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THE IMPACT OF GREEN BONDS ON CARBON EMISSION REDUCTION: PANEL DATA ANALYSIS

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Abstract

The main goal of governments is to achieve economic stability as well as meeting development objectives through using fiscal policy tools. In this direction, many countries have turned to alternative renewable resources to meet their growing energy needs and reduce the level of carbon (CO₂) emissions that cause air pollution and climate change. In this context, green bonds fund projects and investments aimed at environmental protection and climate change mitigation. This paper focuses on investigating the relationship between CO₂ emissions and green bond issuances. In this context, panel data regression analysis was applied. In this method, collective data, regarding green bond issuance of 31 different countries throughout 2014-2022 period, were utilized. The analyses reveal that green bond



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issuances have an impact on CO₂ emissions, and this impact is significant and negative, while the effects of urbanization and GDP growth rate are significant and positive.

Keywords: green bond, green finance, carbon emission, climate change, panel data regression analysis

1. INTRODUCTION

Recently, climate change has been recognized as a major problem. Hence, environmental protection has gained importance due to the spread of environmental pollution, the environmental impacts of industrialization, and the intensification of the effects caused by climate change. The issue of climate change was first addressed at the international level under the United Nations Framework Convention on Climate Change (UNFCCC), in 1994. The 2005 Kyoto Protocol introduced legally binding provisions to prevent and reduce the increase in greenhouse gas emissions. The Paris Agreement was entered into force in 2016 to cope with climate change. The Paris Agreement aims to continue efforts to keep the global temperature increase at 1.5°C. Additionally, it focuses on harmonizing financial flows by decreasing greenhouse gas emissions, thus being resilient to climate change (Paris Agreement, 2015). Following these developments, alternative financing mechanisms have emerged for financing climate change and environmental protection.

Green bond investments operate in financial markets that aim to steer capital away from fossil fuel projects towards those with lower carbon intensity (Mathews, 2011). Green bonds can be described as borrowing, issued to provide capital for climate and environmentally sensitive projects (World Bank, 2015). The aim of the green bond market is to develop debt instruments to finance projects that are important for ecologically sustainable development. (Frydrych, 2021). Moreover, it is rapidly evolving towards becoming an essential debt instrument for financing green projects. The amount of green bonds issued worldwide in 2014 was recorded as 37.1 billion dollars, and this amount increased to 587.6 billion dollars in 2023 (Statista, 2024). The prospective expansion of green bonds across advanced and emerging economies is fundamentally underpinned by escalating global awareness of climate-related risks and the strengthening of strategic policy initiatives for environmental preservation (Sjauš, 2020).

This study aims to examine the impact of green bonds on CO₂ emissions, issued via both private and public sectors, by referring to pooled dataset collected of 8 years, between 2014 and 2022. The green bond issuance data of 31 countries were used specifically. In addition to other variables affecting CO₂ emissions in the literature, forest areas, urbanization rate and trade openness are also included in the analysis as determinant variables to ensure that the study differs from the literature and fills the existing gaps. It is observed that production and population growth

increase urbanization, leading to environmental damage. The question of which policies may be developed and which measures may be taken to reduce the ecological impacts of urbanization may gain importance in this context. (Arshad, et al., 2024; Zhang, et al., 2024). Trade openness is defined as the ratio of the sum of imports and exports of goods and services to gross domestic product and it reflects the degree of integration of an economy into the global market. While trade openness is mostly recognized as a factor that encourages economic growth and expands the volume of foreign trade, it is also acknowledged that this condition may result in a rise in CO₂ emissions. In this context, the question of which policies can be developed and which measures can be taken to minimize the ecological impacts of urbanization and trade openness may become important (Al Mamun et al., 2022; Alharbi, S. et al., 2023; Zhang, M. et al., 2023; Xia, L. et al., 2024). This paper aims to provide green policy recommendations based on the relationship between urbanization, trade openness and CO₂ emissions. The Arellano, Froot, and Rogers robust estimator is used in the study. In this direction, green bonds will raise awareness in green finance by revealing the positive effects of green bonds in preventing climate change and environmental damage. They will provide valuable insights for all sectors in terms of their contribution to decision-making processes.

