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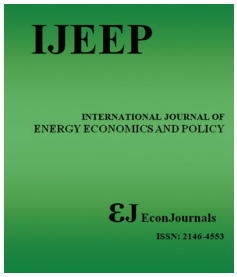

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The Role of Green Bonds in Financing Sustainable Energy Projects: Trends and Prospect

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ABSTRACT

This study investigates the determinants of green bond issuance across multiple countries from 2017 to 2023, with a panel data analysis approach. The analysis focuses on the impact of interest rates, renewable energy capacity, carbon emission reduction, and GDP on green bond issuance. To determine the long-run equilibrium relationship among these variables, the Pedroni co-integration test was employed. The results confirmed the presence of co-integration, validating the use of Panel Dynamic OLS (DOLS) for estimating the long-run coefficients. DOLS, which includes leads and lags of the differenced independent variables, were utilized to account for potential endogeneity and serial correlation, providing robust estimates. The findings indicate that higher interest rates are associated with lower green bond issuance, while greater renewable energy capacity and higher GDP positively correlated with increased green bond issuance. Carbon emission reduction shows a negative relationship, suggesting a saturation effect in countries with significant existing reductions.

Keywords: Green Bonds, Panel Data Analysis, Fixed Effects Model, Sustainable Finance, Renewable Energy
JEL Classifications: G12, G15, Q56, C23

1. INTRODUCTION

Green bonds have emerged as a vital financial instrument in addressing environmental challenges and promoting sustainable development. These bonds specifically designed to fund projects that have positive environmental benefits, such as renewable energy, energy efficiency, and pollution prevention. The global market for green bonds has grown substantially over the past decade, driven by increasing awareness of environmental issues and the need for significant investments to meet climate goals (Flammer, 2021). As countries strive to achieve their commitments under the Paris Agreement, green bonds offer a viable solution for mobilizing the necessary capital for green projects (Tolliver et al., 2019, s. 064009). The issuance of green bonds influenced by various economic and environmental factors. Interest rates, for instance, play a crucial role in determining the cost of borrowing and, consequently, the attractiveness of issuing green bonds (Zerbib, 2019). Similarly, the capacity of renewable energy infrastructure can significantly impact the volume of green bonds issued, as larger capacities often require substantial financing (Ehlers and Packer, 2017). Additionally, efforts to reduce carbon emissions closely linked to the issuance of green bonds, as these bonds frequently used to finance projects aimed at lowering greenhouse gas emissions (OECD, 2020). Understanding the interplay of these factors is essential for policymakers and investors seeking to promote green finance and sustainable development. This study aims to explore the determinants of green bond issuance amounts across multiple countries from 2017 to 2023, using panel data analysis approach. The research examines the impact of interest rates, renewable energy capacity, carbon emission reduction, and GDP on green bond issuance. The fixed effects model employed to control for unobserved heterogeneity, based on the results of the Hausman test. The paper organized as follows: Section 2 reviews the relevant literature on

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green bonds and their determinants. Section 3 describes the data and methodology used in the analysis. Section 4 presents the empirical results and discusses their implications. Finally, Section 5 concludes the study and offers policy recommendations.

This study significantly advances the literature on green finance by identifying the key determinants of green bond issuance across multiple countries from 2017 to 2023. By employing the Pedroni co-integration test and panel dynamic OLS (DOLS), the research addresses potential endogeneity and serial correlation, providing robust and reliable results. The findings reveal that higher interest rates negatively affect green bond issuance, while increased renewable energy capacity and GDP positively influence it. The negative relationship between carbon emission reduction and green bond issuance suggests a saturation effect in countries with significant existing reductions. This study's methodological contributions and practical insights for policymakers, investors, and financial institutions enhance our understanding of green bond markets and support the development of effective policies and strategies for promoting sustainable finance.

