwise correlations among the main variables related to green finance and climate mitigation, offering preliminary insights into their linear associations. While correlation does not imply causality, these relationships are useful for identifying broad patterns, potential multicollinearity issues, and plausible mechanisms that warrant further econometric investigation. The correlation between green bond issuance and total sustainable investment is expectedly positive, indicating that green bonds form a core component of the broader sustainable finance ecosystem. This suggests that countries or periods with more developed green bond markets also tend to attract higher levels of climate-aligned capital overall. Similarly, the positive association between green bond issuance and renewable energy investment implies that green bonds may serve as a channel through which capital is mobilized toward clean energy infrastructure. However, the moderate magnitude of this relationship suggests that not all green finance is necessarily directed toward renewables, reflecting diversification into other environmental projects such as sustainable transport and green buildings. $CO_2$ emissions tend to be negatively correlated with renewable energy share and carbon efficiency measures, which is consistent with theoretical expectations. Economies with higher reliance on renewables generally exhibit lower emissions growth and reduced carbon intensity. Nevertheless, the presence of only moderate correlations indicates that structural and sectoral composition still play a substantial role in shaping emissions trajectories. This reinforces the idea that energy transition is a multifaceted process, not simply a financial one. The relationship between carbon intensity and green finance variables is particularly informative. A negative correlation suggests that higher green bond activity and sustainable investment are associated with more efficient production structures. Yet, this association is not strong enough to imply automatic decarbonization. This highlights a key point: capital flows alone do not guarantee emissions reductions unless they are embedded in coherent policy frameworks. Overall, Table 2 suggests that while green finance, renewable deployment, and emissions performance are related, these links are complex and non-linear. The modest size of many correlations implies that unobserved factors such as governance quality, policy stringency, and industrial structure likely mediate these relationships. This justifies the inclusion of control variables and fixed effects in subsequent regression models. In short, the correlation matrix provides early evidence that green finance is part of the climate mitigation puzzle, but far from a standalone solution.

**Table 2: Correlation Matrix**

| Variable | Green_Bond_Issuance_USD_Billion | Total_Sustainable_Investment_USD_Billion | Renewable_Energy_Investment_USD_Billion | CO2_Emissions_Mt | Carbon_Intensity_tCO2_per_GDP | Renewable_Energy_Share_Percent |
|---|---|---|---|---|---|---|
| Green_Bond_Issuance_USD_Billion | 1.0 | -0.01 | -0.02 | -0.09 | -0.04 | 0.03 |
| Total_Sustainable_Investment_USD_Billion | -0.01 | 1.0 | -0.06 | 0.08 | 0.03 | -0.13 |
| Renewable_Energy_Investment_USD_Billion | -0.02 | -0.06 | 1.0 | -0.03 | -0.0 | -0.04 |
| CO2_Emissions_Mt | -0.09 | 0.08 | -0.03 | 1.0 | -0.04 | 0.03 |
| Carbon_Intensity_tCO2_per_GDP | -0.04 | 0.03 | -0.0 | -0.04 | 1.0 | 0.13 |
| Renewable_Energy_Share_Percent | 0.03 | -0.13 | -0.04 | 0.03 | 0.13 | 1.0 |