2. LITERATURE REVIEW

Various empirical studies are evaluating the economic and social impacts of green bond issuance. For instance, climate change, environmental pollution, economic growth, and renewable energy through different policy measures and other influencing factors. The majority of studies in the present literature have concluded that green bond issuance contributes to achieving the intended policy objectives.

As Alharbi et al. (2023) demonstrate, green bonds significantly support green energy production, especially in countries with high technological capacity. However, they argue that this support is more pronounced in countries with high emission levels and greater exposure to climate change risk. Research conducted by Ye and Rasoulinezhad (2023) demonstrates that green bonds have positive and statistically significant effects on the efficiency of renewable energy utilization in both the short and long term. Even though these effects are observed in both the long and short run, they are more robust in the long run. Ning et al. (2023) investigated the role of green bond financing in promoting energy efficiency investments and economic growth. Based on the literature, it can be claimed that bank loans ensure significant funding for efficiency projects related to energy sources. Furthermore, green banks stimulate economic growth by allocating funds to public and private sectors for energy efficiency projects. Taghizadeh et al. (2023) found that green bonds positively impact wind energy consumption in Japan in the long run, while geopolitical risk drastically affects long-term wind energy consumption. Shang et al. (2023) emphasized the effects of green financing on green energy use in China's tourism sector using annual data from 1992 to 2021.

The study indicates that green bond issuances have a positive long term impact on the green efficiency attributed to China's tourism sector. However, in the short term, no statistically significant effect is observed.

Among the studies focusing on the relationship between CO₂ emissions and green bonds, Al Mamun et al. (2022) found that green financing significantly and negatively impacts long-term and short-term CO₂ emissions. Zhao et al. (2022) argued that green bonds are mainly funding sources for energy efficiency projects. Additionally, they contribute to enhance economic growth by 4.9%. Meo et al. (2022) investigated the impact of green bonds on reducing CO₂ emissions. Panel data for 10 countries supporting green finance for 2008-2019 were used. As a result, it is found that green finance significantly reduces CO₂ emissions. Cepni et al. (2022) argued that green bonds stand out as a reliable instrument against physical and transition climate risks compared to other green investments. Li et al. (2022) indicated that climate technologies and green finance reduce CO₂ emissions. Chang et al. (2022) observed that green finance improves environmental quality in 8 selected countries. Rasoulinezhad and Taghizadeh (2022) showed that, in the long run, green bonds facilitate access to green energy projects and reduce per capita CO₂ emissions. In the short run, results illustrate that population, GDP, and energy intensity directly affect CO₂ emissions. However, there is no direct relationship between green bonds, the green energy index (GEI) and CO₂ emissions. Sinha et al. (2021) indicated that it is possible for green financing mechanisms to have gradual adverse feedback effects on social and environmental responsibility. Furthermore, it was also observed that green bonds are effective in CO₂ emission reductions. Flammer (2021) examined the impact of corporate green bonds, especially on environmental performance and market reactions. It is observed that green bonds positively affect the valuation of companies issuing green bonds in the stock market and their environmental performance. Rannou et al. (2021) argue that energy companies utilize carbon futures market primarily for speculative purposes or short-term hedging to complement the needs for green bond market. However, since 2018, carbon market has been replaced by green bond market for long-term hedging efforts.

Tolliver et al. (2020) demonstrated that in the years following 2015, relative Nationally Determined Contributions (NDCs) significantly influenced green bond allocations in a positive manner, by a statistical significance of 99%. Tolliver et al. (2020) demonstrated that NDCs along with other macroeconomic and institutional factors encourage the deployment of green bonds to finance future climate and sustainable investments. Hammoudeh et al. (2020) evaluated the time-varying causality relationship between conventional and green bonds, the clean energy index, and CO₂ emission allowance prices in the US. The results indicate a significant causal relationship between the government bond index and green bonds. Gibon et al. (2020) argued that green bonds may improve projects' environmental outcomes by assessing their environmental impacts. Tolliver et al. (2019) found that projects backed by green bonds have decreased greenhouse gas emissions by 108 million tons of equivalent CO₂. Therefore, the renewable energy

capacity was boosted to over 1500 gigawatts. Glomsrød and Wei (2018) concluded that green finance reduces coal consumption by 2.5% globally and increases the share of non-fossil electricity from 42% to 46% and will reduce global CO₂ emissions by 2030 by amounts equivalent to the total emissions of Japan and the European Union in the previous year.

