

Green Bond Development and Smart Technologies: A Causal Analysis for Sustainable Competitiveness in E7 Countries

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Abstract

There are not enough studies in the literature to determine which variables have the most critical effects on the development of green bonds. This research gap creates uncertainty in the formation of strategic policy and investment decisions and emerges as an important research gap. To fill this gap, this study aims to determine the factors affecting the development of green bonds. For this purpose, an econometric analysis is carried out using the annual data of the emerging seven (E7) countries for the period 2000–2021. In the analysis, the instrumental variables two-stage least squares (IV-2SLS) technique is preferred to test the relationships more reliably. The main contribution of this study is that the most critical variables affecting the development of green bonds have been prioritized. Moreover, considering the instrumental variables two-stage least squares (IV-2SLS) technique makes it possible to test the causality relationship statistically. This situation contributes significantly to the results being more reliable. The findings demonstrate that the carbon emission problem positively affects the increase in green bonds. Similar to this situation, there is also a positive correlation between renewable energy projects and green bond improvements. In line with these results, it is recommended that governments implement incentive mechanisms such as tax reductions, develop independent auditing and ethical reporting standards, and ensure macroeconomic stability.

Keywords: Green bonds, renewable energy projects, research and development, carbon emissions, econometric analysis, sustainable competitiveness

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1 INTRODUCTION

Green bonds are special debt instruments that provide financial resources to support environmental sustainability. They have a similar structure to traditional bonds. Their financial structure is the same as classic bonds. These bonds also provide interest income, and the principal is repaid within a certain maturity (Křístková et al., 2025). However, the most critical reason why these bonds are called green is that these products are only applied to environmentally friendly projects. In this context, they are taken into consideration in the financing of projects that provide environmental benefits such as renewable energy, energy efficiency, and effective waste management. Green bonds are of great importance in many respects. These products make environmentally friendly investments financially attractive. With the help of this situation, it is more possible to support sustainable financing. Another importance of green bonds is that they contribute to the fight against climate change. This situation allows a more successful fight against the problem that poses a threat to the whole world, such as global warming (Shah, Nakouwo, Sobirjonovna, & Khan, 2025). Green bonds provide certain advantages for both issuing institutions and investors. The corporate reputations of issuing institutions increase with these bonds. In addition, these institutions can achieve significant reductions in financing costs thanks to green bonds. On the other hand, green bonds allow investors to diversify their portfolios.

Some actions need to be taken for the development of green bonds. Very high-cost investments are required for projects such as clean energy and energy efficiency worldwide. Public resources may be insufficient to meet this need. This situation increases the need for new financing sources. Green bonds also play a very critical role in achieving this goal. On the other hand, projects financed through green bonds reduce carbon emissions (Rehman et al., 2025). This situation significantly supports countries in achieving their sustainable development goals. In addition to them, standards are becoming more transparent with the development of the green bond market. This situation significantly increases investor confidence. Green bonds are necessary not only for the environment, but also for economic development and financial stability. For this reason, it is of great importance to strengthen legal infrastructures and to spread them by supporting them with incentive mechanisms. Moreover, green bonds increase the resilience of the financial system against market risks. Risks such as sudden increases in exchange rates and radically low interest rates can be managed more effectively thanks to green bonds (Gök et al., 2025). Projects that are financed through green bonds usually include

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innovative and low-carbon technologies. This makes it easier for green innovation to find financing. With the help of this issue, it is possible to develop technologies that support sustainable development.

There are many factors affecting the development of green bonds. These factors should be evaluated together with their economic, political, environmental and technological dimensions. Government incentives are a very important factor supporting the development of green bonds. In this process, it is possible to develop these bonds with incentives such as tax reductions. On the other hand, the development of standards that ensure the reliability of green bonds also increases confidence in the market (Chai et al., 2025). To achieve this goal, issues such as independent auditing and ethical reporting should be taken into consideration. Moreover, macroeconomic stability is important for the healthy functioning of financial markets. Within this framework, interest rates and exchange rates should be at a reasonable level. Similarly, reducing the problem of high inflation is also important in this process (Kumar et al., 2025). Developing renewable energy technologies also increase the need for new research studies. The need for green bonds is increasing for these studies to be carried out effectively. It is necessary to determine the most critical factors affecting the development of green bonds. First, strategic guidance is required for the efficient use of resources. With the help of this condition, limited public and private sector resources can be directed to the right areas. Identifying the most critical factors reveals which ones to prioritize. Governments and regulatory bodies must design effective policy tools to develop the green bond market. Clarification of critical factors ensures that practices such as tax incentives and legal regulations are more efficient. The green bond market is still a developing area in many countries and contains uncertainty. Identifying critical factors contributes to reducing this uncertainty by increasing market confidence.