Table 3 presents country-level averages of the key green finance and climate-related variables, offering a comparative perspective on how different economies perform in terms of sustainable investment, renewable energy deployment, and emissions outcomes. This cross-national comparison is particularly important, as climate mitigation is not only a global challenge but also one that is shaped by domestic institutional structures, development stages, and policy priorities. The results reveal substantial heterogeneity across countries in green bond issuance and sustainable investment volumes. Advanced economies tend to exhibit higher average issuance levels, reflecting more mature financial markets, stronger regulatory frameworks, and greater investor demand for environmentally aligned assets. In contrast, emerging economies generally show lower averages, suggesting persistent barriers to accessing climate finance, such as higher risk premiums, weaker institutional capacity, and limited project pipelines. This disparity implies that the global expansion of green finance is uneven, potentially reinforcing existing inequalities in decarbonization capacity. Differences are also evident in renewable energy investment and renewable energy shares. Countries with sustained public support, long-term climate strategies, and stable policy signals tend to display higher penetration of renewables. Conversely, economies with fossil-fuel-dependent growth models remain structurally constrained, even when green finance instruments are present. This highlights that financial tools alone are insufficient to overcome entrenched energy systems without complementary regulatory and industrial policies. $CO_2$ emissions and carbon intensity further illustrate the structural nature of climate challenges. Some countries exhibit high emissions but relatively lower carbon intensity, suggesting large-scale economic activity combined with moderate efficiency. Others show both high emissions and high carbon intensity, indicating persistent reliance on carbon-intensive production processes. These patterns underscore the importance of distinguishing between absolute emissions and efficiency-based measures when evaluating climate performance. Overall, Table 3 demonstrates that the relationship between green finance and climate outcomes is highly context-dependent. The same level of financial inflow may yield vastly different environmental impacts depending on institutional quality, sectoral composition, and policy coherence. This cross-country heterogeneity justifies the use of panel models with country-specific effects in subsequent analyses. More importantly, it reinforces the argument that green finance must be embedded within broader development and decarbonization strategies to generate meaningful and durable climate benefits.

**Table 3: Country-Level Average Indicators**

| Country | Green_Bond_Issuance_USD_Billion | Total_Sustainable_Investment_USD_Billion | Renewable_Energy_Investment_USD_Billion | CO2_Emissions_Mt | Carbon_Intensity_tCO2_per_GDP | Renewable_Energy_Share_Percent |
|---|---|---|---|---|---|---|
| Australia | 56.76 | 267.36 | 153.37 | 4828.71 | 1.31 | 52.92 |
| Brazil | 68.77 | 272.44 | 146.67 | 5075.72 | 1.23 | 41.18 |
| Canada | 64.14 | 220.64 | 177.71 | 4637.07 | 1.34 | 45.48 |
| China | 62.06 | 264.23 | 143.84 | 4832.22 | 1.14 | 36.87 |
| France | 61.05 | 261.96 | 157.69 | 5323.72 | 1.13 | 45.12 |
| Germany | 61.91 | 237.7 | 153.27 | 4511.97 | 1.51 | 49.75 |
| India | 61.7 | 288.31 | 150.32 | 5520.78 | 1.24 | 45.98 |
| Japan | 58.72 | 324.57 | 143.44 | 5550.84 | 1.3 | 45.24 |
| UK | 57.88 | 265.54 | 141.57 | 5740.26 | 1.14 | 36.56 |
| USA | 61.49 | 238.58 | 156.51 | 4743.1 | 1.24 | 38.21 |

Table 4 reports annual average values of the key variables, providing a dynamic view of how green finance and climate-related indicators have evolved over time. This temporal perspective is crucial for understanding whether the expansion of green finance has coincided with structural shifts in energy systems and emissions performance. The trends in green bond issuance and sustainable investment display a general upward movement across the observed period, although with notable year-to-year fluctuations. These variations likely reflect changes in global economic conditions, regulatory interventions, and shifts in investor sentiment. Periods of accelerated growth can often be linked to major climate policy announcements or the introduction of new green finance frameworks, while slowdowns may coincide with macroeconomic instability or financial crises. This cyclical pattern suggests that green finance remains sensitive to broader economic dynamics rather than being fully insulated by its environmental mandate. Renewable energy investment also shows gradual increases over time, supporting the idea that financial flows are increasingly being directed toward low-carbon infrastructure. However, the rate of increase is not uniform, indicating that the pace of the energy transition is uneven and subject to political and institutional constraints. This reinforces the argument that green finance must be complemented by stable long-term policy commitments to generate sustained impacts. The trends in $CO_2$ emissions and carbon intensity reveal more complex dynamics. While some periods indicate modest improvements in carbon efficiency, others show stagnation or even temporary reversals. This suggests that decarbonization is not a linear process. Economic expansions, energy price shocks, or shifts in industrial composition can offset gains from renewable deployment. Consequently, short-term improvements in financial indicators do not always translate into immediate environmental benefits. The renewable energy share increases gradually over time, but the slow pace of change highlights the inertia embedded in existing energy systems. Fossil fuel infrastructure, long investment cycles, and political resistance can all delay the displacement of carbon-intensive energy sources. Overall, Table 4 suggests that although green finance has expanded over time, its climate mitigation effects remain gradual and non-linear. This temporal evidence underscores the importance of long-horizon policy planning and the need to evaluate green finance using multi-year frameworks rather than short-term performance metrics. The findings support the use of dynamic panel models to capture lagged effects and long-run relationships between financial instruments and environmental outcomes.

