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GREEN BONDS AS CATALYSTS FOR CHANGE: DRIVING CO₂ REDUCTION AND SUSTAINABLE FINANCE ACROSS EUROPE

Abstract

The purpose of the article. The growing importance of sustainability and climate change mitigation has spurred a rise in green bond issuance across the European Union (EU). However, questions remain about the long-term effectiveness of these instruments in reducing CO₂ emissions, particularly given economic, governance, and environmental factors such as GDP and forest cover. Understanding the dynamics of various types of green bonds, including certified and self-labelled bonds, is essential for assessing their role in promoting sustainable development.

Methodology. Methodology/approach: the study aims to assess the relationship between green bond issuance and CO₂ emissions reduction in 25 EU countries from 2007 to 2022. It evaluates how different types of green bonds, including Climate Bonds Initiative (CBI)-aligned and social green bonds, contribute to decarbonization, considering factors such as governance quality, economic performance, and natural infrastructure. The research employs descriptive statistics, correlation analysis, and fixed- and random-effects panel data models.

Results of the research. Findings/implications: The results reveal that CBI-aligned green bonds have a statistically significant impact on reducing CO₂ emissions, with coefficients indicating an 8.5% reduction for a 1% increase in bond value. Self-labelled green bonds exhibit greater variability in effectiveness due to limited certification. Social green bonds have minimal impact on CO₂ emissions reductions, reflecting their broader focus on both environmental and social goals. Economic indicators, such as GDP per capita and forest cover, positively moderate the relationship between green bonds and emissions reduction, underscoring the importance of institutional capacity and natural carbon sinks in achieving sustainability goals.

Keywords: CO₂ emissions; sustainability; European Countries; panel data analysis

JEL Class: Q56, Q58, C33, O44



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Introduction

Green bonds fund decarbonization and support sustainable growth. They leverage capital markets to support environmental goals aligned with the EU's climate targets under the European Green Deal and the Paris Agreement. These frameworks aim to make the EU the first climate-neutral continent by 2050, emphasizing the need for financial mechanisms that blend economic advancement with environmental progress stewardship. Despite their increasing prominence, the effectiveness of green bonds in reducing CO₂ emissions is not yet fully understood, particularly when contextual factors such as economic prosperity, forest cover, and capital market maturity are accounted for (Bestvina et al., 2023). Although previous studies have identified the direct impacts of green bonds on environmental outcomes (Zhang et al., 2022), there remains limited exploration of the systemic factors that influence their efficacy across varying national and economic landscapes. Furthermore, the diverse typologies of green bonds—ranging from self-labelled and Climate Bonds Initiative (CBI)-aligned instruments to social green bonds—exhibit varying levels of impact, necessitating a deeper investigation into their individual contributions to decarbonisation goals (Flammer, 2020).

This study investigates how green bond issuance influences CO₂ emission reductions across EU countries, examining economic, natural, and market factors, and assessing their cost-effectiveness and broader socioeconomic and ecological impacts to inform sustainable climate mitigation strategies. The theoretical basis for green bonds lies within the discipline of environmental finance, which explores how financial markets and instruments can be utilized to achieve sustainability objectives. GB can be explained through portfolio theory and decarbonization economics, linking financial returns with environmental objectives. (Markowitz, 1952; Eccles et al., 2014).

Green bonds are crucial to decarbonisation economics, supporting the transition to low-carbon systems through targeted financial tools. The large capital needed for renewable energy and low-emission infrastructure often hinders their implementation. Green bonds address this issue by providing the liquidity necessary to fund these initiatives, thereby bridging the gap between financing needs and climate objectives (Al Mamun et al., 2022). Furthermore, they facilitate the internalisation of environmental externalities, encouraging both issuers and investors to prioritise projects with measurable environmental impacts, such as reductions in greenhouse gas emissions. Green bonds represent the practical application of portfolio theory and decarbonisation economics, functioning at the intersection of public policy and market-driven mechanisms. Governments and regulatory agencies foster favourable conditions for green bond issuance by providing incentives such as tax benefits, certification frameworks, and policy alignments, as exemplified by the EU Green Deal (European Commission, 2019). The following research questions have been formulated to guide and structure the analysis.

RQ1: Primary Question:

To what extent does issuing different types of green bonds (self-labelled, Climate Bonds Initiative (CBI)-aligned, and social green bonds) contribute to reducing CO₂ emissions across European Union countries? **Secondary Questions:**

RQ1.1. How do economic factors such as GDP per capita and governance quality moderate the relationship between green bond issuance and CO₂ emissions reduction?

RQ1.2. What are the differences in effectiveness among self-labelled, CBI-aligned, and social green bonds in achieving environmental sustainability goals?

This study contributes to the sustainable-finance literature in several important ways. First, unlike many previous studies that treat green bonds as a homogeneous category, it distinguishes among self-labelled green bonds, Climate Bonds Initiative (CBI)-aligned green bonds, and social green bonds, enabling a direct comparison of their environmental effectiveness. Second, the study employs a long-term panel dataset covering 25 European countries over the period 2007–2022, encompassing both the early development and subsequent expansion of the European green-bond market. Third, the analysis integrates institutional, economic, and environmental dimensions by considering governance quality, GDP per capita, and forest cover simultaneously. Finally, the study investigates not only whether green bonds are associated with lower CO₂ emissions but also which bond structures generate the strongest decarbonisation effects. This multidimensional approach provides new evidence on the mechanisms by which sustainable finance instruments contribute to climate transition objectives in Europe.

The paper begins with an introduction outlining the research objectives and the significance of green bonds in promoting sustainability. The literature review explores prior studies on green bonds and environmental finance. The methodology specifies data sources and econometric models. The results demonstrate the varying effectiveness of different bond types in CO₂ reduction. The discussion interprets the findings, and the conclusion summarises the key insights, while outlining limitations and suggestions for future research, which provide recommendations for further exploration.

Literature Review

Green bonds have become an essential part of sustainable finance. Early studies primarily concentrated on the financial performance of green bonds, often overlooking their environmental impacts (Silva et al., 2024). Recent literature has shifted focus towards evaluating their effectiveness in achieving decarbonisation and broader sustainable development objectives (Wang et al., 2022). Green bonds have emerged as critical instruments for facilitating sustainable development, enabling financial markets to align with global environmental goals (Chen et al.,

2024). These bonds provide a mechanism for mobilising capital towards projects that mitigate environmental degradation while offering financial returns. Scholars have categorised green bonds into distinct types, including self-labelled bonds, certified bonds (e.g., Climate Bonds Initiative-aligned bonds), and social green bonds, each demonstrating varying levels of transparency, performance, and environmental impact (Flammer, 2020; Wang et al., 2022).

Self-labeled green bonds are issued without formal third-party verification, raising concerns about their effectiveness due to the risk of greenwashing—a scenario where issuers exaggerate the environmental benefits of their projects (Anh Tu et al., 2020). While these bonds can contribute to sustainability when backed by credible issuers, studies suggest that their impact on carbon reduction remains limited compared to certified alternatives (Cheong & Choi, 2020).

In contrast, certified green bonds, which adhere to internationally recognised standards set by the Climate Bonds Initiative (CBI), demonstrate superior performance in achieving environmental goals. Empirical research highlights that these bonds are associated with significant reductions in CO₂ emissions, primarily due to structured oversight, monitoring, and reporting (Fatica & Panzica, 2020). Developed countries with advanced financial infrastructures, such as those within the EU, have capitalised on these bonds to support renewable energy, sustainable transport, and other green infrastructure projects (Alamgir & Cheng, 2023).

Social green bonds aim to tackle both environmental and social challenges, making them broader in scope than traditional green bonds. While they are effective in financing sustainable infrastructure, these bonds tend to have a more moderate impact on direct environmental outcomes, such as carbon reduction. Scholars argue that their dual objectives may limit their ability to achieve specific environmental goals compared to bonds with a narrower focus (Dan & Tiron-Tudor, 2021).