There are not enough studies in the literature to determine which variables have the most critical effects on the development of green bonds. The development of green bonds depends not on a single factor but on multiple factors. However, a healthy analysis becomes difficult without making a comparative prioritization among these factors. Closing this gap brings a new methodological approach and strategic insight to the literature. To eliminate this deficiency, this study evaluates the factors affecting the development of green bonds. In this process, annual data for the emerging seven (E7) countries in the period 2000-2021 are analyzed. An econometric analysis is performed using the instrumental variables two-stage least squares (IV-2SLS) technique. Studies on determining the factors affecting the development of green bonds

are limited. This situation leads to a lack of guiding information and makes it difficult to develop strategic policies. In this context, there is no consensus in the literature on which strategies should be implemented as a priority. This deficiency can be considered as the most basic motivation of this study. Determining which factors are more critical allows public and private sector resources to be directed more efficiently. This situation includes the motivation to guide decision makers in the design of political instruments. Hence, this study tries to find the appropriate answers for the following research questions.

- (1) What are the main factors affecting the development of green bonds?
- (2) How do carbon emission reductions, renewable energy investments and R&D studies affect the development of green bonds?
- (3) According to the data for the period 2000–2021 in E7 countries, are there significant causal relationships between the factors supporting the development of green bonds?

Although the title of the study refers to “smart technologies”, the empirical model does not include direct indicators of digital or smart technology applications. Instead, R&D expenditure and patent applications are used as proxies for innovation capacity, which indirectly reflects the technological foundations that enable the development and diffusion of smart technologies in emerging economies. Renewable electricity output is included as an indicator of the adoption of technologically advanced clean-energy systems, which are a central component of smart and sustainable energy transitions. While these variables do not measure smart technologies in a narrow sense, they capture the technological capability and energy-transition dynamics that underpin smart-technology development in the E7 countries.

The main contributions of this study to the literature are demonstrated below. (1) The most critical variables affecting the development of green bonds have been prioritized. In the literature, only relationship determination is usually made. However, it is not determined which variable is relatively more effective. This study provides a concrete contribution to guide policy and investment decisions by determining the priority level of the factors. (2) The use of the instrumental variables two stage least squares technique in the study also has some advantages. This technique makes it possible to test the causality relationship statistically. This situation contributes significantly to the results being more reliable. Since the causal relationships are determined, the strategic recommendations to be developed based on the results of the study

become stronger. (3) The issue of green bonds is extremely important for the E7 countries. The E7 countries account for a significant portion of total global carbon emissions. Therefore, sustainable projects are of critical importance to these countries. On the other hand, the E7 countries need large-scale investments in renewable energy projects. To finance these investments sustainably, it is necessary to turn to instruments such as green bonds.

This study makes a distinct contribution to the empirical literature on the determinants of green bond development. Existing studies primarily examine specific drivers such as carbon emissions, renewable energy investments, financial development, or policy instruments, yet they rarely offer a comparative assessment of which factors are relatively more influential at the country level. Moreover, most analyses focus on advanced economies or global markets, whereas empirical evidence for emerging economies remains limited. By concentrating on the E7 countries, this study provides new insights for a group of economies that play a critical role in global emissions and green finance needs. Another novelty is the prioritization of key determinants, allowing a clearer understanding of their relative importance for strategic policy formation. Finally, the use of an instrumental variables two-stage least squares approach introduces a causal perspective that is largely absent from prior empirical works. Together, these contributions clarify the position of the study within the existing literature and address the previously overstated claims about the research gap.

The organization of this manuscript is given as follows. The research gap in the green bond literature is explained in the second part. The third section includes the steps of the instrumental variables two stage least squares technique. The next section focuses on the findings of this analysis. The fifth section gives information about the discussing of these findings. The final section demonstrates the main concluding issues.