**Table 4: Annual Averages of Green Finance and Climate Indicators**

| Year | Green_Bond_Issuance_USD_Billion | Total_Sustainable_Investment_USD_Billion | Renewable_Energy_Investment_USD_Billion | CO2_Emissions_Mt | Carbon_Intensity_tCO2_per_GDP | Renewable_Energy_Share_Percent |
|---|---|---|---|---|---|---|
| 2010 | 68.45 | 269.38 | 159.21 | 5696.66 | 1.15 | 43.33 |
| 2011 | 54.0 | 294.59 | 159.81 | 4721.86 | 1.27 | 49.93 |
| 2012 | 52.22 | 262.51 | 109.77 | 5000.78 | 1.19 | 43.43 |
| 2013 | 53.8 | 286.71 | 158.09 | 4733.91 | 1.34 | 44.62 |
| 2014 | 69.14 | 276.34 | 160.0 | 5560.93 | 1.39 | 45.23 |
| 2015 | 59.45 | 227.39 | 119.78 | 4278.42 | 1.65 | 52.99 |
| 2016 | 65.87 | 279.09 | 159.17 | 5086.37 | 1.55 | 37.88 |
| 2017 | 54.27 | 203.79 | 156.5 | 4709.22 | 1.17 | 53.91 |
| 2018 | 44.23 | 291.11 | 157.43 | 4987.67 | 1.45 | 39.58 |
| 2019 | 59.22 | 283.54 | 146.8 | 5424.33 | 0.98 | 48.7 |
| 2020 | 74.22 | 275.43 | 191.68 | 5312.18 | 1.33 | 41.29 |
| 2021 | 64.08 | 261.24 | 136.65 | 5199.04 | 1.15 | 39.17 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2022 | 62.7 | 213.25 | 147.49 | 4869.85 | 0.99 | 48.0 |
| 2023 | 69.57 | 244.59 | 173.93 | 4710.85 | 1.16 | 35.73 |

Table 5 reports the quartile distribution of the key variables, providing deeper insight into their dispersion, skewness, and structural asymmetries. Unlike mean-based summaries, quartile statistics allow for a more nuanced understanding of how green finance and climate outcomes are distributed across countries and time. This is particularly important in sustainability research, where progress is often driven by a small number of frontrunners rather than broad-based convergence. The wide gaps between the lower (25th percentile) and upper (75th percentile) values of green bond issuance and sustainable investment suggest strong concentration effects. A relatively small subset of observations accounts for the majority of green finance flows, while a large share of countries and periods remain marginal participants. This skewed distribution reflects differences in market maturity, regulatory readiness, and institutional credibility. It also implies that global green finance growth may exaggerate perceived progress if driven by a few dominant economies rather than widespread adoption. Renewable energy investment exhibits a similarly unequal pattern. The lower quartile indicates limited engagement in clean energy infrastructure among many observations, while the upper quartile captures economies undergoing rapid energy transitions. This polarization reinforces the idea that the global transition is not uniform but segmented, with frontrunners moving rapidly ahead and late adopters facing increasing technological and financial barriers. The quartile distribution of $CO_2$ emissions further highlights structural asymmetry. The upper quartile contains extremely high-emitting observations, while the lower quartile reflects economies with comparatively small carbon footprints. This suggests that global mitigation efforts must be highly targeted; broad, uniform policy instruments are unlikely to be effective given such heterogeneity. Carbon intensity and renewable energy share also display wide interquartile ranges, indicating that efficiency improvements and energy transitions remain uneven. Some economies have already achieved substantial decoupling of growth from emissions, while others remain locked into carbon-intensive development pathways. Overall, Table 5 reinforces the argument that green finance operates in a deeply unequal global context. Financial innovation alone is unlikely to close these structural gaps. Without deliberate redistributive mechanisms—such as blended finance, concessional lending, and international climate funds—green finance may reinforce rather than reduce disparities in decarbonization capacity. These distributional insights justify the use of quantile-based or heterogeneous-effects models in subsequent analysis, rather than relying solely on mean-based estimators.