Green bonds have appeared as a vital instrument for sustainable investment and environmental resilience, gaining popularity among environmentally conscious investors and those seeking portfolio diversification (Cortellini & Panetta, 2021; Diaz-Rainey et al., 2023). The market has expanded rapidly since 2007, surpassing the £500 billion mark in 2018 (Abhilash et al., 2022a). Green bonds play a crucial role in financing renewable energy projects and promoting sustainability in European countries (Wang et al., 2023). Research has concentrated on market pricing, economic and environmental impacts, and legal issues surrounding green bonds (Cheong & Choi, 2020). Factors influencing the growth of green bonds include favourable regulatory environments and enhanced disclosure quality (Anh Tu et al., 2020). This instrument has demonstrated potential to support post-pandemic recovery efforts (Chen et al., 2020). Despite its expansion, challenges persist in securing funding for environmentally friendly projects (Anh Tu et al., 2020). The field continues to evolve, with ongoing research investigating various aspects of green bonds (Abhilash et al., 2022b). Green bonds have emerged as a promising

financial instrument for promoting sustainability and reducing carbon emissions across Europe and globally. Multiple studies have found that green bond issuance is associated with decreased CO₂ emissions at both national and state levels (Flammer, 2020; Fatica & Panzica, 2020; Pata et al., 2025). The effectiveness of green bonds is enhanced by third-party certification and external review processes (Flammer, 2021; Fatica & Panzica, 2020). Green bond proceeds are increasingly allocated to renewable energy, clean water, and low-carbon transportation projects (Taghizadeh-Hesary et al., 2023). Factors influencing green bond issuance in the EU include ESG ratings, fiscal balance, and population (Dan & Tiron-Tudor, 2021). While green bonds show promise, some studies suggest their impact on emissions reduction may be limited or variable (Bestvina et al., 2023; Wyszowska & Filipiak, 2024). Overall, green bonds appear to play a catalytic role in driving sustainable finance and CO₂ reduction across Europe, though their effectiveness may depend on various economic and governance factors (Alamgir & Cheng, 2023).

Economic factors, including national GDP levels and regulatory frameworks, also significantly influence the effectiveness of green bonds. Stronger governance structures and more developed capital markets enhance green bonds' ability to achieve sustainability targets (Bestvina et al., 2023). Conversely, emerging markets may face barriers, such as limited investor confidence and insufficient institutional support, which hinders the issuance and impact of green bonds (Nguyen et al., 2024).

However, critics highlight several limitations to the optimistic narrative surrounding green bonds. Methodological flaws, including short data horizons and a lack of long-term performance assessments, challenge claims of significant environmental impact (Saha & Maji, 2025). Additionally, the effectiveness of green bonds is often confounded by external variables such as shifts in energy policy and market volatility, complicating efforts to isolate their impact on carbon reduction (Wang & Taghizadeh-Hesary, 2023).

In conclusion, while green bonds hold promise as tools for sustainable development, their success depends on factors such as bond type, certification standards, and the economic context. Future research should focus on improving data transparency, enhancing certification frameworks, and expanding empirical analysis to assess long-term environmental and economic outcomes.

Methods

The study investigates the link between green bond issuance and CO₂ emission reductions in EU countries and Switzerland from 2007 to 2022. It uses descriptive statistics, correlation analyses, and panel data models to analyze different green bond types, such as Self-Labeled Bonds, CBI Aligned Bonds, and Social Green Bonds. Data from sources like the World Bank and green bond records cover 25 countries, excluding Malta and Cyprus due to limited data. Variables

include GDP per capita, CO₂ emissions, forest coverage, and green bond values. Key statistics and correlation coefficients assess relationships between green bonds and emissions. Correlation results were generally insignificant and varied across years and bond types (see tables 1–6).

Table 1

Pearson correlation coefficient between CO₂ emissions and Self-Labeled Green Bonds value

Year	Correlation coefficient	P-value
2016	−0.457	0.543
2017	−0.041	0.948
2018	−0.534	0.466
2019	−0.130	0.759
2020	−0.320	0.401

Source: Own study.

Table 2

Spearman's correlation coefficient between CO₂ emissions and the Self-Labeled Green Bonds value

Year	Correlation coefficient	P-value
2016	−0.4	0.75
2017	0.4	0.517
2018	−0.4	0.75
2019	0.143	0.752
2020	−0.4	0.291

Source: Own study.

Table 3

Pearson correlation coefficient between CO₂ emissions and the CBI Aligned Green Bonds value

Year	Correlation coefficient	P-value
2012	0.244	0.843
2013	0.671	0.145
2014	0.461	0.18
2015	0.23	0.552

Year	Correlation coefficient	P-value
2016	0.621	0.031
2017	−0.017	0.953
2018	0.456	0.076
2019	0.003	0.991
2020	0.265	0.288

Source: Own study.

Table 4

Spearman's correlation coefficient between CO₂ emissions and the CBI Aligned Green Bonds value

Year	Correlation coefficient	P-value
2012	−0.5	1
2013	0.314	0.564
2014	0.127	0.733
2015	0.467	0.213
2016	0.545	0.071
2017	0.429	0.128
2018	0.379	0.148
2019	0.029	0.923
2020	0.148	0.558

Source: Own study.

Table 5

Pearson correlation coefficient between CO₂ emissions and the value of Social Green Bonds

Year	Correlation coefficient	P-value
2017	0.363	0.479
2018	−0.741	0.259
2019	−0.674	0.097
2020	−0.157	0.664

Source: Own study.

Table 6.*Spearman's correlation coefficient between CO₂ emissions and the value of Social Green Bonds*

Year	Correlation coefficient	P-value
2017	0.091	0.864
2018	-0.4	0.75
2019	-0.607	0.167
2020	0.079	0.838

Source: Own study.

Panel data models, including fixed effects, random effects, and first difference models, were employed to investigate unobserved differences, variations within and between countries, and the impact of changes in green bond issuance over time. All analyses utilized R ver.4.4.2 software, with significance set at $p < 0.05$.

Panel data models provide insights into the behaviour of units across different entities and over time. Linear panel data models commonly used in econometrics can be represented as follows:

$$\gamma_{it} = \alpha_{it} + \beta_{it}x_{it} + u_{it}$$

Where:

$i = 1, \dots, n$: Index for each country;

$t = 1, \dots, T$: Time index;

u_{it} : Random error term with a mean of zero.

If the individual-specific component is entirely absent, the pooled OLS estimator is the most efficient estimator for β .

If there is no unobserved individual effect (i.e., no country-specific component) and the errors are spherical, pooled OLS is a consistent and efficient estimator of β . Alternatively, unobserved individual-specific components can be eliminated using first-differencing techniques:

$$\Delta\gamma_{it} = \alpha_{it} + \beta\Delta + \Delta u_{it}$$

where:

$$\Delta\gamma_{it} = \gamma_{it} - \gamma_{it-1};$$

$$\Delta x_{it} = x_{it} - x_{it-1};$$

$$\Delta u_{it} = u_{it} - u_{it-1}.$$

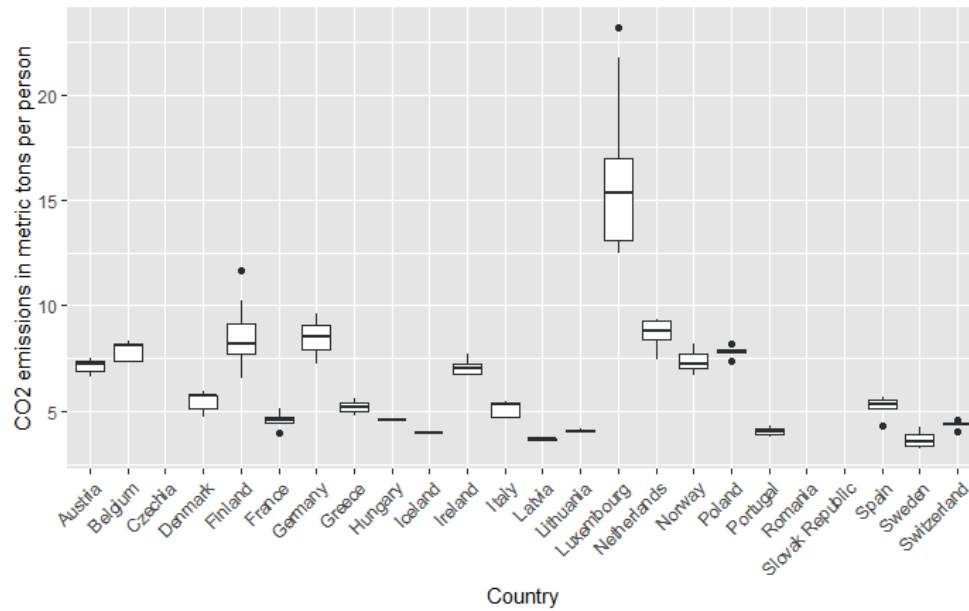
In the analysis, the dependent variable is an annual CO₂ emission level, which refers to the average level of CO₂ emission in a given country during a specific year. The main explanatory variable is the value of green bond issuance, measured in millions of USD, specifically for CBI Aligned or Social Green Bonds, with values lagged by one year relative to CO₂ levels. The control variables include GDP per capita, which is also lagged by one year; forest cover, defined as the proportion of forest area relative to the total area of the country and likewise lagged by one year; and the Worldwide Governance Index (WGI), an indicator of governance quality, which is likewise lagged by one year. This section presents various graphical characteristics of the data. The selection of control variables is grounded in the environmental finance and ecological economics literature. GDP per capita was included because economic development influences both the capacity to issue green bonds and the ability to invest in low-carbon technologies. Wealthier economies generally possess more developed financial markets, stronger environmental regulations, and greater resources for financing climate-transition projects. Forest cover was incorporated as a proxy for natural carbon sequestration capacity. Forest ecosystems function as carbon sinks and therefore may independently affect national CO₂ emission balances, regardless of financial-market developments. The Worldwide Governance Indicators (WGI) variable was included to capture institutional quality, regulatory effectiveness, and government capacity to implement environmental policies. Strong governance structures improve monitoring, transparency, and the allocation efficiency of green-finance instruments. Consequently, GDP per capita, forest cover, and governance quality are expected to moderate the relationship between green bond issuance and CO₂ emissions by influencing both the implementation and effectiveness of climate-related investments.