2 LITERATURE REVIEW

2.1 THE IMPORTANCE OF GREEN BONDS FOR ENVIRONMENT-FRIENDLY INVESTMENTS

Renewable energy projects are studies that aim to produce energy obtained from sources that constantly renew themselves in nature. In this process, sunlight, wind speed, stream flow and steam from hot waters underground are used to produce electricity (Khalili et al., 2025). This allows carbon gas not to be released into the atmosphere while energy is being produced. In other words, the biggest advantage of renewable energy projects is that they do not cause

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environmental pollution like fossil fuels. Thus, energy can be produced, and this situation does not cause problems in human health (Solangi and Magazzino, 2025). By reducing carbon emissions caused by fossil fuels, the problem of climate change can be combated much more successfully. Another advantage of renewable energy projects is that countries can produce their own energy. This situation reduces countries' dependence on foreign sources for energy. With the help of this issue, it is possible for countries to ensure their energy security. Thus, political problems experienced with other countries do not prevent countries from supplying energy. Renewable energy projects are especially necessary today (Wei et al., 2025). There can be many different reasons for this situation. First, fossil fuel reserves are depleting. Due to this situation, there is a risk of not being able to obtain energy from these fuels after a certain period. On the other hand, problems such as global warming and environmental pollution are increasing radically. It is accepted that the most fundamental source of these problems is fossil fuel-based energy production (Bashir et al., 2025). Therefore, these problems can be combated more successfully with the use of clean energy. In addition to them, energy demand is constantly increasing. Therefore, turning to sustainable and clean energy sources is no longer a choice, but a necessity.

Research and development studies are both necessary and very important for the development of renewable energy projects. The biggest disadvantage of these projects is that they are negatively affected by climatic differences. These differences sometimes cause interruptions in energy production. This situation is a very important problem especially for industrial manufacturers (Doğan et al., 2025). To combat this problem effectively, energy storage projects need to be developed. On the other hand, the realization of energy storage investments causes new costs. Therefore, the necessary actions need to be taken to ensure the effectiveness and efficiency of these projects (Dai et al., 2025). In this process, the realization of research and development studies is of critical importance. Thanks to these studies, it is possible to reduce the costs of energy storage projects. This supports the increase in the financial performance of the projects. Moreover, more energy can be stored with research and development studies. Increasing the capacity of the stored energy allows the effectiveness of the projects (Xie and Lin, 2025). This helps to increase the income of the projects. Furthermore, another disadvantage of renewable energy projects is that the initial costs are very high. This situation makes investors nervous, and this allows for investments to be reduced (Zhang et al., 2025). Research and development studies also contribute to reducing the cost of obtaining renewable energy. Thus,

it is possible to ensure the cost effectiveness of projects. This situation allows investors to increase their interest in projects.

To develop renewable energy projects, it is necessary to develop sustainable financing instruments such as green bonds. Green bonds are debt instruments issued to finance projects that provide environmental benefits (Behera et al., 2025). Renewable energy plants and projects aimed at reducing carbon emissions can be financed with these bonds. Renewable energy projects have high initial costs. Green bonds help direct investors' capital to these projects. One of the biggest advantages of these bonds is that their costs are low (Lin and Zhang, 2025). Therefore, it is possible to ensure the cost effectiveness of projects by using these bonds. Moreover, green bonds are subject to certain environmental standards and are audited. In this way, transparency increases, and investor confidence is ensured. On the other hand, a very high amount of funds is needed to realize renewable energy projects (Bampaou and Panopoulos, 2025). In this process, green bonds provide the necessary long-term resources for renewable projects. Therefore, they are financial instruments that play a key role in the development of renewable energy projects. The long-term nature of these bonds is also a critical advantage. Green energy projects have a very long-term return (Oladapo et al., 2025). Therefore, there is a critical need for such financial products to ensure effective financing of such projects.

2.2 KEY INDICATORS OF GREEN BOND IMPROVEMENTS

The phenomenon of carbon emissions makes a significant contribution to the development of green bonds. High carbon emissions can cause significant environmental pollution. This is a factor that threatens human health. Therefore, some actions need to be taken to reduce this problem. Guesmi et al. (2025) highlighted that fossil fuel use is considered the main cause of global warming. This situation increases the demand for projects financed with environmental solutions such as renewable energy. According to Muchiri et al. (2025), green bonds become one of the basic tools in financing these projects. On the other hand, increasing emissions force states to develop certain projects. These policies direct companies to environmental investments. Křístková et al. (2025) reached a conclusion that green bond issuance increases for the financing of these investments. Moreover, global agreements such as the Paris Agreement and the European Green Deal make it mandatory to reduce carbon emissions (Pata et al., 2025). In line with these agreements, both the public and private sectors are forced to

make large-scale green investments. Green bonds can be increasingly preferred for the financing of these investments (Shah, Murodova, & Khan, 2025).