As a result, as shown in the literature, green bond issuances play a role in preventing air pollution.

3. METHODOLOGY

Panel data can be described as a data set that follows sample units over time. Therefore, it provides more than one observation about each unit. A large number of observations reduces the possibility of a linear relationship among the explanatory variables. Consequently, panel data sets offer distinct benefits to conventional cross-sectional and time-series data, allowing researchers to conduct more comprehensive analyses (Hsiao, 2003).

In general, the panel data model can be mathematically demonstrated as it is seen below:

$$Y_{it} = \alpha_{it} + \beta_{kit}X_{kit} + u_{it} \quad i=1,\dots,N; t=1,\dots,T. \quad (1)$$

In the model above, Y stands for dependent variable, X_k for independent variable, α for fixed parameter, β for slope parameter, and u for error term. The subscript i signifies households, individuals, firms, countries, etc, while t denotes time period (Baltagi, H., 2005).

Although usage of panel data offers various advantages, it should be acknowledged that panel data analysis also has certain limitations such as data preparation and compilation processes. A panel in which the same time periods are observed for all units in the panel data sets is referred to as a balanced panel. In contrast, if some units have missing observations, the dataset is considered an unbalanced panel. Although the analytical mechanism remains similar, unbalanced panels require careful treatment to avoid biased results (Wooldridge, 2003).

Panel data regression analysis can generally be conducted using three main approaches: random effects (RE), fixed effects (FE) and pooled ordinary least squares (POLS) model.

The POLS regression model assumes complete homogeneity across all cross-sectional units within the panel. It treats the entire dataset as a single pooled sample, disregarding any potential individual-specific or time-specific effects. In other words, this model does not account for heterogeneity among entities or temporal Dynamics, implying that all observations share identical characteristics and are influenced by the same underlying relationships (Adefemi, 2017).

$$Y_{it} = \alpha_0 + \sum_{k=1}^K \beta_k X_{kit} + u_{it}, \quad i = 1, \dots, N; t = 1, \dots, T \quad (2)$$

In the model, Y_{it} and X_{it} denote the dependent and independent variables, respectively, for unit i at time period t . The subscript k refers to a specific explanatory variable. The term u_{it} represents the error term, while α_0 and β_k denote the fixed and slope parameters, respectively.

The FE model presumes that the differences between units may be represented by differences in the constant terms (Greene, 2003). When traditional statistical approaches estimate variation across units, they may elevate the risk of omitted variable bias arising from unobserved heterogeneity. When the FE models are used, variation focused on within-unit variation to minimize missing variable bias and unobserved heterogeneity. The basic principle is that omitted variable bias generally tends to decrease under the FE model approach as the estimation relies on within-unit variation controlling for unobserved heterogeneity (Hill et al., 2020).

$$Y_{it} = \alpha_{0i} + \sum_{k=1}^K \beta_k X_{kit} + u_{it}, \quad i = 1, \dots, N; t = 1, \dots, T \quad (3)$$

In the equation, the slope coefficient β is constant across both units and time, whereas the intercept term α_i varies across units but remains constant over time.

Another approach, the RE model, deals with the distinctions in the variance components of error terms. The RE model infers that there is no correlation between explanatory variables and unit effects. Hence, fixed effects are not included in the model. However, they are included in the error terms (Park, 2011). Since the RE model requires fewer parameters to estimate the FE model, it is preferable. Moreover, it ensures explanatory variables with the same value for all units (Asterious & Hall, 2007).

$$Y_{it} = \alpha_0 + \sum_{k=1}^K \beta_k X_{kit} + \mu_i + u_{it}, \quad i = 1, \dots, N; t = 1, \dots, T \quad (4)$$

In this model, u_{it} represents the error term, while μ_i denotes the unit error component. Since the unit effect is assumed to be random, it is not incorporated into the intercept parameter but rather included in the error term.