Figures 1–5 present some descriptive statistics. They reveal significant variations in CO₂ emissions, green bond issuance, and GDP across EU countries. Countries with higher median CO₂ emissions, such as Luxembourg and Germany, also exhibit substantial variability, indicating diverse environmental challenges and emission patterns. In contrast, nations like Sweden and Portugal demonstrate lower and more consistent emissions, reflecting effective mitigation efforts.

Green bond issuance (USD) varies significantly across countries, with economically advanced nations like Germany, France, and the Netherlands leading in volume. This suggests a correlation between financial market maturity and green bond market activity. Similarly, GDP levels vary widely, with wealthier economies contributing more to green financing initiatives, underscoring the role of economic capacity in fostering sustainable finance. These patterns underscore the interplay between economic development, environmental goals, and financial innovation in the EU context.

Figure 1

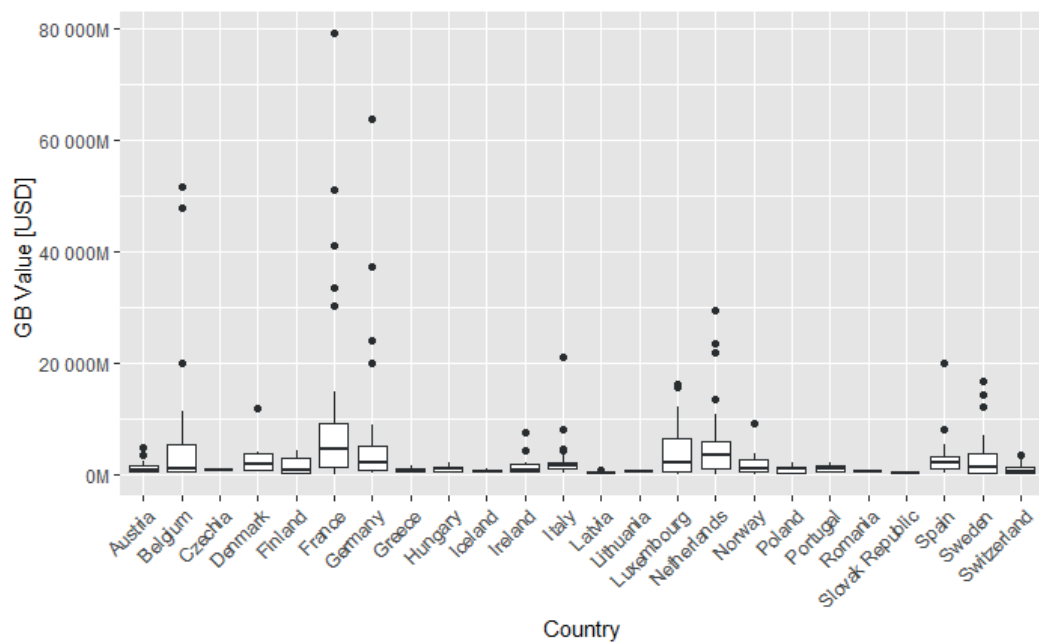
Boxplot showing CO₂ emissions by country for Self-Labeled Green Bonds



Source: Own study.

Figure 2

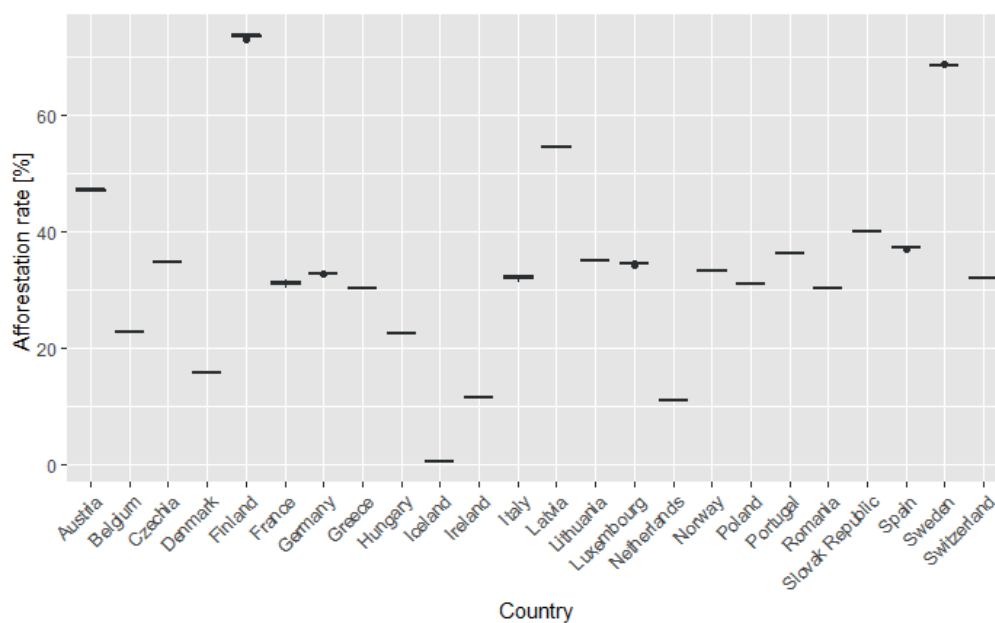
GB [USD] value in individual countries



Source: Own study.