Renewable energy investments are an important variable for the development of green bonds. Renewable energy projects are the most common area of use of green bonds. This situation causes renewable energy investments to play a locomotive role in the growth of the green bond market (Sreenu, 2025). Renewable energy projects usually have high initial investment costs. Green bonds meet the financing needs of these investments. Thus, they make it easier for investors and energy companies to focus on renewable projects (Naifar, 2025). On the other hand, renewable energy projects need to be developed to achieve carbon emission reduction targets. This situation also causes an increase in green bond issuance (Chai et al., 2025). Moreover, Zeng et al. (2025) underlined that renewable energy projects are becoming quite popular both environmentally and economically. Businesses can also show more interest in these projects to improve their image in the market positively. This situation also allows the demand for green bonds to increase. Furthermore, Aloui et al. (2025) determined that government incentives also enable the development of these projects. As governments encourage renewable energy investments, more projects can be created. The increase in projects increases the financing needs of these projects and creates demand for green bonds.

Research and development (R&D) studies contribute significantly to the development of green bonds. These studies improve green project production. New technologies can be obtained through R&D (Li et al., 2025). These bonds are needed to develop projects such as low-cost energy storage systems. Thanks to R&D studies, the environmental impacts of projects become more clearly measurable. This can significantly increase investors' interest in these projects. This increases the transparency of green bond investments (Kumar et al., 2025). On the other hand, these studies also provide cost efficiency in green projects. R&D offers solutions that reduce costs and increase applicability (Azad and Devi, 2025). In this way, projects to be funded with green bonds become more applicable and profitable. Moreover, K. Wu et al. (2025) underlined that the technological breakthroughs required to achieve zero carbon targets are made possible by R&D. Huo et al. (2025) identified that green bond financing plays a critical role for projects based on these technologies. Therefore, R&D development increases the strategic importance of the green bond market.

Recent empirical studies highlight several key determinants of green bond development that align with the variables considered in this study. Research shows that carbon emissions play a central role in shaping green financing needs, as countries facing higher environmental pressure tend to issue more green bonds to support mitigation and transition strategies. Prior evidence also indicates that renewable energy expansion is one of the main sectors driving green bond issuance, reflecting the large capital requirements and long-term financing structures of clean energy projects. Furthermore, innovation-related indicators such as R&D expenditure and patent activity have been linked to green technology deployment, although their empirical effects on green bond markets vary across countries depending on the composition and direction of R&D investments. These findings provide the conceptual basis for selecting CO₂ emissions, renewable electricity, and innovation variables as determinants in our empirical model and motivate the expectation that they influence green bond development in the E7 economies.

Although numerous studies have examined individual drivers of green bond development—such as carbon emissions, renewable energy expansion, or innovation indicators—the existing literature provides limited comparative evidence on the relative importance of these factors. Most prior contributions analyze one determinant in isolation or focus on bivariate relationships, offering little guidance on how these variables jointly shape green bond markets in emerging economies. As a result, the literature lacks a coherent synthesis that clarifies which determinants are consistently more influential and under what conditions their effects strengthen or weaken. This absence of comparative and causally oriented evidence creates uncertainty for policymakers who must prioritize among multiple competing drivers. By addressing this gap, the present study provides a systematic evaluation of key determinants using E7 data and offers insight into their relative importance for the development of green bond markets.

3 METHODOLOGY

3.1 DATA AND VARIABLE DEFINITIONS

To ensure transparency and replicability, this subsection provides a detailed description of all variables used in the empirical analysis, including their definitions, data sources, measurement units, and transformations. Green bond development is proxied by public and publicly guaranteed (PPG) bonds (net flows, current US dollars), obtained from the World Development Indicators (WDI) (World Bank, 2025). Although this variable does not capture green bonds at

the individual issuance level, it reflects the scale of long-term bond-based public financing available for environmentally oriented projects at the country level. In the context of emerging economies, green bond markets are closely embedded within broader sovereign and publicly supported debt markets, as governments often act as issuers, guarantors, or anchor participants in green bond frameworks. Therefore, PPG bond flows are used as a macro-level proxy for green bond development, capturing the financing capacity that supports large-scale green and sustainability-related investments.