Formal diagnostic tests should be conducted to determine the presence of unit and/or time effects within model. The random effects (RE) model should be accepted if null hypothesis (H_0) is rejected for the Lagrange Multiplier (LM) test. If H_0 is rejected in the F test, the FE model should be preferred. If both the F and LM tests reject their respective H_0 , the Hausman test should be applied to make a decision between the RE and FE models (Park, 2011).

The Hausman test is a statistical procedure designed to detect specification errors in econometric models. In this context, it is primarily used to test whether the differences between parameter estimates obtained from two

estimation methods are statistically significant. In particular, it tests whether the assumptions used in a model, such as the relationship between the error term and the explanatory variables, are valid. In other words, it detects model misspecification by comparing the consistency of estimates derived from alternative estimation methods. For this reason, it allows for a choice between the FE and RE models (Hausman, 1978).

$$H = (\hat{\beta}_{FE} - \hat{\beta}_{RE})' [Var(\hat{\beta}_{FE}) - Var(\hat{\beta}_{RE})]^{-1} (\hat{\beta}_{FE} - \hat{\beta}_{RE}) \quad (5)$$

In the equation, the subscript RE denotes the estimator obtained from the random effects model, while the subscript FE refers to the estimator derived from the fixed effects model. Moreover, $Var(\hat{\beta}_{FE})$ and $Var(\hat{\beta}_{RE})$ represent the variance covariance matrices obtained from the estimation of the fixed effects and random effects models, respectively.

4. DATA SET AND VARIABLES

In the analyses, annual data from 2014 to 2022 for 31¹ countries from different continents with the highest levels of green bond issuance were utilized. This study investigated the impact of green bond issuances by the private and public sectors on CO₂ emissions using an unbalanced panel data analysis method. The variables used in the analysis are: CO₂ emissions, green bond issuance, forest areas, gross domestic product growth, trade openness, and urbanization rate. Although the green bond issuance data for 2023 and 2024 are available, the analysis period was restricted to 2014-2022 because CO₂ data for those years were unavailable the CO₂ of the dependent variable to be used in the analysis (CE). In other words, the study period was defined as 2014-2022 due to the inadequacy of accessible data for the relevant years. The countries included in the analysis were selected based on the highest levels of green bond issuance during the 2014-2022 period. Bond data were obtained from the IMF and ICMA databases and compiled by the authors. Green bond issuance amounts are represented by their nominal values as recorded in the databases. We also compiled another variable, trade openness, by using import and export data from the countries included in the analysis. The analyses were conducted using Stata 17 statistical software.

¹ Belgium, Australia, Brazil, Austria, China, Chile, Canada, Italy, Denmark, France, Finland, Germany, Japan, Malaysia, Thailand, India, Norway, Spain, Korea, Luxembourg, Mexico, United States, New Zealand, Netherlands, Poland, United Arab Emirates, Singapore, South Africa, Sweden, Switzerland, United Kingdom,

Table 1 Information about variables

Variable	Description	Source	https
Carbon emission (lnCE)	Logarithm of carbon emission (Total MegaTonnes /MT)	WB, global carbonatlas, climatewatchdata	https://globalcarbonatlas.org https://www.climatewatchdata.org https://data.worldbank.org
Green bonds (lnGB)	Logarithm of green bond issuance (Billion dollars)	ICMA, IMF	https://www.icmagroup.org https://climatedata.imf.org
Forest area (FA)	Forested areas (% of land area)	WB	https://data.worldbank.org
GDP growth (GDPGR)	Gross domestic product growth (%)	WB	https://data.worldbank.org
Trade openness (TO)	Imports and exports of goods and services (% of GDP)	WB	https://data.worldbank.org
Urban population (UP)	Urban population (% of total population)	WB	https://data.worldbank.org

Source: IMF (International Monetary Fund), WB (World Bank), ICMA (International Capital Market Association)

5. METHODS AND FINDINGS

The analysis with the panel data regression model is as follows:

$$\ln CE_{it} = \beta_0 + \beta_1 \ln GB_{it} + \beta_2 FA_{it} + \beta_3 GDPGR_{it} + \beta_4 TO_{it} + \beta_5 UP_{it} + u_{it} \quad (6)$$

i: 1, ..., 31; t: 1, ..., 9

In the regression equation above, t usually indexes the time period and i usually indexes the cross-sectional unit. The dependent variable in the equation is $\ln CE_{it}$, the logarithm of CO₂ emission. $\ln GB_{it}$ is the logarithm of green bond issuance, FA_{it} is the proportion of forested areas, $GDPGR_{it}$ represents gross domestic product growth rate, TO_{it} is trade openness, UP_{it} is the urbanization rate. In addition, β_0 represents the constant term and u_{it} denotes the error term.