2. CONCEPTUAL FRAMEWORK

The issuance of green bonds influenced by a complex interplay of economic and environmental factors. Understanding these determinants is crucial for policymakers and investors aiming to promote green finance. This section presents a conceptual framework that identifies and explains the key factors affecting green bond issuance: interest rates, renewable energy capacity, carbon emission reduction, and GDP. Interest rates are a fundamental economic variable influencing the cost of borrowing. Lower interest rates reduce the cost of financing, making it more attractive for issuers to float green bonds. Conversely, higher interest rates increase borrowing costs, potentially dampening green bond issuance. Empirical evidence suggests that interest rates significantly affect bond prices and yields, influencing investment decisions in the green bond market (Zerbib, 2019). Hence, hypothesized that higher interest rates are associated with lower green bond issuance amounts. The capacity of renewable energy infrastructure represents a critical factor in the issuance of green bonds. Projects requiring substantial capital investments, such as solar farms, wind turbines, and hydroelectric plants, often seek funding through green bonds.

The expansion of renewable energy capacity necessitates significant financial resources mobilized through green bonds (Ehlers and Packer, 2017). Therefore, an increase in renewable energy capacity expected to positive correlation with higher green bond issuance. Efforts to mitigate climate change through carbon emission reduction closely linked to the green bond market. Green bonds frequently issued to finance projects aimed at reducing greenhouse gas emissions, such as energy efficiency upgrades, clean transportation, and sustainable waste management (OECD, 2020). As countries implement stricter emission reduction targets, the demand for green financing instruments like green bonds is likely to increase. It is posited that greater carbon emission reductions will lead to higher green bond issuance amounts. The gross domestic product (GDP) of a country or region serves as an indicator of its economic health and capacity to undertake large-scale projects. Higher GDP levels reflect greater economic resources and stability, enabling governments and corporations to invest in sustainable projects through green bonds (Flammer, 2021). Although the relationship between GDP and green bond issuance is not always straightforward, generally hypothesized that higher GDP is associated with increased green bond issuance, given the availability of more financial resources for green investments.

3. LITERATURE REVIEW

When we look at the literature on the subject, it can be seen that very interesting studies have been carried out both in the country and abroad in recent years. As Berensman (2017) put it, banking system assets play an important role in the international financial system as they represent the shares of global financial assets. In states with positive market conditions and developing economies, there are established systems and criteria to activate the green finance system and sustainable development and to popularize green finance. Some of these measures and systems include priority lending requirements and ways to obtain below-market financing through interest rate subsidies. Although banks are vulnerable to the risk of misdirection of financial resources due to this system, they have an important share in green financing (Berensman, 2017).

Aw et al. (2017) define the concept of sustainable funds as "*a set of criteria used to evaluate the activities of investee companies from governance, environmental and social impact perspectives*." According to the author, social responsibility investments are "an investment thesis that takes into account financial return and ethical behavior to bring about social and environmental change (Aw et al., 2017). International Investment Bank Morgan Stanley (2018) has collected information from officials in these organizations on trends, motivations, challenges and implementation approaches in sustainable investing, called "*Sustainable Signs*," covering 118 pension companies, public asset institutions, insurance and other large asset management companies worldwide. According to the results of this survey, 84% of investors are in search and tendency to invest in such environmental funds; In fact, 60% of these investors have invested in these funds in the last 4 years. According to the results, it is important for investors to be able to determine clear benefits for greater adoption of sustainable investment practices. Having meaningful data and the right tools accelerates this process and makes it permanent. According to the survey, the biggest challenges cited by asset owners include the availability of quality sustainability data (23%) and a lack of information about sustainable investing (16%). According to the conclusion of the report, more than three-quarters of asset owners not only invest in these funds; they now recognize that they have a responsibility to ensure global sustainability through their investments. However, they also consider risk and return as the driving forces behind their adoption of sustainability in this field (Morgan Stanley, 2018).