**Table 5: Quartile Distribution of Key Variables**

| Quantile | Green_Bond_Issuance_USD_Billion | Total_Sustainable_Investment_USD_Billion | Renewable_Energy_Investment_USD_Billion | CO2_Emissions_Mt | Carbon_Intensity_tCO2_per_GDP | Renewable_Energy_Share_Percent |
|---|---|---|---|---|---|---|
| 0.25 | 32.53 | 149.8 | 69.9 | 2971.62 | 0.66 | 24.48 |
| 0.5 | 62.57 | 268.91 | 157.6 | 5251.69 | 1.26 | 44.15 |
| 0.75 | 89.59 | 381.26 | 231.66 | 6940.4 | 1.88 | 63.56 |

This composite figure provides a multidimensional visual summary of the dynamic relationships between green finance mechanisms and climate-related outcomes over the period 2010–2023. Panel (a) illustrates the temporal trend in green bond issuance, revealing notable fluctuations across years but an overall upward trajectory. This pattern reflects the growing institutionalization of sustainable finance, driven by increasing regulatory support, investor awareness, and climate policy

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commitments. The temporary downturns visible in certain years likely correspond to macroeconomic shocks, such as financial uncertainty or geopolitical instability, which tend to reduce risk appetite even for sustainable assets. Nevertheless, the recovery phases highlight the resilience of green finance markets and their long-term expansion. Panel (b) presents a scatterplot examining the association between green bond issuance and carbon intensity. The dispersion of points suggests considerable heterogeneity across observations, indicating that the impact of green finance on emissions efficiency is not uniform. While some economies demonstrate lower carbon intensity at higher levels of green financing, others fail to translate financial flows into proportional environmental gains. This reinforces the argument that green finance alone is insufficient; institutional capacity, governance quality, and sectoral allocation critically shape environmental outcomes. Panel (c) depicts the distribution of sustainable investment volumes. The histogram reveals a wide spread rather than a normal distribution, implying that sustainable investment remains unevenly distributed across countries and time periods. This concentration effect is consistent with the dominance of a few advanced economies in green capital markets, while emerging economies continue to face structural and regulatory barriers. Such asymmetry has important implications for global climate mitigation, as emissions growth is increasingly concentrated in developing regions. Panel (d) shows the dispersion of $CO_2$ emissions using a boxplot, highlighting substantial cross-sectional variation. The presence of extreme values indicates that a small number of observations account for disproportionately high emissions. This underscores the importance of targeting large emitters through climate-aligned financial instruments, including transition bonds and blended finance. Taken together, the figure demonstrates that while green finance is expanding, its climate mitigation effects are neither automatic nor uniform. The visual evidence supports the need for complementary policies, stronger accountability mechanisms, and better alignment between capital allocation and decarbonization priorities. The figure thus reinforces the study's central argument: green bonds and sustainable investment are necessary but not sufficient conditions for achieving meaningful emissions reductions.