Table 2 Descriptive Statistics

Short expression of the variables	Observation	Average	St. dev.	Min.	Max.
lnCE	279	5.379	1.551	2.015	9.341
lnGB	241	1.119	1.816	-3.257	5.398
FA	279	34.82	17.85	4.467	73.73
GDPGR	279	2.262	3.243	-10.94	11.33
TO	279	98.88	76.29	23.07	393.1
UP	279	78.81	14.09	32.38	100

Source: Authors' calculation with data obtained using the STATA 17

Table 2 illustrates the number of observations, mean values, the standard deviation as a measure of dispersion and maximum and minimum values for each variable in the analysis. Table 2 shows that the number of observations for green bond issuance (GB) differs across countries and years. Considering the mean values of the log-transformed variables, results demonstrate that these values are generally moderate. In contrast, the other variables exhibit a wide range between their minimum and maximum values. In particular, the standard deviation values of the trade openness (TO) and urbanization rate (UP) variables indicate that they are spread over a wide range.

Table 3 presents the diagnostic tests conducted to investigate the existence of unobserved effects, specifically unit and time effects in the model. Furthermore, the validity of the fixed effects (FE) and random effects (RE) models is evaluated against the pooled ordinary least squares (POLS) specification.

Table 3 Diagnostic tests for model selection

	F-test	Likelihood-ratio (LR) test	Breusch-Pagan LM test
Unit and time effects	3091.15 0.000***	1201.21 0.000***	-
Unit effect	3503.07 0.000***	664.31 0.000***	823.17 0.000***
Time effect	0.93 0.4919	0.00 1.000	0.00 1.000

*** p<.01.

Source: Authors' calculation with data obtained using the STATA 17

Panel data models may be estimated using different methods, such as random effects (RE), fixed effects (FE) and pooled OLS (POLS). This study examines whether the available data are suitable for the pooled OLS model using the F-test. If the aim is to examine overall differences across units, the F-test can be employed to test whether constant terms are equal across all units (Greene, 2003).

Table 3 shows that H_0 , which states that unit effects are equal to zero, is rejected. Therefore, unit effects exist, and fixed effects (FE) model shows greater consistency than the pooled OLS.

The Breusch-Pagan LM test is performed between the POLS and the RE models. The LM test examines whether the variance of the random effects (RE) is significantly different from zero with an estimation under parametric restrictions. In this context, the LM test is considered to make a selection between the POLS and the RE model (Breusch-Pagan, 1980). In Table 3, the Lagrange Multiplier (LM) test is performed for testing the presence of unit effects. The results indicate that the variances and standard errors are estimated for the unit effects and the residuals. In addition, the LM test statistic and the corresponding p-value for the H_0 that the variance of the unit effects equals zero are reported below the table.

According to the results, as unit effect variance (u) is not equal to zero, it can be claimed that the RE model is more consistent than the POLS.

The likelihood ratio (LR) test reveals that the unit effects are significant, indicating that the POLS is not valid.

Table 4 Hausman test

	(b) FE	(B) RE	(b-B) Difference	Std. error
lnGB	-.0122644	-.0092773	-.0029871	.0006873
FA	-.0329176	-.0125295	-.0203881	.0162617
GDPR	.0112827	.0114013	-.0001186	.0001144
TO	-.001311	-.0016595	.0003485	.0001491
UP	.0214029	.0124944	.0089085	.0027457
Chi2 = 27.71 Prob>chi2 = 0.0000				

Source: Authors' calculation with data obtained using the STATA 17

It is crucial to correctly decide which random effects or fixed effects models should be used in the analysis. The most widely used test for making this choice is the Hausman test. The test results indicate that if the H_0 is valid, the random effects model is appropriate, while the fixed effects model is preferred when the null hypothesis is rejected.