Flammer (2021) aimed to investigate the effectiveness of green bonds and their implications for public policy. The study focused

on whether green bonds contribute to improved environmental performance and influence investor behavior. Key variables included green bond issuance, environmental performance metrics (such as carbon emission reductions), financial performance indicators, and investor-related variables (e.g., stock prices and investor demand). The methodology employed a Difference-in-Differences (DiD) approach to compare firms that issued green bonds with those that did not, before and after the issuance, alongside fixed effects models and propensity score matching to ensure robustness (Flammer, 2021, s. 95-128). Findings indicated that firms issuing green bonds experienced significant improvements in environmental performance, particularly in reducing carbon emissions. Positive financial impacts, such as increased stock prices and higher investor demand, were also observed, suggesting that green bonds enhance market valuation and attract environmentally conscious investors. These findings underscore the role of green bonds in promoting corporate sustainability and influencing market dynamics. Tolliver et al. (2019) examined the role of green bonds in achieving the Paris agreement and sustainable development goals (SDGs), focusing on the environmental benefits of green bonds and their potential to mobilize capital for sustainable projects. Variables included green bond issuance amounts, environmental impact measures (such as carbon emission reductions and renewable energy capacity), and SDG-related indicators. The methodology involved a panel data analysis approach, using fixed effects and random effects models to account for unobserved heterogeneity across countries and over time. The study revealed that green bonds significantly contribute to financing projects that support the Paris Agreement and SDGs, highlighting a positive relationship between green bond issuance and environmental benefits like increased renewable energy capacity and reduced carbon emissions. These results suggest that green bonds are effective in mobilizing private capital towards achieving global climate and sustainability targets.

Zerbib (2019) investigated the effect of pro-environmental preferences on bond prices, specifically examining whether green bonds trade at a premium compared to conventional bonds. The study sought to understand the market valuation of green bonds and the extent to which investors are willing to pay a premium for environmentally friendly investments. Key variables included green bond prices, conventional bond prices, bond characteristics (e.g., maturity, credit rating), and market variables (e.g., interest rates, economic indicators). The methodology employed a matching method to compare green bonds with similar conventional bonds, controlling for bond-specific characteristics, followed by a regression model to estimate the premium for green bonds. The study found that green bonds trade at a premium, indicating investors' willingness to accept lower yields for bonds that contribute to environmental sustainability. This premium attributed to pro-environmental preferences among investors who value the environmental benefits associated with green bonds. Ehlers and Packer (2017) explored the financial structures and certification processes of green bonds, focusing on understanding the characteristics of green bond issuances and the role of certification in ensuring environmental integrity. Variables included green bond issuance amounts, financial structures (e.g., use of proceeds, bond tenure), certification status (certified vs. non-certified), and environmental performance indicators. The methodology involved a descriptive analysis of green bond issuances, comparing certified and non-certified green bonds, and a regression analysis to examine the impact of certification on bond pricing and investor demand. The study revealed that certification plays a crucial role in the green bond market by providing credibility and assurance to investors regarding the environmental benefits of the projects funded. Certified green bonds found to attract more investor interest and often achieved better pricing than non-certified bonds. Baker et al. (2018) aimed to analyze the pricing and performance of green bonds compared to conventional bonds. The study focused on understanding whether green bonds yield different returns than conventional bonds and how they perform in secondary markets. Key variables included green bond yields, conventional bond yields, bond characteristics (e.g., maturity, rating), and market conditions. The methodology used a regression analysis to compare the yields of green and conventional bonds while controlling for various bond-specific and market-specific factors. The findings indicated that green bonds tend to have slightly lower yields compared to conventional bonds, reflecting a green premium. The study also found that green bonds perform similarly to conventional bonds in secondary markets, suggesting that they are viable investment instruments without significant performance trade-offs (Baker et al., 2018).