Figure 3

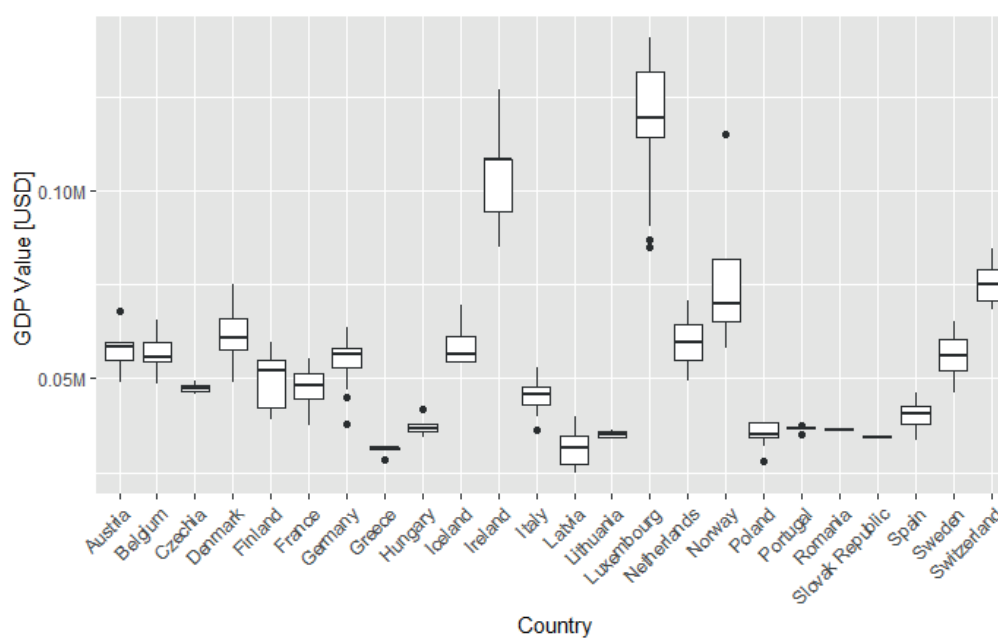
GB [USD] value in individual countries



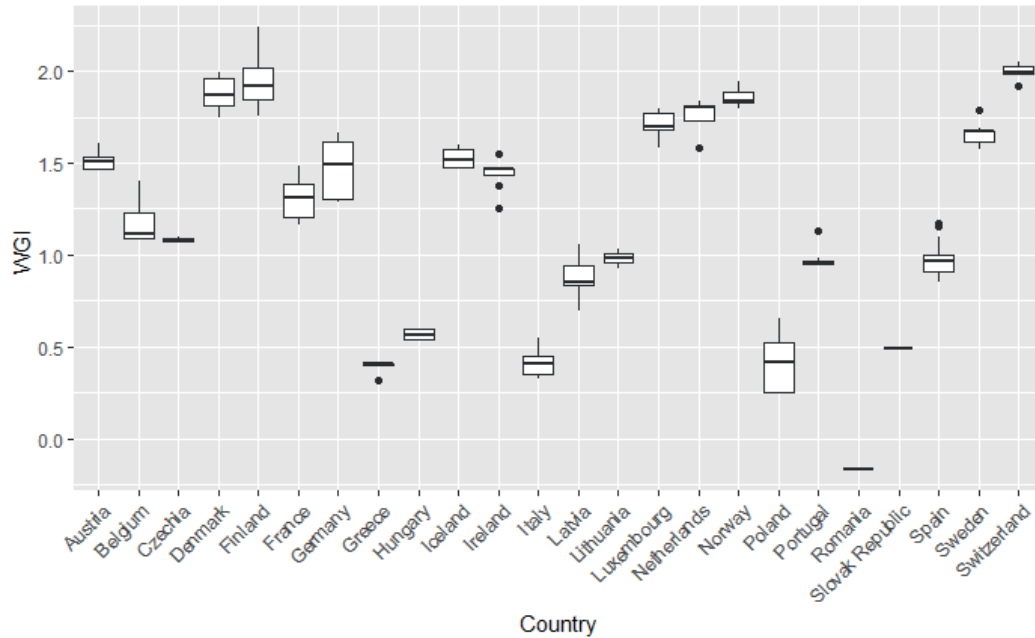
Source: Own study.

Figure 4

GB value [USD] within the countries



Source: Own study.

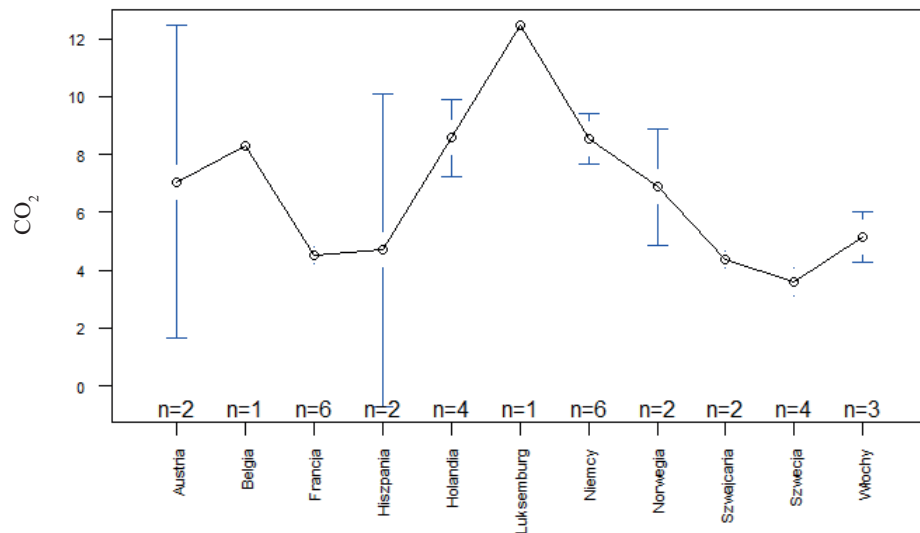
Figure 5*GB value [USD] within the countries**Source:* Own study.

To model the relationship between Green Bonds and CO₂ emissions, we employed a panel data regression model. For the analysis, the data was log-transformed due to the significant differences in magnitude between Green Bond values and economic indicators. The comprehensive analysis presented in the table below encapsulates the aggregated results derived from panel data models focusing on three distinct categories of green financial instruments: Self-Labeled Green Bonds, CBI Aligned Green Bonds, and Social Green Bonds. Within this framework, coefficients, confidence intervals, and p-values are distinctly emphasised in bold where statistical significance is established ($p < 0.05$). Additionally, an asterisk (*) denotes the inclusion of lagged data by one year, specifically in relation to CO₂ levels.

Figure 6 illustrates the heterogeneity across countries for Self-Labelled Green Bonds. In this visualisation, dots represent the mean CO₂ values for each country, while the whiskers indicate the 95% confidence intervals for these means. It is evident that there is substantial variation across countries, suggesting significant cross-country differences in the relationship between Self-Labeled Green Bonds and CO₂ emissions (Figures 6–7).

Figure 6

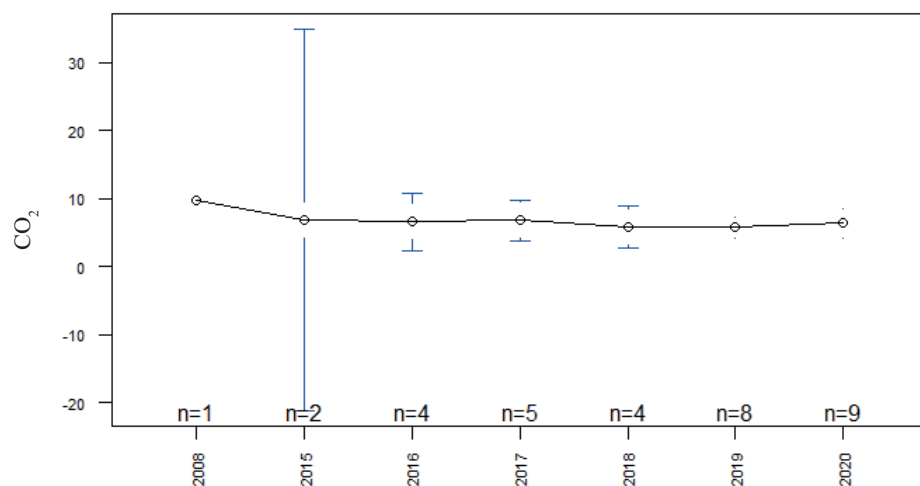
Heterogeneity between countries for CO₂ emissions with Self-Labeled Green Bonds



Source: Own study.

Figure 7

Heterogeneity between years for CO₂ emissions with Self-Labeled Green Bonds



Source: Own study.

To adopt a more systematic approach, we employed a random-effects panel data model, as the Hausman test p-value of 0.965 indicates that the random-effects model is more suitable than the fixed-effects model. In this model, the dependent variable is the level of CO₂ emissions. The dependent variable is the log of CO₂ emissions. Table 7 reports the estimates. Self-Labeled Green Bonds (lagged one year) are statistically significant ($p < 0.001$). The coefficient of -0.031 implies that a 1% increase in green-bond issuance is associated with a 0.031% decrease in CO₂ emissions, holding other variables constant.

Table 7

A panel data model showing the relationship between Self-Labeled Green Bonds and CO₂ emissions

Variable	Coefficient	2.5%	97.5%	P-value
Intercept	8.971	7.212	10.73	< 0.001
Value [USD]*	-0.031	-0.042	-0.019	< 0.001
GDP*	-0.459	-0.667	-0.251	< 0.001
Forestry*	-0.491	-0.663	-0.319	< 0.001
WGI*	0.177	0.061	0.292	< 0.001

The * symbol is intended to emphasise that the model used, in accordance with the concept from the publication, data values taken a year earlier than the explained variable (CO₂ level), if they were available.