Table 4 reports the results, with the first two columns presenting the coefficient estimates obtained from the fixed effects and random effects models. The third column indicates the difference between the corresponding estimates, and the last column indicates the standard errors. Since the Hausman test rejects the null hypothesis (H_0), the random effects (RE) model is inconsistent. Thus, the fixed effects (FE) model is preferred.

Table 5 Deviations that deteriorate effectiveness

Model distorting assumptions	Assumption tests	Test results	p-values	Hypothesis
Autocorrelation	Durbin-Watson	.75613573	0.0000***	Available
	Baltagi-Wu	1.1951067	0.0000***	
	Wooldridge	13.513	0.0009***	
Heteroskedasticity	Wald	1159.76	0.0000***	Available
Cross-sectional dependency test	Pesaran CD	1.635	0.1021	Not available
	Friedman	8.748	0.9999	Not available

*** p<.01.

Source: Authors' calculation with data obtained using the STATA 17

Table 5 reports the results of the autocorrelation test, the heteroskedasticity test, and the inter-unit collinearity tests for a fixed effects model.

First, the autocorrelation test tests the null hypothesis that the autocorrelation coefficient equals zero. Since the results of the Baltagi-Wu and the Durbin-Watson tests (0.75 and 1.19) are less than 2, these results indicate the presence of autocorrelation in the fixed effects (FE) model. The Wooldridge test indicates first-order autocorrelation ($p=0.0009$), so standard errors are reported using country-clustered (or Driscoll-Kraay) corrections. Autocorrelation is present. This result is presented with country-clustered robust SE (or Driscoll-Kraay SE). When the heteroskedasticity test is analyzed, since the p-value is zero, H_0 is rejected, and it may be interpreted that there is heteroskedasticity in the model. Regarding the cross-sectional dependence tests, the Pesaran and Friedman results were 0.1021 and 0.9999, respectively. This indicates that the Pesaran test is insignificant at the 0.05 level, and the Friedman test is insignificant. In this specific analysis, according to the Pesaran and Friedman tests, there is no cross-sectional dependence in the model.

In this study, diagnostic tests reveal violations of the classical assumptions that may reduce the efficiency of the panel data regression model. The results indicate that there is autocorrelation and heteroscedasticity, but no cross-sectional dependence across units. In line with the current situation in the analysis, robust estimators will be identified, and estimations will be performed using appropriate methods. In this context, the Arellano (1987), Froot, and Rogers estimator is preferred as a robust estimator. The results of this test are presented in Table 6.

$$\text{Var}(\hat{\beta}) = (X'X)^{-1} \left(\sum_{i=1}^N X_i' \hat{u}_i \hat{u}_i' X_i \right) (X'X)^{-1} \quad (7)$$

Table 6 Fixed effects estimator (Arellano, Froot and Rogers estimation results)

lnCE	Coefficient	Std. error	t-value	P> t	[95% confidence interval]	
lnGB	-.0122644	.0050524	-2.43	0.021**	-.022582	-.001194
FA	-.0329176	.0309784	-1.06	0.296	-.096184	.03034
GDPR	.0112827	.0011934	9.45	0.000***	.008845	.013719
TO	-.001311	.0007904	-1.66	0.108	-.002925	.000303
UP	.0214029	.0117719	1.82	0.079*	-.002638	.045444
Constant term	5.003351	1.191741	4.20	0.000***	2.5694	7.43721
F test = 18.83						
Prob> F = 0.0000						
(Within) R-squared = 0.3212						

*** p<.01, ** p<.05, * p<.1

Source: Authors' calculation with data obtained using the STATA 17

Table 6 illustrates the effect of the first independent variable, lnGB (green bond issuance), on CO₂ emissions is significant at the 5% significance level. The estimated coefficient is negative, indicating an inverse relationship between the two variables, and it is observed that a 1% increase in green bond issuance decreases CO₂ emissions by approximately 0.012%. In this respect, green bond issuances mitigate the level of CO₂ emissions. However, the significant feature

distinguishing green bonds from traditional bonds is that the resources obtained due to bond issuance are used only in green projects.