Hachenberg and Schiereck (2018) investigated the determinants of green bond issuance and their impact on bond pricing. The study aimed to identify the key factors that influence the decision to issue green bonds and how these factors affect the pricing of green bonds. Key variables included issuer characteristics (e.g., size, industry, credit rating), bond characteristics (e.g., maturity, coupon rate), and market conditions. The methodology employed a logistic regression to identify the determinants of green bond issuance and an ordinary least squares (OLS) regression to analyze the impact of these determinants on bond pricing (Hachenberg and Schiereck, 2018, s. 371-383). The findings suggested that larger firms and those with higher credit ratings are more likely to issue green bonds. Additionally, green bonds found to be priced at a premium compared to conventional bonds, indicating a positive market perception of green bonds. Karpf and Mandel (2018) investigated the yield differences between green bonds and conventional bonds to understand if investors require a premium for green bonds. Key variables included bond yields, bond ratings, and issuer characteristics. The study utilized a matching method to pair green bonds with similar conventional bonds and conducted a regression analysis to compare their yields. The findings indicated that green bonds generally have lower yields than conventional bonds, suggesting a "*Greenium*" where investors are willing to accept lower returns for bonds that finance environmentally beneficial projects. This premium reflects the growing demand and positive perception of green bonds in financial markets (Karpf and Mandel, 2018, s. 161-165). Bachelet et al. (2019) examined the financial performance and volatility of green bonds compared to conventional bonds. The study focused on whether green bonds provide similar returns and exhibit different risk profiles. Key variables included bond returns, volatility measures, and market indices. The methodology involved a comparative analysis of green and conventional bonds using regression models and volatility

clustering techniques. The results showed that green bonds have comparable financial performance to conventional bonds, with no significant difference in returns. However, green bonds exhibited lower volatility, indicating a more stable investment profile, which can be attractive to risk-averse investors (Bachelet et al., 2019).

Tang and Zhang (2020) analyzed the impact of green bond issuance on firm performance, particularly focusing on environmental and financial outcomes. Variables included green bond issuance amounts, firm environmental scores, financial performance metrics (e.g., ROA, stock returns), and control variables such as firm size and industry. The study employed a panel data analysis with fixed effects models to control for unobserved heterogeneity. The findings indicated that firms issuing green bonds improved their environmental performance, as reflected in higher environmental scores, and experienced positive financial impacts, including increased stock returns and improved profitability. This study highlighted the dual benefits of green bonds for enhancing both environmental and financial performance (Tang and Zhang, 2020, s. 101427). Nanayakkara and Colombage (2019) investigated the role of green bonds in financing renewable energy projects and their impact on energy transition. Key variables included green bond issuance, renewable energy investments, and energy production metrics. The methodology involved a time-series analysis and co-integration techniques to assess the long-term relationship between green bond financing and renewable energy deployment. The study found that green bonds significantly contribute to the financing of renewable energy projects, leading to increased investments in solar, wind, and hydroelectric power. This positive impact supports the argument that green bonds are an effective tool for driving the global energy transition towards sustainable sources (Nanayakkara and Colombage, 2019, s. 4425-4437). Hyun et al. (2020) explored the determinants of green bond pricing and issuance, focusing on market liquidity and investor sentiment. The study included variables such as green bond yields, market liquidity measures, investor sentiment indices, and bond characteristics. The methodology utilized a mixed-effects regression model to analyze the pricing and issuance determinants. The findings suggested that green bond yields influenced by market liquidity and positive investor sentiment, with more liquid markets and favorable sentiment leading to lower yields. The study also found that green bonds tend to be issued more frequently in markets with higher liquidity and strong investor interest in sustainable investments (Hyun et al., 2020, s. 73-95).