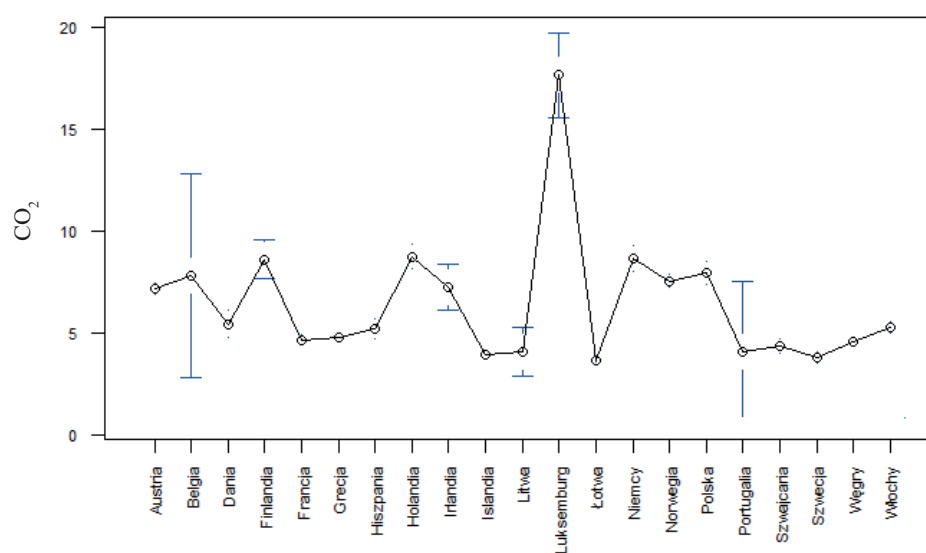
Source: Own study.

Figures 8–9 depict the variability among countries for CBI Aligned Green Bonds. In this visualisation, dots signify the average CO₂ values for each nation, while the whiskers represent the 95% confidence intervals for these averages. Similar findings can be observed as in the earlier example, emphasising significant differences among countries in the link between CBI Aligned Green Bonds and CO₂ emissions (Figures 8–9).

We employed a fixed effects panel data model using the same set of explanatory variables as in the previous model. The Hausman test ($p\text{-value} = 0.001$) indicates that the fixed effects model is more appropriate than the random effects model. The table below presents the estimation results. It can be observed that CBI Aligned Green Bonds are a statistically significant variable ($p < 0.001$). The coefficient of -0.085 indicates an average percentage decrease in CO₂ levels over time within each country when the value of Green Bonds increases by 1% (Table 8 in p. 72).

Figure 8

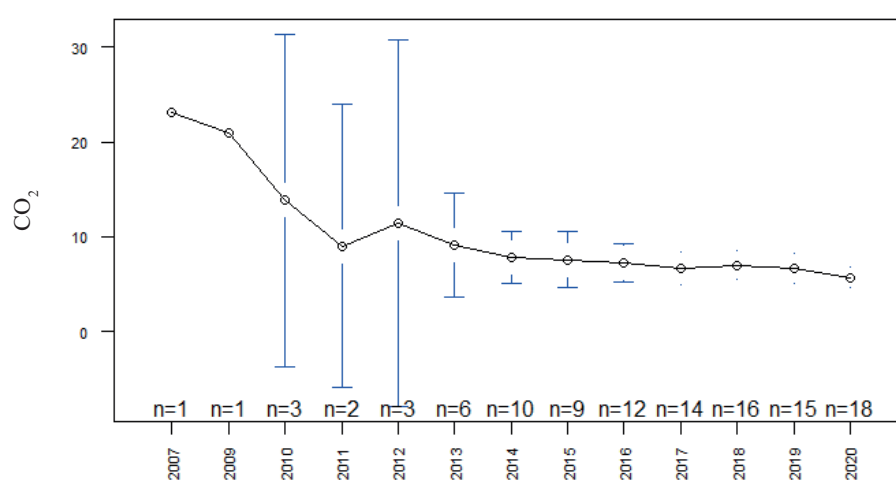
Cross-country heterogeneity for CO₂ emissions with CBI Aligned Green Bonds



Source: Own study.

Figure 9

Inter-annual heterogeneity for CO₂ emissions with CBI Aligned Green Bonds



Source: Own study.

Table 8

A panel data model showing the relationship between CBI Aligned Green Bonds and CO₂ emissions

Variable	Coefficient	2.5%	97.5%	P-value
Value [USD]*	−0.085	−0.126	−0.043	< 0.001
GDP*	1.137	0.911	1.363	< 0.001
Forestry*	−0.446	−0.608	−0.284	< 0.001
WGI*	0.107	−0.204	0.419	0.502

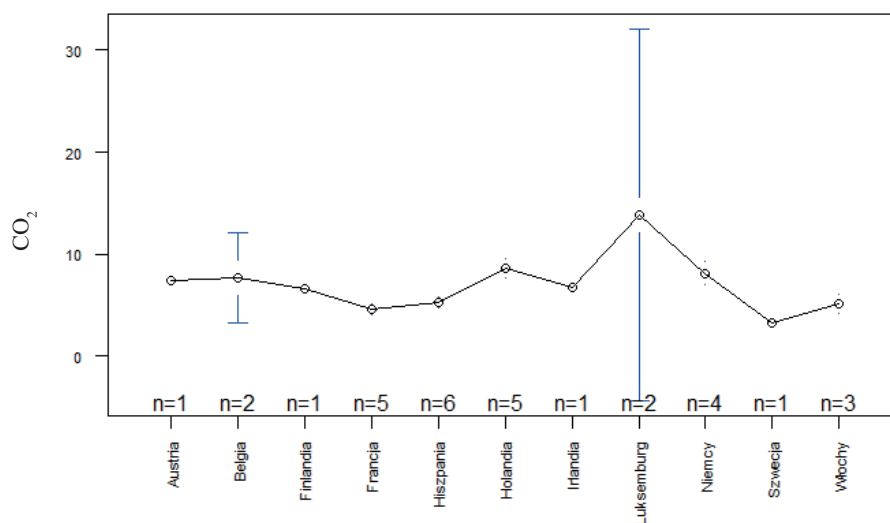
The * symbol is intended to emphasize that the model used – in accordance with the concept from the publication – data values taken a year earlier than the explained variable (CO₂ level), if they were available.

Source: Own study.

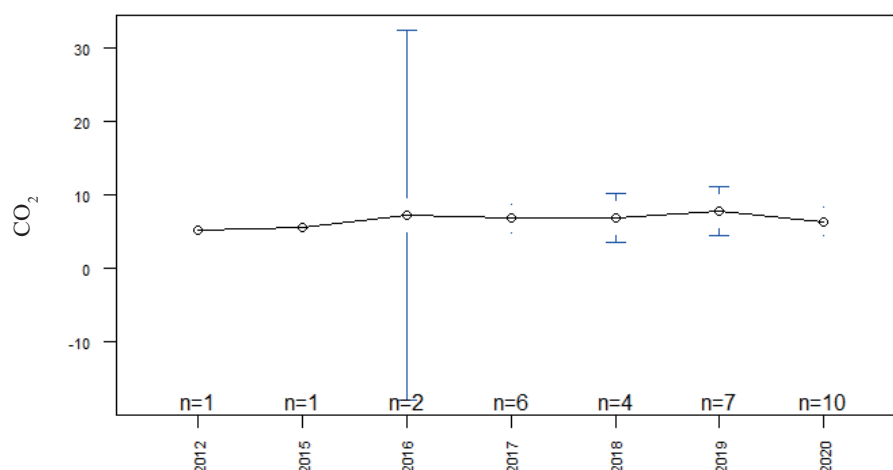
Heterogeneity across countries for Social Green Bonds is illustrated through a visualisation where dots represent the mean CO₂ values for each country, and the whiskers indicate the 95% confidence intervals for these means. Similar conclusions can be drawn as in previous cases, highlighting significant cross-country variability in the relationship between Social Green Bonds and CO₂ emissions (Figures 10–11).

Figure 10

Cross-country heterogeneity for CO₂ emissions with Social Green Bonds



Source: Own study.

Figure 11*Heterogeneity between years for CO₂ emissions with Social Green Bonds**Source:* Own study.

In this case, we employed a fixed effects panel data model using the same set of explanatory variables as in the previous analysis. The Hausman test ($p\text{-value} = 0.001$) indicates that the fixed effects model is more appropriate than the random effects model.

Table 9 presents the estimation results. It can be observed that the variable representing the value of Social Green Bonds is not statistically significant ($p = 0.707$). The coefficient of -0.024 indicates an average percentage decrease in CO₂ levels over time within each country for each 1% increase in Green Bonds, although this result is not statistically significant (Table 9).