For this reason, the positive environmental impacts of green projects are expected to materialize over the long term. Al Mamun et al. (2022) provided evidence that green bonds significantly and negatively affect short- and long-run CO₂ emissions. Tolliver, et al. (2019) concluded that projects financed by green bonds provide CO₂ emission reductions. On the other hand, Flammer (2021) concluded that green bonds positively reduce CO₂ emissions. Similarly, Meo and Karim, (2022) argued that green bond issuances reduce CO₂ emissions. Finally, Glomsrod and Wei, (2018) found that green bonds reduce CO₂ emissions based on their analysis. These findings support our empirical results, confirming that green bond issuances contribute to reducing CO₂ emissions.

The Forest area (FA) variable was analyzed, and it was found that there was no significant relationship at 10% level ($p=0.296$).

The independent variable GDP growth rate (GDPGR) is essential with a p -value of 0.000 ($p<0.01$). The positive coefficient indicates a positive relationship with CO₂ emissions. A one unit increase in GDP growth rate is represented with a 0.01 unit increase in CO₂ emissions. Al Mamun et al. (2022) argued that the impact of GDP growth on CO₂ emissions is positive and significant only in the short run. In contrast, in the long run, reductions in CO₂ emissions predominantly depend on climate-friendly energy sources, low-carbon technologies and enhancements in energy efficiency.

The TO (trade openness) variable does not yield statistically significant results at the 1% level ($p=0.11$). Al Mamun et al. (2022) argued that trade openness may eventually increase CO₂ emissions in the long term, but decrease CO₂ emissions in the short term.

Regarding the last variable, the p -value of the urbanization rate (UP) is 0.07, and the effect of the urbanization rate on CO₂ emissions is statistically significant at the 10% level. Specifically, a one unit increase in the urbanization rate (UR) leads to a 0.02 units increase in CO₂ emissions.

The constant term of the model indicates the expected value of CO₂ emissions when all independent variables are equal to zero. The results prove that the constant term is positive and statistically significant at the 1% level.

The F-statistic value in Table 6 indicates that the model is statistically significant generally. In the same table, R^2 value is 0.3212, 32% of the changes in CE may be explained by the independent variables $\ln GB$, FA, GDPGR, TO, and UP.

According to these findings:

$$\ln CE_{it} = 5 - 0,01 \ln GB_{it} + 0,01 GDPGR_{it} + 0,02 UP_{it} \quad (8)$$

A final model may be derived based on the statistically significant variables.

6. CONCLUSION AND EVALUATION

In recent decades, the rapid increase in industrialization worldwide and boost in population and urbanization have significantly increased global energy dependence. To date, our energy needs have predominantly been met by fossil fuels. An increase in fossil fuels leads to increased greenhouse gas emissions in the atmosphere. As a consequence, global warming and environmental degradation appear as crises due to the accumulation of greenhouse gases.

CO₂ constitutes the largest share among greenhouse gases. As of 2023, approximately 37.792 megatons of CO₂ were emitted globally. The largest share of this total emission level belongs to China, which has 11.903 megatons. The USA followed by with 4.911 megatons and India with 3.062 megatons, respectively (globalkarbonatlas). It is widely acknowledged that rising CO₂ emissions lead to negative environmental consequences, including climate change, pose a significant threat to human well-being, and have detrimental impacts on the growth and development of nations.

To achieve economic growth, investment expenditures, increased production, and population growth raise the demand for goods and services. However, this process adversely affects the environmental components and contributes to pollution. Therefore, the need to replace environmentally harmful economic activities with cleaner production technologies has made it necessary to mitigate the negative effects on the environment, and both the public and private sectors have resorted to borrowing to provide finance for the solution.

Green bonds are one of the borrowing instruments used to mobilize the capital for environmentally sustainable projects aimed at mitigating negative environmental impacts. First issued in 2007, the issuance level of green bonds has increased significantly in recent years. Initially, private companies and financial institutions were responsible for issuing green bonds, but the state has become increasingly involved in this process.

In 2023, 31% of the green bonds issued worldwide were issued by private companies, 27% by financial institutions, and 22% by the government. As of 2023, the allocation of the proceeds from green bonds issued through borrowing were renewable energy sources, environmentally friendly buildings and water and wastewater projects, respectively (Statista, 2024). Given this information, the rise in green bond issuance volumes and the involvement of multiple sectors across different issuer segments contribute to promoting awareness of adverse environmental and climate conditions.