Research and development (R&D) expenditure is measured as a percentage of GDP and sourced from the WDI. This variable captures national innovation capacity and technological investment intensity, which form the foundation for developing and deploying green and smart technologies. Patent applications by residents are used as an output-based indicator of innovation activity and technological diffusion, reflecting the commercialization and applicability of innovative outcomes. Carbon dioxide (CO₂) emissions excluding land use, land-use change, and forestry (LULUCF) are measured in metric tons per capita and sourced from the WDI. This variable represents environmental pressure and serves as a key driver of demand for green financing instruments, as higher emissions increase regulatory, social, and financial incentives for green investment.

Renewable electricity output is measured as a percentage of total electricity generation and obtained from the WDI. This indicator captures the extent to which clean and technologically advanced energy systems are integrated into national energy structures, representing a primary use-of-proceeds category for green bond financing. All monetary values are expressed in current US dollars. No deflation was applied, as the empirical strategy focuses on cross-country variation rather than real intertemporal comparisons. To reduce potential scale effects and ensure robustness, additional estimations using logarithmic transformations and exclusion-based specifications were conducted, yielding consistent results. The chosen variables jointly operationalize the technological, environmental, and financing dimensions required to address the research question on green bond development in E7 economies.

3.2 INSTRUMENTAL VARIABLES – TWO-STAGE LEAST SQUARES METHODOLOGY

IV-2SLS (Instrumental Variables - Two-Stage Least Squares) method is one of the linear regression analyses encountered with endogenous problems. Endogenousness is a problem

encountered when independent variables are related to the error term. This problem causes biased estimates (Ailer et al., 2025). IV-2SLS uses mediating variables (instrumental variables) to solve this problem. These variables are related to the independent variables and have no relationship with the error term. In the first stage of the two-stage least squares (2SLS) method, the relationship between the independent variable and the instrumental variable is determined. In the second stage, the estimate of the dependent variable is analyzed (Rafique et al., 2025).

A linear equation model is created as Equation (1).

$$Y = XB + \varepsilon \quad (1)$$

Wherein Y is dependent variable and X is independent variables. In addition, B is coefficients of regression and ε is error term. However, the relationship between X and ε is significant. In this situation, IV-2SLS model is constructed. In the first stage of this model, the instrumental variable (Z) is used. For this, the relationship of X and Z is examined using Equation (2) (Fang et al., 2025).

$$X = ZC + u \quad (2)$$

Wherein Z can explain X but is not related to the error term (ε). u is the error term of Equation (2). C are the regression coefficients of the experimental variable. After that, the second stage is applied. The new linear model is constructed as Equation (3).

$$Y = \hat{X}B + v \quad (3)$$

Wherein $\hat{X}$ are the estimated values obtained in the first stage. v is the error term of second stage. Finally, the coefficients are obtained using Equation (4) (Luo and Wu, 2025).

$$\hat{B}_{IV} = \left(X' \hat{Z} (\hat{Z}' \hat{Z})^{-1} \hat{Z}' X \right)^{-1} X' \hat{Z} (\hat{Z}' \hat{Z})^{-1} \hat{Z}' Y \quad (4)$$

Wherein $\hat{Z}$ are the estimated values of the instrumental variables. X' is the transpose of X . In the empirical specification of this study, the dependent variable in Equations (1)–(4) corresponds to the green bond variable (Green Bonds), while the regressors X represent R&D expenditure, patent applications (PA), CO₂ emissions per capita, and renewable electricity output (RE). Among these regressors, R&D and PA are treated as potentially endogenous because innovation-related variables may simultaneously influence and be influenced by green bond issuance through feedback mechanisms between technological capacity and green

financing. To address this endogeneity, the study employs lagged values of R&D and PA as instrumental variables. These instruments satisfy the relevance condition because past innovation performance is strongly correlated with current innovation indicators, and they satisfy the exogeneity condition because past values are unlikely to be directly affected by contemporaneous shocks to green bond issuance in the E7 economies. CO₂ emissions and renewable electricity output are treated as exogenous, as their variation is largely driven by long-term structural and environmental policies rather than short-term financing dynamics. In this context, Equation (2) models the first-stage relationship between each endogenous regressor (R&D and PA) and its instrument, while Equation (3) uses the fitted values obtained from these first stages to estimate their causal effect on Bonds. The selection between fixed and random effects using the Hausman test ensures an appropriate panel structure before implementing IV-2SLS, and the ADF tests confirm the stationarity properties of the variables to avoid spurious results. These steps collectively justify the econometric specification adopted in the final IV-2SLS model.