Table 9*A panel data model showing the relationship between Social Green Bonds and CO₂ emissions*

Variable	Coefficient	2.5%	97.5%	P-value
Value [USD]*	-0.024	-0.141	0.093	0.707
GDP*	-1.296	-3.131	0.539	0.238
Forestry*	13.627	-15.59	42.845	0.412
WGI*	0.701	0.129	1.273	0.074

The * symbol is intended to emphasise that the model used, in accordance with the concept from the publication, data values taken a year earlier than the explained variable (CO₂ level), if they were available.

Source: Own study.

Expanding the research with additional variables and, due to significant data gaps, it was decided to run simple models with one variable at a time to assess better the direct impact of the studied variables on the issue. Secondly, each time, the values of variables lagged by one year were used as explanatory variables to determine the delayed impact of these variables on the phenomenon. Empty spaces in the tables mean no coefficients because the random effects model did not converge.

Table 10

Summary table with the results of panel models

Variable	Model	Coefficient	2.5%	97.5%	P-value
Intercept		8.971	7.212	10.73	< 0.001
Value [USD]		−0.031	−0.042	−0.019	< 0.001
GDP	Self-Labeled GB	−0.459	−0.667	−0.251	< 0.001
Foerstry		−0.491	−0.663	−0.319	< 0.001
WGI		0.177	0.061	0.292	< 0.001
Intercept		8.971	7.212	10.73	< 0.001
Value [USD]		−0.085	−0.126	−0.043	< 0.001
GDP	CBI Aligned GB	1.137	0.911	1.363	< 0.001
Foerstry		−0.446	−0.608	−0.284	< 0.001
WGI		0.107	−0.204	0.419	0.502
Intercept		8.971	7.212	10.73	< 0.001
Value [USD]		−0.024	−0.141	0.093	0.707
GDP	Social Green GB	−1.296	−3.131	0.539	0.238
Forestry		13.627	−15.59	42.845	0.412
WGI		0.701	0.129	1.273	0.074

Source: Own study.

Self-Labeled Green Bonds significantly influence CO₂ emissions, with models exhibiting high explanatory power (up to 88% in the fixed-effects model). Key factors include previous-year emissions, GDP, energy efficiency, energy market activity, afforestation, and green bond financing, all of which demonstrate varying degrees of positive or negative impacts.

Table 11*Comparison of pooled, fixed and random effects panel data models for Self-Labeled Green Bonds*

variable	coef_ pooled	p_ pooled	coef_FE	p_FE	coef_ random	p_ran- dom	R2_ pooled	R2_ random	R2_FE_ within	AIC*	BIC*	AIC_FE	BIC_ FE	AIC_ RE	BIC_ RE	BP	Hausman
prev_GB	-0.001	0.249	-0.000	0.045	—	—	0.224	—	0.412	68.103	68.936	10.906	11.739	—	—	7.241	—
prev_PKB	0.001	0.240	-0.000	0.001	-0.001	0.001	0.227	0.311	0.776	68.037	68.870	-5.487	-4.654	10.728	11.561	5.221	4.769
prev_ Zalesienie	-0.074	0.011	-1.557	0.178	-0.078	0.039	0.458	0.304	0.214	62.016	62.849	15.838	16.671	26.321	27.154	16.702	1.965
prev_WGI	1.176	0.266	6.504	0.110	1.669	0.217	0.219	0.304	0.288	68.209	69.043	14.148	14.981	25.636	26.469	9.205	2.082
prev_CO ₂	0.925	0.001	1.569	< 0.001	0.939	0.001	0.981	0.235	0.884	4.904	5.737	-16.665	-15.832	2.838	3.671	1.139	10.338
prev_FEC	0.001	0.293	0.000	0.063	0.001	0.395	0.212	0.281	0.369	61.436	62.144	12.794	13.502	23.282	23.990	8.887	4.209
prev_EP	0.169	0.630	-1.013	< 0.001	-0.935	0.000	0.155	0.280	0.824	62.485	63.193	-6.366	-5.658	3.245	3.953	6.584	2.732
prev_EMI	-0.013	0.678	0.123	0.031	0.079	0.044	0.151	0.281	0.460	62.557	63.265	10.452	11.160	18.930	19.639	6.768	2.830

*pooled model

Source: Own study.

The fixed effects model was the best fit for CBI Aligned Green Bonds, showing the lowest AIC and BIC values, with Hausman tests favoring FE over RE. Key predictors included previous CO₂ emissions and the WGI, both of which significantly impacted current emission levels, while the model also effectively balanced complexity, predictive accuracy, and robustness to heteroscedasticity.

Table 12*Comparison of pooled, fixed and random effects panel data models for CBI Aligned Green Bonds*

variable	coef_ pooled	p_ pooled	coef_ FE	p_FE	coef_ random	p_ran- dom	R2_ pooled	R2_ random	R2_FE_ within	AIC*	BIC*	AIC_ FE	BIC_ FE	AIC_ RE	BIC_ RE	BP	Hausman
prev_GB	-0.001	0.674	-0.001	0.009	—	—	0.003	—	0.102	440.007	442.389	216.439	218.821	—	—	289.654	—
prev_PKB	0.001	0.001	-0.001	0.001	-0.001	0.001	0.496	0.353	0.764	385.416	387.798	109.632	112.014	184.270	186.652	74.714	19.431
prev_ Zalesienie	-0.025	0.267	-2.078	0.015	-0.035	0.545	0.017	0.350	0.091	438.917	441.299	217.446	219.828	235.658	238.040	287.578	6.037
prev_WGI	2.595	0.011	4.592	0.013	3.329	0.009	0.081	0.346	0.096	433.513	435.895	216.984	219.366	230.423	232.805	296.020	1.028
prev_CO ₂	0.953	0.001	0.977	0.001	0.953	0.001	0.984	0.217	0.779	109.095	111.477	104.459	106.841	109.095	111.477	3.806	0.139
prev_FEC	-0.001	0.07	0.001	0.988	-0.001	0.950	0.054	0.306	0.001	356.354	358.544	150.938	153.127	161.996	164.185	203.686	0.001
prev_EP	0.069	0.694	-1.497	0.001	-1.297	0.001	0.002	0.320	0.712	387.852	390.086	117.565	119.799	145.490	147.724	246.150	74.980
prev_EMI	-0.034	0.196	0.058	0.001	0.053	0.001	0.041	0.301	0.348	333.762	335.906	93.615	95.758	108.921	111.064	176.332	2.599

*pooled model

Source: Own study.

In the fixed effects model, the most significant factor was prev_CO_2 , with a coefficient of 1.615 ($p = 0.001$) and an R^2_{FE} of 0.785, indicating a strong positive relationship between greenhouse gas emissions and the dependent variable within countries. Energy efficiency (prev_EP) showed a negative impact with a coefficient of -1.227 ($p < 0.001$), while a higher concentration of the energy sector (prev_EMI) was positively associated, with a coefficient of 0.157 ($p = 0.004$); GDP per capita had a slight negative effect, and WGI was not statistically significant. The FE model outperformed the pooled model in fit and accuracy, confirmed by lower AIC and BIC values and supported by Hausman and Breusch–Pagan tests that favoured fixed effects over the random model.

Table 13

Comparison of pooled, fixed and random effects panel data models for Social Green Bonds

variable	coef_ pooled	p_ pooled	coef_ FE	p_FE	coef_ random	p_ran- dom	R2_ pooled	R2_ random	R2_FE_ within	AIC*	BIC*	AIC_ FE	BIC_ FE	AIC_ RE	BIC_ RE	BP	Hausman
prev_GB	-0.001	0.094	-0.001	0.375	—	—	0.169	—	0.079	77.98	78.87	23.232	24.122	—	—	10.339	—
prev_PKB	0.001	0.001	-0.001	0.001	0.001	0.599	0.64	0.333	0.731	62.916	63.806	1.074	1.965	34.027	34.917	6.422	201.185
prev_ Zalesienie	-0.096	0.073	-3.674	0.162	-0.056	0.652	0.191	0.333	0.186	77.483	78.373	21.027	21.918	33.111	34.001	1.758	2.215
prev_WGI	4.082	0.002	5.156	0.057	4.439	0.002	0.476	0.327	0.317	69.654	70.545	17.86	18.751	27.633	28.524	2.135	0.141
prev_CO ₂	0.819	0.001	1.615	0.001	0.802	0.001	0.962	0.283	0.785	22.373	23.263	-2.931	-2.04	13.516	14.407	0.199	9.699
prev_FEC	-0.001	0.175	0.001	0.937	-0.001	0.148	0.115	0.333	0.001	79.093	79.983	24.709	25.6	32.689	33.579	10.333	0.089
prev_EP	-0.143	0.734	-1.227	0.001	-1.136	0.001	0.012	0.334	0.854	81.091	81.981	-9.901	-9.01	4.227	5.117	6.638	1.152
prev_EMI	-0.084	0.029	0.157	0.004	0.062	0.168	0.267	0.332	0.575	75.708	76.598	9.306	10.196	29.318	30.209	3.894	44.92

*pooled model

Source: Own study.