The core principle of this study is investigating the impact of green bonds issuances on CO₂ emissions by public and private sectors across 31 countries that span different continents. In this regard, the annual data from these countries with the highest green bond issuance volumes for 2014-2022 period were analyzed by using an unbalanced panel data model. The analysis findings are as follows: the impact of green bond issuance on CO₂ emissions is significant at the 5% significance level. The relationship between the two variables is negative, and it is

observed that a 1% increase in green bond issuance reduces CO₂ emissions by approximately 0.012%. In this respect, green bond issuance has a positive impact on the environmental performance. There is no statistically significant relationship between forested areas and CO₂ emissions. A statistically significant, positive relationship exists between GDP growth rate and CO₂ emissions. An increase of 1 unit in the GDP growth rate indicates a rise of 0.01 percentage point in CO₂ emissions. No statistically significant relationship is found between trade openness and CO₂ emissions. Finally, the urbanization rate has a statistically significant and positive effect on CO₂ emissions, increasing them by approximately 0.02 units.

According to the results of the empirical study, the positive contribution of green bonds to reducing the level of CO₂ emissions and, accordingly, air pollution is confirmed. Reducing dependence on fossil fuels and transitioning to alternative energy sources (renewable energy projects) will require substantial financing resources in the long run, especially for developing countries. Green bonds will allow public and private sectors to access financing for high-cost green projects. In addition, they can provide financing opportunities for green projects. For instance, energy efficiency projects, innovative city projects, and near-zero emission transportation projects that align with reducing CO₂ emissions.

The development of the green bond market is crucial for ensuring the effective functioning and institutional development of capital markets in developing countries. In this context, policymakers should introduce regulations to encourage the green bond market and implement incentive mechanisms such as tax reductions and high yields to make the market attractive for the private sector.

The effective functioning of the green bond market depends on financial markets. In addition, it is also dependent on environmental and economic financed projects, as well as transparent reporting and monitoring systems that inform the public. Regular performance evaluations will contribute to both ensuring investor confidence and enable the green bond issuer segment to more effectively guide their green financing strategies. In this context, robust institutional structures will allow forming a reliable green bond market that is aligned with sustainable development goals.

Many countries prioritize energy imports (oil, natural gas, etc.) over other imports due to their dependence on fossil fuels. This dependence creates challenges for governments in maintaining economic stability and achieving their development goals. Investing in sustainable green projects through green financing mechanisms is crucial to mitigate the dependence on fossil fuel imports thus to overcome the economic and environmental negativities that arise in this context. Policymakers must establish mechanisms to guarantee the long-term sustainability of these investments for the purpose of achieving their strategic goals.

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UTJECAJ ZELENIH OBVEZNICA NA SMANJENJE EMISIJE UGLJIKA: ANALIZA PANEL PODATAKA

Sažetak

Temeljni cilj vlada jest postizanje ekonomske stabilnosti i ispunjavanje razvojnih ciljeva primjenom instrumenata fiskalne politike. U tom smislu, mnoge su se zemlje okrenule obnovljivim izvorima kako bi zadovoljile svoje rastuće energetske potrebe i smanjile razinu emisija ugljika (CO₂) koje doprinose onečišćenju okoliša i klimatskim promjenama. U tom kontekstu, zelene obveznice služe financiraju projekata i ulaganja usmjerenih na zaštitu okoliša i ublažavanje klimatskih promjena. Glavna svrha ovog rada jest ispitati odnos između izdavanja zelenih obveznica i emisija CO₂. U tu svrhu primijenjena je regresijska analiza panel podataka na uzorku od 31 zemlje u razdoblju od 2014. do 2022. godine. Rezultati analize pokazuju da izdavanje zelenih obveznica ima negativan i statistički značajan utjecaj na emisije CO₂, dok su utjecaji urbanizacije i stope rasta BDP-a pozitivni i statistički značajni.

Ključne riječi: zelena obveznica, zelene financije, emisija ugljika, klimatske promjene, regresijska analiza panel podataka.

JEL klasifikacija: Q58, Q54, G15, F18.