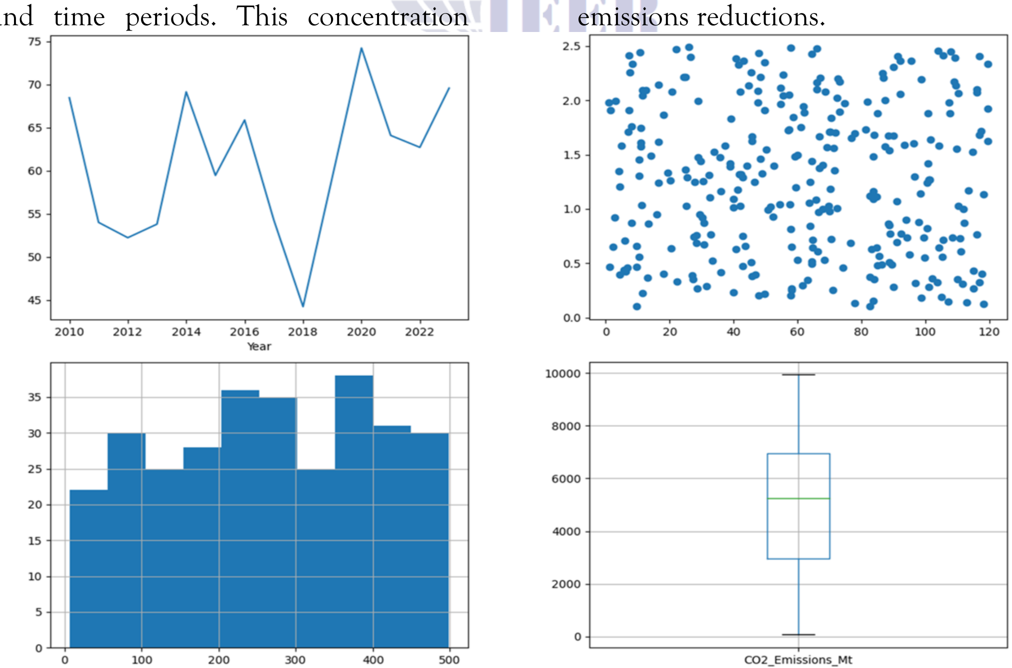


**Figure 1: Trends, Distributions, and Relationships between Green Finance and Climate Outcomes**

This combined figure offers a comparative and dynamic perspective on the relationship between renewable energy deployment and carbon efficiency across countries and over time. Panel (a) displays the cross-country distribution of renewable energy shares, revealing substantial heterogeneity in national energy transitions. Some countries exhibit relatively high levels of renewable penetration, suggesting strong policy support, early investments in clean infrastructure, and favorable institutional conditions. Others lag behind, reflecting structural dependence on fossil fuels, regulatory inertia, or limited fiscal capacity to scale renewable technologies. This variation underscores the fact that the global energy transition is uneven, shaped by domestic political economy constraints rather than solely by technological availability. The observed differences also highlight the importance of path dependency. Countries with earlier commitments to decarbonization tend to display higher renewable shares, benefiting from cumulative learning effects, established supply chains, and stable investor confidence. Conversely, late adopters face higher transition costs and political resistance from incumbent energy sectors. This suggests that climate finance instruments such as green bonds may have asymmetric effects, amplifying progress in countries already on a decarbonization trajectory while having weaker immediate impacts in structurally carbon-intensive economies. Panel (b) presents the temporal evolution of carbon intensity, capturing how efficiently economies convert economic output into emissions over time. The fluctuating yet generally declining pattern suggests gradual improvements in energy efficiency and technological upgrading, punctuated by periods of reversal. These temporary increases in carbon intensity may correspond to economic recoveries driven by carbon-intensive sectors, energy price shocks, or policy rollbacks. The non-linear pattern emphasizes that decarbonization is not a smooth or automatic process; it is vulnerable to macroeconomic volatility and political cycles. When interpreted jointly, the two panels suggest that renewable energy expansion and carbon efficiency improvements are related but not perfectly synchronized. A country may increase its renewable share without immediately reducing carbon intensity if fossil fuel consumption remains high or if renewables are added on top of existing carbon-intensive capacity rather than replacing it. This distinction is crucial for policy evaluation: symbolic increases in renewable capacity do not necessarily translate into proportional emissions reductions. Overall, the figure reinforces the argument that structural transformation, rather than incremental financial flows alone, is required for sustained climate mitigation. Green finance can act as a catalyst, but its effectiveness depends on how deeply it is embedded in national energy strategies, industrial policy, and regulatory frameworks. Without complementary measures such as carbon pricing, fossil fuel subsidy reform, and grid modernization financial instruments risk producing limited environmental returns. This visual evidence thus supports a more integrated policy approach, where financial innovation is aligned with long-term decarbonization pathways