4 ANALYSIS

The results of the analysis on the relationship between green bonds and the technological and sustainability dynamics of the E7 economies are presented in this section. In this framework, research and development expenditure (% of GDP) and patent applications are employed as indicators of innovation capacity and the diffusion of smart technologies. Carbon dioxide (CO₂) emissions excluding LULUCF per capita capture environmental pressures that shape countries' transition needs and influence their sustainable competitiveness. Renewable electricity output (% of total electricity output) reflects the adoption of cleaner and technologically advanced energy systems. Public and publicly guaranteed (PPG) bonds (NFL, current US\$) are used as the outcome variable, representing the scale of green bond development. The dataset consists of annual observations for the E7 countries covering the period 2000–2021.

The dataset used in this study is compiled from internationally recognized and publicly accessible statistical sources. R&D expenditure (% of GDP), patent applications by residents, CO₂ emissions per capita, and renewable electricity output (% of total electricity generation) are obtained from the World Bank World Development Indicators (WDI). The dependent variable, public and publicly guaranteed (PPG) bonds (NFL), is also sourced from the WDI database and reported in current US dollars. No deflation was applied, as all analyses rely on

cross-country variations rather than intertemporal real-value comparisons. As a robustness check, we re-estimated the model using the logarithmic transformation of the dependent variable as well as an alternative exclusion-based specification in which each E7 country was removed one at a time. The direction and significance of the key coefficients remained generally consistent across these alternative specifications, indicating that the main findings are not sensitive to basic changes in model structure or sample composition. The data is collected from the World Bank's website. Descriptive statistics for all variables are summarized in Table 1.

Tab. 1 – Descriptive statistics. Source: own research

	Mean	Standard Deviations	Min	Max
R&D	.978	.475	.27	2.43
PA	102799.59	298101.355	277	142664
Green Bonds	5967627023	13202410590	-16846033000	72778141000
CO2	5.11	3.68	.94	13.53
RE	3.01	2.442	1.152	8.9496

The correlation coefficients between these variables are estimated and exhibited in Table 2.

Tab. 2 – Correlation matrix. Source: own research

	R&D	PA	Green Bonds	CO2	RE
R&D	1.000				
PA	0.758	1.000			
Green Bonds	0.353	0.688	1.000		
CO2	0.391	0.262	0.114	1.000	
RE	0.208	-0.082	-0.134	-0.322	1.000

According to correlation matrix, the bonds are correlated with other variables at 95% confidence level ($p < .05$). The stationarity of the variables is checked on a country basis with ADF. The p-values of ADF tests according to levels are shared in Table 3.

Tab. 3 – ADF tests. Source: own research

	R&D		PA		CO2		RE		Green Bonds	
	Level 0	Level 1	Level 0	Level 1	Level 0	Level 1	Level 0	Level 1	Level 0	Level 1
China	.962	.001	.820	.000	.479	.018	.636	.000	.569	.010
India	.874	.000	1.000	.040	.011		.435	.009	.271	.009
Brazil	.000		.995	.030	.256	.014	.338	.010	.053	.000
Mexico	.157	.008	.000		1.000	.045	1.000	.000	.781	.000

	R&D		PA		CO2		RE		Green Bonds	
Russia	.681	.007	.752	.001	.540	.000	.000		.008	
Turkey	.999	.001	.998	.001	.905	.037	.988	.001	.999	.034
Indonesia	.020		.072	.000	.001		.088	.000	.000	

According to p-values in Table 3, these variables are stationary at different levels according to country group. Next, the Hausman test is applied to determine a choice between fixed and random effects models. The effect's results are illustrated in Table 4.

Tab. 4 – Fixed and random effects. Source: own research

	Fixed Effects	Random Effects
R2	.4769	.5416
R2 (Within)	.4769	.4439
R2 (Between)	.1588	.9548
R2 (Overall)	.4152	.5416
F-stat	27.352	36.921
P-value	.0000	.0000

At the same time, the coefficients and standardized coefficients of the models are expressed in Table 5.

Tab. 5 – Model parameters. Source: own research

	Fixed Effects		Random Effects	
Const.	1.92E+09	.2089	1.19E+10	4.9015
R&D	1.69E+09	.2394	-1.26E+10	-3.8169
PA	3.83E+04	6.2098	4.53E+04	9.8598
CO2	-3.39E+08	-.1789	1.37E+08	.4983
RE	8.07E+06	.0349	3.25E+07	.7673

In this situation, the Hausman test statistics and p value are displayed in Table 6.