In the studies on green bonds, different researches have been brought to the agenda in order to evaluate some religious sensitivities in the process. It is possible to include the interest-sensitive segments in the system in terms of bond issuances and financing of green projects. Thus, it may be possible to study this issue there and Morea and Poggi (2017) conducted a case study in Italy to demonstrate the importance of incentives in achieving grid parity. In this study evaluating the technical-energy-economic feasibility of wind energy systems. Based on the studies, it was suggested that the sukuk method, which complies with sharia, be used as an alternative tool to limit the degree of advantage in financing (Morea and Poggi, 2017, s. 53-60). Sukuk are financial certificates issued as a means of providing financing to governments and companies, offering investors interest-free fixed income. In their study, Kandır and Yakar (2017) detailed the characteristics of green bonds and examined the usability of green bonds in Turkey. He suggested creating the necessary market conditions and making legal regulations to finance Turkey's green projects, (Kandır and Yakar, 2017, s. 85-110). Keshminder et al. In the study conducted by, the green sukuk market in Malaysia was discussed. In the study, the authors suggested that green sukuk could be used in the construction industry as well as in the energy market. They said that the green sukuk market is small and has liquidity constraints, and that states can only overcome this by making regulations regarding the performance, risks and opportunities of green sukuk (Keshminder et al., 2019, s. 1-22). The article "*Green Is the Next Big Thing*" in the October 2007 issue of "Investing" magazine, written by Jeffrey R. Kosnett, points out that the increasing need for alternative energy and the increasing investments in this regard, green investment funds and green stocks developing. This have an increasing importance in the financial world and the issue of individual investors draws attention to his interest (Kosnett, 2007, s. 32-34).

In the article titled "*The Color of Money*" in the November 2021 issue of Engineering and Technology magazine, it is mentioned that investments in renewable energy are growing very strongly around the world. In this sense, wind farms, biofuel power plants etc. In this context investments in these fields increased from $50.3 billion to $84.5 billion in 2006, quadrupling their value in 2004. The article also says that increasing consumer demand for energy efficiency and green energy will drive more investment (Edwards, 2021, s. 1-4). The number of studies comparing the performance of socially responsible investments and traditional funds continues to increase. It is possible to predict that as climate and environmental awareness increases, the studies on this subject will deepen. In addition to the fact that the data sets and methods used in the research are different, the fact that they cover different regions causes different results to be obtained in the studies. In one of these studies, Amenc and Sourd (2008) examined the return performance of socially responsible investment funds in France between 2002 and 2006 by modeling them with the Fama-French triple factor. They claimed that the coefficients in the study took negative values and that both the short data period and the age of the funds were not old enough, causing the results obtained to be not statistically significant. According to the findings, it was seen that socially responsible investments did not perform well and had higher risks for the mentioned period (Amenc and Sourd, 2024). In their study, Ibikunle and Steffen (2015) compared the performance of 175 green funds and 259 traditional funds in Europe between 1991 and 2014. It was concluded that although green-themed funds showed lower performance in the entire period, they performed better than traditional funds between 2012 and 2014. They stated that they expect the performance of green funds to increase further in the coming periods (Ibikunle and Steffen, 2015, s. 337-355).

Camp (2018) in his study investigated the performance of social responsibility investment funds in 13 different countries compared to indices and similar traditional funds. No significant results have been obtained showing that socially responsible investment funds perform better in the short term or perform statistically worse or

similar in the long term (Camp, 2018). Yue et al. (2020) in their study, they analyzed the performances of 30 sustainable-themed funds and 30 traditional funds in Europe with annual return, Triple factor and Carhart model. They explained that the triple factor model was more appropriate in explaining the results. According to the findings, they stated that they could not access sufficient information about sustainable themed funds being less risky but performing better than both indicator indices and traditional funds. They stated that the increasing interest in sustainable funds may increase the risks of the funds in the coming periods (Yue et al., 2020, s. 8034). Okuyan and Deniz (2020) in their study examined the performance of socially responsible investments and traditional investments in Turkey using the XUSRD and XU100 market indexes. Based on the analysis using daily data for the 5-year period between 2014 and 2019, the findings obtained from the Sharpe and Treyner ratios of the XUSRD index showed that there is no difference between the performances of socially responsible and traditional investments in terms of risk-adjusted return in Turkey (Okuyan and Deniz, 2020, s. 2312-2320).