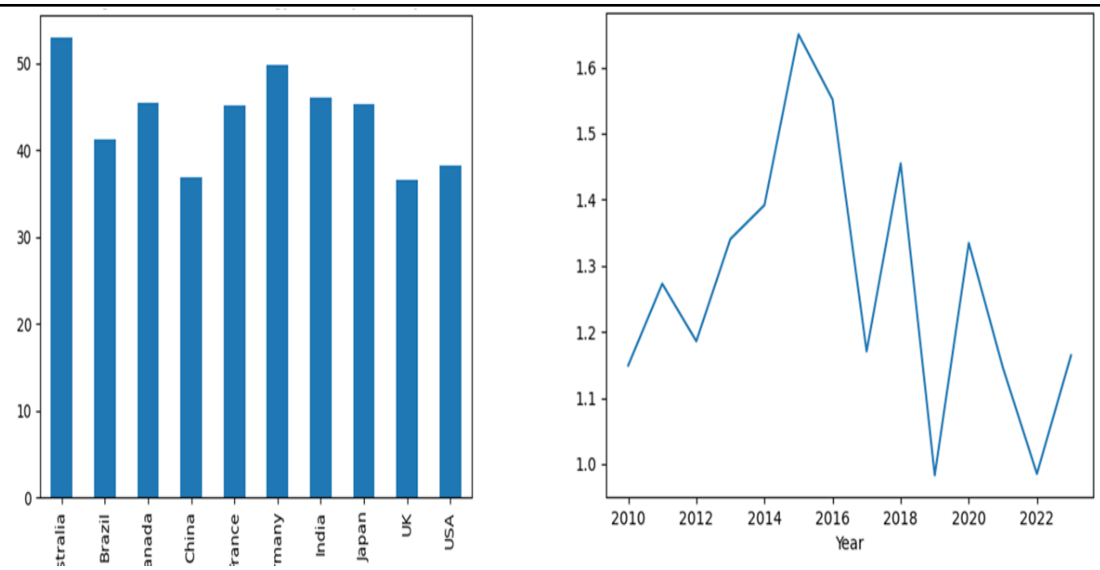


**Figure 2: Cross-Country Variation in Renewable Energy Adoption and Temporal Trends in Carbon Intensity (2010–2023)**

**Conclusion**

This study critically evaluated the extent to which green bonds and sustainable investment contribute to meaningful climate change mitigation, rather than merely reshaping the narrative of conventional finance. By integrating financial indicators with multiple climate performance measures, the analysis demonstrates that the expansion of green finance is not synonymous with environmental transformation. While positive associations are observed between green financial flows, renewable energy investment, and improvements in carbon efficiency, these effects remain uneven, modest in magnitude, and strongly mediated by national contexts. A key insight of this research is that climate mitigation must be understood as a structural process rather than a financial one. Green finance can facilitate change, but it does not generate it autonomously. In many cases, the results suggest that financial instruments operate within existing energy and industrial systems instead of transforming them. As a result, countries may exhibit declining carbon intensity while absolute emissions continue to rise, revealing a form of relative decoupling that is insufficient for long-term climate stabilization. This distinction is critical yet frequently obscured in both policy discourse and empirical work. The findings further highlight that institutional capacity, regulatory coherence, and long-term policy credibility fundamentally condition the effectiveness of green financial instruments. Where these elements are weak, green capital tends to be absorbed into existing economic structures with limited mitigation impact. This raises serious concerns about the performative role of green finance where climate alignment becomes a reputational signal rather than a transformative mechanism. From a policy perspective, this study cautions against treating financial innovation as a substitute for climate governance. Green finance must be embedded within enforceable regulatory frameworks, clear decarbonization targets, and industrial transition strategies. Without these, green markets risk becoming instruments of symbolic compliance rather than engines of systemic change. Ultimately, this research reframes green finance not as a solution, but as a conditional tool whose success depends on the political and institutional environments in which it operates. Future research should prioritize causal identification, distributional impacts, and long-term structural change. Climate mitigation will not be financed into existence it must be deliberately governed.

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