Tab. 6 – Hausman test results. Source: own research

	Values
Test	1.1987
P	.0698

As can be seen in Table 6, since the p value is higher than .05, the random effects model is selected. Thus, the IV-2SLS model is created. IV-2SLS estimation summary is shown in Table 7.

Tab. 7 – IV-2SLS estimation summary. Source: own research

Dep. Variable	Green Bonds
Estimator	IV-2SLS
Cov. Estimator	Robust
R-Squared	.5497
Adj. R-Squared	.5346
F-Statistic	49.284
P-value (F-Stat)	.0000

The independent variables explain about 55% of the bonds. Moreover, according to the F statistic value, the model is significant at 95% confidence level ($F=49.284$; $p<.05$). VIF values of independent variables are examined and the values in question are shown in Table 8.

Tab. 8 – VIF values. Source: own research

	VIF
R&D	3.801
PA	2.945
CO2	1.600
RE	1.638

As can be seen VIF values in Table 8, there is no multicollinearity problem. Later, model parameters are examined. Model parameter estimates are illustrated in Table 9.

Tab. 9 – IV-2SLS parameter estimates. Source: own research

	Parameter	Std. Err.	t-stat	p-value	Lower CI	Upper CI
R&D	-3.47E+09	2.34E+09	-1.4865	.1371	-8.05E+09	1.11E+09
PA	3.50E+04	7.29E+03	4.7952	.000	2.07E+04	4.93E+04
CO2	4.96E+08	2.38E+08	2.0863	.037	3.00E+07	9.61E+08
RE	6.41E+07	3.27E+07	1.9599	.05	-2.53E+03	1.28E+08

When the coefficients are examined, the coefficients of PA, CO2 and RE are significant at the 95% confidence level, while the coefficient of R&D is not statistically significant. In other words, as patents increase, the bond value of E7 countries increases. This may indicate that innovation is supported by financing. In addition, increasing CO2 emissions increases the bond value for E7 countries. This may be due to the high infrastructure/energy investment. Beyond statistical significance, the economic interpretation of the coefficients offers additional insights into the dynamics of green bond development in the E7 countries. The negative and statistically

insignificant coefficient of R&D suggests that increases in research and development expenditure do not immediately translate into higher green bond issuance. This may be due to the long-term and uncertain nature of R&D investments, where financial returns and technological outcomes materialize only after considerable time lags. Moreover, in emerging economies, a substantial portion of R&D spending may not directly target green technologies, which could weaken its short-run association with green bond financing. The borderline significance of renewable electricity output also reflects structural characteristics of the E7 energy landscape. Although renewable capacity is expanding, renewable projects often rely on alternative financing channels such as public subsidies or bilateral agreements, reducing their direct dependence on green bond markets. The positive and significant coefficient of CO₂ emissions aligns with the expectation that higher environmental pressure increases the urgency of green financing. Countries facing rising emissions may issue more green bonds as part of broader sustainability commitments or in response to regulatory and international pressures. These interpretations enrich the empirical findings by linking statistical outcomes to the underlying economic mechanisms shaping green bond development. Finally, renewable energy investments also have a positive effect. However, the significance level of RE is borderline. Tests are applied for instrumental variable validity and power. The test results are summarized in Table 10.

Tab. 10 – Instrument validity and strength tests. Source: own research

	Statistic	P
Hansen's J Test	3.57	0.124
Weak Instrument F (First Stage)	17.86	-
Under Identification (LM Stat.)	8.12	0.003

According to Table 10, instrumental variables are valid and there is no weak problem. Moreover, model defined, instrumental valid.

5 DISCUSSION

The carbon emission problem positively affects the increase in green bonds. This problem has become very dangerous especially in recent years. This situation causes the environmental problem to increase significantly. This problem also leads to environmental problems such as global warming and climate change. This situation also seriously threatens economic stability and social life. Ma et al. (2025) defined that carbon emission deepens environmental risks and

increases the need for sustainable investments. This increasing need also encourages the development of green bonds. This result is parallel to the Environmental Kuznets Curve hypothesis in the literature (Lau et al., 2025). According to this hypothesis, environmental degradation increases in the early stages of economic growth. On the other hand, environmental awareness increases after a certain level. This situation also contributes to the reduction of the environmental degradation problem. In this study, the effect of carbon emission on the development of green bonds shows that this sensitivity increases. J. Wu et al. (2025) denoted that green bonds are becoming a strategic tool for financing environmentally friendly projects. Furthermore, the risk of carbon-intensive projects damaging corporate reputation is increasing today. Dian et al. (2025) demonstrated that businesses that want to get rid of negative perception also need environmentally friendly investments. This situation also supports the increase in demand for green bonds.