Saci et al. (2020) investigated the performance of socially responsible investments using daily returns of 64 funds in China between 2016 and 2019 to compare the performance of traditional funds. They stated that socially responsible investment funds are less risky compared to traditional investment funds, but there is no significant return difference. According to regression analysis, they stated that socially responsible investments have a positive return effect on the Chinese market (Saci et al., 2020, s. 1476). In the study conducted by Martí-Ballester (2021), due to the increasing interest of investors in China, the returns of stock investment funds were examined in line with the United Nations development goals in this region. The returns of 111 sustainable development themed stock investment funds were analyzed. In the study, the performances of the funds were investigated between 2009 and 2019 using the Jensen, Fama-French and Carhart's models. According to the results presented, sustainable development goals (SDG)-themed funds showed similar performance to the benchmark indices, the performance of energy investment funds was relatively low compared to other funds, and health-themed funds provided better returns. In the study, it was stated that the indicator indices in China are compatible with the American indicator indices (Martí-Ballester, 2021, s. 858-872). Some problems are revealed in studies conducted specifically in our country on the subject. Kuloğlu and Öncel (2012) mention that constraints such as insufficient purchase guarantees and electricity grid connection criteria that prevent the use of renewable energy in Turkey have a negative impact on green financing applications, and that regulations aimed at reducing the impact of such constraints will pave the way for green financing applications (Kuloğlu and Öncel, 2015, s. 46-49).

Ateş et al. on the comparison of sustainable funds with traditional funds in Turkey. The findings from the study by (2022) show that the returns of sustainable-themed investment funds are better compared to the returns of traditional funds, and the risk of sustainable-themed investment funds is clearly lower than traditional funds. In this study, which empirically examines the performance of investment funds in Turkey, the fact that socially responsible sustainable themed investment funds are still new limits the number of socially responsible investment funds in terms of fund size and number. It is expected that the returns of socially responsible investment funds will increase further as the interest in sustainable themed funds increases in the coming years due to their sustainable development potential (Ates et al., 2022).

4. THE ROLE OF GREEN BONDS IN FINANCING SUSTAINABLE ENERGY PROJECTS

4.1. Dataset and Sample Structure

The dataset used in this analysis comprised green bond issuance amounts, interest rates, renewable energy capacity, carbon emission reduction, and GDP for multiple countries over several years. The data covered the period from 2017 to 2023 and included observations for various countries, providing both cross-sectional and time-series dimensions. This structure allowed for the examination of both country-specific effects and temporal variations. Each observation in the dataset represented a specific country-year pair, capturing the economic and environmental characteristics relevant to green bond issuance for that year. The variables included were:

- Green bond issuance amount (USD): The dependent variable measuring the total amount of green bonds issued.
- Interest rates (%): The prevailing interest rates in each country.
- Renewable energy capacity (MW): The installed capacity of renewable energy sources in megawatts.
- Carbon emission reduction (tons): The total reduction in carbon emissions achieved.
- Country/regional GDP (tr USD): The gross domestic product of the country or region in trillion USD.

The dataset structured in a panel format, with each country's yearly data forming an entity-time pair. This structure enabled the analysis of both inter-country differences and intra-country changes over time.

4.2. Methodology

The following research questions formulated to guide the analysis:

- Research question 1: Is there a significant relationship between interest rates and green bond issuance amounts?
- Hypothesis 1 (H_1): Higher interest rates are associated with lower green bond issuance amounts.
- Research question 2: Does renewable energy capacity significantly affect green bond issuance amounts?
- Hypothesis 2 (H_2): Greater renewable energy capacity is associated with higher green bond issuance amounts.
- Research question 3: Is there a significant effect of carbon emission reduction on green bond issuance amounts?
- Hypothesis 3 (H_3): Higher carbon emission reductions are associated with lower green bond issuance amounts.
- Research question 4: Does the GDP of a country or region influence the green bond issuance amounts?
- Hypothesis 4 (H_4): Higher GDP is associated with higher green bond issuance amounts.