To sum up, in the above statistical analysis we examined the impact of the possession and value of green bonds by the European Union countries on the level of CO₂ emissions, also considering significant confounding variables: GDP, forestation level and WGI, and we supplemented with new variables: FEC, EP, EMI. All these variables were presented in detail in tables. Correlations between both variables were at most average and statistically insignificant, and their large discrepancy can be explained by small data samples for a given year. The applied panel model for all bond types indicated that the variable value of green bonds and other variables were statistically significant in selected cases.

At first glance, the insignificant correlation coefficients reported in Tables 1–6 may appear inconsistent with the statistically significant coefficients obtained from the panel-data models. However, the two approaches address different analytical questions. The correlation analysis

examines simple bivariate associations within individual years and does not account for time lags, country-specific heterogeneity, or confounding variables. As a result, its explanatory power is limited, particularly when sample sizes are small and observations are unevenly distributed across countries and years. In contrast, the panel-data framework exploits both cross-sectional and longitudinal variation, substantially increasing the number of observations and allowing for the control of unobserved country-specific effects. Moreover, the models incorporate lagged explanatory variables and relevant controls such as GDP per capita, forest cover, and governance quality. Consequently, the panel estimations isolate the net effect of green bond issuance on CO₂ emissions more effectively than simple correlation measures. The significant coefficients observed in the panel models therefore suggest that the impact of green bonds becomes visible only after controlling for structural differences among countries and accounting for delayed policy and investment effects.

The panel model results, which show that:

- Climate Bonds Initiative (CBI) – compliant bonds show the strongest negative relationship with CO₂ emissions ($\beta = -0.085$; $p < 0.001$), confirming the effectiveness of environmental certification and supervision;
- Self-labeled green bonds also show a statistically significant emission reduction effect ($\beta = -0.031$; $p < 0.001$), although weaker than certified bonds, which may be due to the lack of certification standards and the potential risk of “greenwashing”.

Social green bonds do not show a statistically significant relationship with CO₂ emissions ($p = 0.707$), which is consistent with their broader – not only environmental – scope of objectives. In addition, GDP per capita (negatively related to emissions), quality of governance (with differential impacts depending on the model), and forest cover (showing an emission-reducing effect) turned out to be significant moderators. Attention should be paid to the energy-efficiency variable (*prev_EP*), which, in each model, had a strong and statistically significant emission-reducing effect (e.g., $\beta = -1.227$ in the FE model for social green bonds).

The broad analysis of cross-country variability and the accurate interpretation of the heterogeneity of the results should be appreciated. It is clearly shown that countries with more developed financial markets (such as Germany or France) and higher institutional quality show better results in the use of green bonds as an instrument of energy transformation.

Conclusion

Descriptive statistics reveal considerable variability in green bond issuance across European Union member states, with economically advanced nations such as Germany and France exhibiting the highest levels of activity. Forest cover and GDP levels consistently moderate the relationship between green bond investments and reductions in CO₂ emissions. Countries with

higher forest cover experience greater CO₂ reductions from green bonds due to natural carbon absorption. Mature capital markets also enhance green bond financing efficiency, as shown by Germany, France, and the Netherlands, which have higher issuance volumes. The IMF (Cheng et al. 2024) found that sovereign green bonds can catalyse sustainable market development. Additionally, a systematic review by Al Hamrani and Al Hamrani (2025) highlighted that ESG performance and corporate governance significantly influence green bond market growth, further supporting the link between market maturity and issuance rates. Lastly, trends and observations indicate a positive trajectory in green bond issuance over time, which correlates with the establishment of improved regulatory frameworks within the EU. However, disparities persist, particularly in nations with less mature markets and governance structures. Integrating the literature review with statistical results highlights the connection between green bond issuance and CO₂ emission reductions in EU countries. The study finds a significant correlation, showing that certified green bonds, particularly those aligned with the Climate Bonds Initiative (CBI), achieve superior environmental performance. This aligns with prior research by Flammer (2021) and Fatica and Panzica (2020) on the importance of strong certification standards for measurable outcomes.

Green bonds connect climate policy with financial markets, encouraging sustainable investment and reducing carbon emissions, particularly CBI-aligned bonds with strict certification. Their effectiveness varies regionally, thriving in wealthy, well-regulated countries while facing challenges in emerging markets due to limited access and governance issues. Addressing certification inconsistencies and researching long-term project impacts are essential for strengthening green bonds as reliable sustainability tools. Green bonds are now integral to climate policies, as highlighted by the European Green Deal, which emphasises their role in achieving the EU's decarbonisation targets. This approach aligns financial incentives with environmental goals, enhancing green financial instruments' effectiveness. Statistical analyses confirm that CBI-aligned green bonds have the most significant impact on CO₂ reductions, as evidenced by coefficients that align with global sustainability benchmarks. This finding aligns with the research conducted by Taghizadeh-Hesary et al. (2023), which examined how the targeted allocation of certified green bond proceeds to renewable energy and low-carbon initiatives optimises their decarbonisation potential. The study further reinforces the idea that economic prosperity, indicated by robust GDP and fiscal stability, acts as a key predictor for the growth of green bond markets, supporting the findings of Dan and Tiron-Tudor (2021)

Forest cover significantly boosts green bonds' effectiveness, especially in countries rich in natural carbon sinks. Alamgir and Cheng (2023) show how financial instruments collaborate with natural resources for sustainability. Furthermore, developed financial markets improve the allocation of green bond proceeds, as seen in Germany and France, where advanced capital

markets enhance green financing for decarbonisation, aligning with Cheong and Choi (2020). Variability also exists among different types of green bonds. Self-labelled green bonds, although they contribute to CO₂ reductions, exhibit greater inconsistency in effectiveness due to varying certification processes and fluctuating investor trust. Anh Tu et al., (2022) highlighted the urgency for standardised labelling criteria to enhance both reliability and performance. Meanwhile, social green bonds, which aim to achieve both environmental and social objectives, yield moderate impacts on CO₂ reductions, as their broader focus may dilute their environmental effectiveness compared to strictly certified green bonds, as corroborated by Mavlutova et al. (2023).

Regional disparities pose additional challenges, especially in less developed markets within emerging economies. As noted by researchers such as Bestvina et al. (2023) and Wyszowska and Filipiak (2024), these areas frequently deal with limited access to capital and governance issues, requiring the enhancement of institutional frameworks to fully harness the transformative potential of green bonds.

This study emphasizes the importance of strategic policies to enhance green bond benefits through improved certification standards, market access, and alignment with environmental goals, while noting limitations such as lack of long-term sustainability analysis and limited global comparison.

Green bonds are crucial for balancing economic growth and environmental sustainability, relying on mature markets, good governance, and certification. Frameworks like the Climate Bonds Initiative (CBI) increase their impact on reducing emissions. Outcomes differ by country; advanced economies leverage their financial systems and institutions, while emerging markets face barriers needing policy action. Combining green finance with natural assets like forests boosts environmental benefits.

Policymakers should promote innovation and credibility in green bonds, encouraging investors to focus on projects that yield both financial returns and environmental gains. Clear reporting and international standards build investor trust.

Market participants can use green bonds for diversification and ESG compliance, with issuers enhancing appeal through transparency. Further research is needed on biodiversity and long-term results.

The findings carry several implications for policymakers, regulators, and market participants. First, the stronger performance of CBI-aligned bonds suggests that certification and external verification mechanisms enhance the environmental effectiveness of green-finance instruments. Policymakers should therefore support the further harmonisation of green-bond standards within the European Union and encourage the adoption of transparent reporting frameworks. Second, the significance of governance quality indicates that institutional capacity remains a critical prerequisite for successful climate-finance initiatives. Countries seeking to expand

sustainable-finance markets should strengthen regulatory oversight, disclosure requirements, and monitoring systems. Third, the moderating role of forest cover highlights the importance of integrating financial instruments with broader environmental policies, including afforestation and ecosystem-protection programmes. Finally, investors may use certification status as an important signal when evaluating the credibility and potential environmental impact of green-bond investments. These findings reinforce the view that effective decarbonisation requires a combination of financial innovation, institutional quality, and environmental stewardship.