Renewable energy projects also affect the increase in green bonds. These projects play a key role in achieving sustainable development goals. These projects allow the reduction of carbon emissions caused by energy production. In addition to this issue, Hassan et al. (2024) underlined that countries can produce their own energy with these investments. This situation contributes significantly to the security of energy supply. This strategic orientation towards renewable energy has also created serious financing needs. The main reason for this is that the initial investment costs of these projects are very high. Estevão and Lopes (2024) discussed that green bonds stand out as an important tool in financing renewable energy investments. Renewable energy projects provide a suitable basis for bond-based financing models. Therefore, the Khan et al. (2024) determined that financing need for renewable energy investments also increases the demand for green bonds. In other words, the targets for increasing renewable energy capacity create a large market for green bonds. This situation reveals a two-way interaction between renewable energy projects and green bonds. Furthermore, according to Opoku et al. (2024), renewable energy projects also make positive contributions in terms of investor confidence. This reduces investors' risk perception and increases the volume of green bonds traded in the market.

Although the literature frequently emphasizes the importance of R&D for green finance and technological transition, the empirical results indicate that R&D expenditure does not exert a statistically significant effect on green bond development in the E7 countries. This finding suggests that aggregate R&D spending may not directly translate into green bond issuance,

particularly in emerging economies where R&D activities are often concentrated in sectors unrelated to environmental or low-carbon technologies. In addition, the benefits of R&D investments typically materialize over longer time horizons, which may weaken their short-run association with green bond markets in a panel framework. Institutional constraints, limited commercialization of research outcomes, and the absence of targeted green innovation policies may further reduce the immediate relevance of R&D expenditure for green bond financing. Therefore, the insignificant coefficient does not contradict the theoretical importance of innovation but rather highlights structural and temporal limitations in the R&D–green finance linkage within the E7 context.

6 CONCLUSION

This study tries to evaluate the factors affecting the development of green bonds. An econometric analysis is created using the annual data of the E7 countries for the period 2000–2021. The instrumental variable two stage least squares technique is taken into consideration to test the relationships more reliably. It is concluded that the carbon emission problem positively affects the increase in green bonds. Moreover, there is also a positive correlation between renewable energy projects and green bond improvements. It is recommended that governments implement incentive mechanisms such as tax reductions, develop independent auditing and ethical reporting standards, and ensure macroeconomic stability. The main contribution of this study is that the most critical variables affecting the development of green bonds have been prioritized. Moreover, considering the instrumental variable two stage least squares technique makes it possible to test the causality relationship statistically. Hence, more reliable results can be achieved.

Based on the empirical findings, the policy implications should focus on the specific determinants identified in the analysis rather than general macroeconomic recommendations. The positive and significant effect of patent activity suggests that policies which strengthen innovation ecosystems—such as supporting applied green technology research, improving patenting processes, and facilitating technology transfer—are likely to enhance green bond market development in the E7 economies. The positive association between CO₂ emissions and green bond issuance indicates that governments facing rising environmental pressures may strategically use green bonds as a financing tool for mitigation and transition projects. Therefore, the design of credible emission-reduction pathways, accompanied by transparent project pipelines, can further stimulate demand for green finance instruments. The borderline

significance of renewable electricity output implies that green bond markets can be strengthened by improving the financial structuring and bankability of renewable energy projects, including standardized reporting frameworks and clearer eligibility criteria for green investments. These recommendations are directly grounded in the empirical outcomes of the study and provide more targeted guidance for policymakers in emerging economies.

The analysis with annual data for the period 2000–2021 is one of the most important limitations of this study. A new analysis can be performed using a wider data set in future studies. This contributes to the results being more reliable. Another limitation is that the analysis was performed only for the E7 countries in the study. Comparative analysis of groups with different development levels can be a suggestion for future studies. On the other hand, the study focused on macroeconomic variables at the country level. This can also be considered as an important limitation for the study. Micro-level analyses such as investor behavior and sector-based demands can be taken into consideration for future studies. Since econometric analysis was performed in this study, variables without numerical data could not be used. This situation can prevent reaching the right strategies. Therefore, a multi-criteria decision-making model can be established for future studies. Owing to this issue, the effects of variables without numerical data can also be analyzed.

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