Several limitations should be noted. Data constraints led to the exclusion of some EU countries, limiting generalizability. The use of data up to 2022 does not reflect recent regulatory developments, such as the European Green Deal. Differences in bond types and certification approaches may affect comparability of results. Moreover, the focus on CO₂ emissions overlooks other dimensions of sustainability, such as resource efficiency. The dominance of advanced economies in the sample may also bias findings, and the assumption of linear relationships may oversimplify complex interactions.

Despite these limitations, the study contributes to the understanding of green bonds as tools supporting climate action and underscores their importance in the transition toward a sustainable economy.

References

- Abhilash, P., Gupta, R., & Singh, N. (2022a). Evolving trends in green bonds: Impacts on environmental sustainability. *Journal of Sustainable Finance*, 15(3), 125–139.
- Abhilash, , Shenoy, S. S., & Shetty, D. K. (2022b). A state-of-the-art overview of green bond markets: Evidence from technology empowered systematic literature review. *Cogent Economics & Finance*, 10(1), 2135834. <https://doi.org/10.1080/23322039.2022.2135834>.
- Al Hamrani, A. R., & Al Hamrani, N. R. (2025). The main determinants of green bond issuance: A systematic review. *Open Journal of Accounting*, 14(1), 67–93. <https://doi.org/10.4236/ojacct.2025.141004>.
- Al Mamun, M. A., Boubaker, S., & Nguyen, D. K. (2022). Green finance and decarbonization: Evidence from around the world. *Finance Research Letters*, 46(Part B), 102807. <https://doi.org/10.1016/j.frl.2022.102807>.
- Alamgir, M., & Cheng, M.-C. (2023). Do green bonds play a role in achieving sustainability? *Sustainability*, 15(13), 10177. <https://doi.org/10.3390/su151310177>.

- Anh Tu, C., Sarker, T., & Rasoulinezhad, E. (2020). Factors influencing the green bond market expansion: Evidence from a multi-dimensional analysis. *Journal of Risk and Financial Management*, 13(6), 126. <https://doi.org/10.3390/jrfm13060126>.
- Bestvina Bukvić, I., Pekanov, D., & Crnković, B. (2023). Green bonds and carbon emissions: The European Union case. *Ekonomski vjesnik/Econviews – Review of Contemporary Business, Entrepreneurship and Economic Issues*, 36(1), 113–123. <https://doi.org/10.51680/ev.36.1.9>.
- Chen, F., Zeng, X., & Guo, X. (2024). Green finance, climate change, and green innovation: Evidence from China. *Finance Research Letters*, 63, 105283. <https://doi.org/10.1016/j.frl.2024.105283>.
- Chen, Z., Marin, G., Popp, D., & Vona, F. (2020). Green stimulus in a post-pandemic recovery: The role of skills for a resilient recovery. *Environmental and Resource Economics*, 76(4), 901–911. <https://doi.org/10.1007/s10640-020-00464-7>.
- Cheng, G., Ehlers, T., Packer, F., & Xiao, Y. (2024). *Sovereign green bonds: A catalyst for sustainable debt market development?* (IMF Working Paper No. 2024/120). International Monetary Fund. <https://doi.org/10.5089/9798400277030.001>.
- Cheong, C., & Choi, J. (2020). Green bonds: A survey. *Journal of Derivatives and Quantitative Studies*, 28(4), 175–189. <https://doi.org/10.1108/JDQS-09-2020-0024>.
- Climate Bonds Initiative. (2022). *Green bonds: The impact on climate change*. <https://www.climatebonds.net>.
- Cortellini, G., & Panetta, I. C. (2021). Green bond: A systematic literature review for future research agendas. *Journal of Risk and Financial Management*, 14(12), 589. <https://doi.org/10.3390/jrfm14120589>.
- Dan, A., & Tiron-Tudor, A. (2021). The determinants of green bond issuance in the European Union. *Journal of Risk and Financial Management*, 14(9), 446. <https://doi.org/10.3390/jrfm14090446>.
- Diaz Rainey, I., Corfee Morlot, J., Volz, U., & Caldecott, B. (2023). Green finance in Asia: Challenges, policies and avenues for research. *Climate Policy*, 23(1), 1–10. <https://doi.org/10.1080/14693062.2023.2168359>.
- Eccles, R. G., Ioannou, I., & Serafeim, G. (2014). The impact of corporate sustainability on organizational processes and performance. *Management Science*, 60(11), 2835–2857. <https://doi.org/10.1287/mnsc.2014.1984>.
- European Commission. (2019). *The European Green Deal*. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.
- Fatica, S., & Panzica, R. (2020). *Green bonds as a tool against climate change?* SSRN. <https://doi.org/10.2139/ssrn.3710020>.

- Flammer, C. (2020). Corporate green bonds. *Journal of Financial Economics*. SSRN. <https://doi.org/10.2139/ssrn.3125518>.
- Flammer, C. (2021). Corporate green bonds. *Journal of Financial Economics*, 142(2), 499–516. <https://doi.org/10.1016/j.jfineco.2021.01.010>.
- Markowitz, H. (1952). Portfolio selection. *The Journal of Finance*, 7(1), 77–91. <https://doi.org/10.1111/j.1540-6261.1952.tb01525.x>.
- Mavlutova, I., Spilbergs, A., Verdenhofs, A., Natrins, A., Arefjevs, I., & Volkova, T. (2023). Digital transformation as a driver of the financial sector sustainable development: An impact on financial inclusion and operational efficiency. *Sustainability*, 15(1), 207. <https://doi.org/10.3390/su15010207>.
- Nguyen, P.-H., Nguyen, L.-A. T., Le, H.-Q., & Tran, L.-C. (2024). Navigating critical barriers for green bond markets using a fuzzy multi-criteria decision-making model: Case study in Vietnam. *Heliyon*, 10(13), e33493. <https://doi.org/10.1016/j.heliyon.2024.e33493>.
- Pata, U. K., Kartal, M. T., Ahmed, Z., & Sinha, A. (2025). Relationship between green bonds and carbon neutrality: Evidence from top five emitting countries' sectoral CO₂ emissions. *Financial Innovation*, 11, 10. <https://doi.org/10.1186/s40854-024-00691-7>.
- Saha, R., & Maji, S. G. (2025). Do green bonds reduce CO₂ emissions? Evidence from developed and developing nations. *International Journal of Emerging Markets*, 20(7), 2913–2934. <https://doi.org/10.1108/IJOEM-05-2023-0765>.
- Silva, F., Ferreira, A., & Cortez, M. C. (2024). The performance of green bond portfolios under climate uncertainty: A comparative analysis with conventional and black bond portfolios. *Research in International Business and Finance*, 70(Part A), 102354. <https://doi.org/10.1016/j.ribaf.2024.102354>.
- Taghizadeh-Hesary, F., Phoumin, H., & Rasoulinezhad, E. (2023). Assessment of role of green bonds in renewable energy resource development in Japan. *Resources Policy*, 80, 103272. <https://doi.org/10.1016/j.resourpol.2022.103272>.
- Wang, T., Liu, X., & Wang, H. (2022). Green bonds, financing constraints, and green innovation. *Journal of Cleaner Production*, 381(Part 1), 135134. <https://doi.org/10.1016/j.jclepro.2022.135134>.
- Wang, Y., & Taghizadeh-Hesary, F. (2023). Green bonds markets and renewable energy development: Policy integration for achieving carbon neutrality. *Energy Economics*, 123, Article 106725. <https://doi.org/10.1016/j.eneco.2023.106725>.
- World Bank. (2022). *World development indicators*. <https://datatopics.worldbank.org/world-development-indicators>.

- Wyszkowska, D., & Filipiak, B. Z. (2024). The impact of green bond for achieving sustainable development goals. *Economics and Environment*, 90(3), 879. <https://doi.org/10.34659/eis.2024.90.3.879>.
- Zhang, D., Mohsin, M., & Taghizadeh-Hesary, F. (2022). Does green finance counteract the climate change mitigation: Asymmetric effect of renewable energy investment and R&D. *Energy Economics*, 113, 106183. <https://doi.org/10.1016/j.eneco.2022.106183>.