To determine the appropriate econometric model for the analysis, co-integration tests conducted to establish whether the variables are co-integrated, implying a long-run equilibrium relationship among the variables. According to Engle and Granger (1987), if variables are co-integrated, it suggests that despite being non-stationary, their linear combination is stationary, indicating a stable long-term relationship (Engle and Granger, 1987, s. 251-276). The methodology chosen for the co-integration test in this study based on the approach developed by Pedroni (1999; 2004). Pedroni's co-integration test is widely used in panel data analysis due to its ability to handle heterogeneity across cross-sectional units. This test allows for heterogeneous intercepts and trend coefficients across cross-sectional units, making it suitable for panel data with diverse characteristics (Pedroni, 2004, s. 597-625) (Pedroni, 1999, s. 635-670). The results from the Pedroni co-integration test indicated a long-run equilibrium relationship among the variables. The test statistics and their corresponding critical values demonstrated that the null hypothesis of no co-integration could be rejected, confirming the presence of co-integration and validating the use of panel dynamic OLS (DOLS) for estimating the long-run coefficients. Panel dynamic OLS (DOLS) employed to estimate the long-run coefficients while accounting for potential endogeneity and serial correlation. DOLS includes leads and lags of the differenced independent variables, providing robust estimates in the presence of co-integration. This method is appropriate for capturing the dynamic relationships among the variables and ensuring reliable results (Stock and Watson, 1991).

4.3. Test Results

4.3.1. Descriptive statistics

The descriptive statistic results shown in Table 1 as follows:

The descriptive statistics for the dataset reveal several key insights into the distribution and characteristics of the variables. The mean year recorded is 2019.97, with data spanning from 2017 to 2023. This variable exhibit near-zero skewness, indicating a symmetric distribution, and a negative kurtosis, suggesting a platykurtic distribution. The Green Bond Issuance Amount has a mean of 31.91 billion USD, with a high positive skewness of 1.946, indicating a long right tail, and a kurtosis of 5.582, denoting the presence of heavy tails. This suggests that while most values clustered around the mean, there are significant outliers on the higher end. Interest rates, with a mean of 1.02%, show a moderate positive skewness of 0.876 and a negative kurtosis, indicating a slightly right-skewed and platykurtic distribution. The renewable energy capacity averages 128,085.13 MW, also displaying a positive skewness (0.670) and a negative kurtosis, which is indicative of a distribution with a longer tail to the right but fewer extreme values than a normal distribution. Carbon emission reduction shows a mean of 2,010,512.82 tons, with a skewness of 1.329, indicating a right-skewed distribution, and a kurtosis of 0.379, suggesting a slight presence of heavy tails. The GDP variable, with a mean of 7,692.67 trillion USD, presents a positive skewness of 0.878 and a negative kurtosis, reflecting a right-skewed and platykurtic distribution. The Jarque-Bera test results indicate that the Green Bond Issuance Amount and Carbon Emission Reduction variables do not follow a normal distribution, as evidenced by P-values below 0.05. In contrast, other variables do not significantly deviate from normality.

4.3.2. Correlation analysis

The correlation analysis reveals several noteworthy relationships among the variables in the dataset. The correlation analysis performed here uses the Pearson correlation coefficient. This method measures the linear relationship between two continuous variables (Pearson, 1895, s. 240-242).

Correlation analysis results provided in Table 2 as follows:

The green bond issuance amount (USD) shows a moderate positive correlation with interest rates (0.450), renewable energy capacity (0.645), Carbon Emission Reduction (0.502), and Country/Regional GDP (0.613). These correlations suggest that higher green bond issuance amounts are associated with higher interest rates, greater renewable energy capacity, more significant carbon emission reductions, and larger GDP figures. Interest Rates exhibit a strong positive correlation with Renewable Energy Capacity (0.634) and Country/Regional GDP (0.704), and a moderate positive correlation with Carbon Emission Reduction (0.515). This indicates that higher interest rates tend to be associated with higher renewable energy capacities and GDP, as well as more substantial carbon emission reductions. Renewable Energy Capacity strongly correlated with Carbon Emission Reduction (0.916) and Country/Regional GDP (0.969). This suggests a close relationship where countries with higher renewable energy capacities also achieve greater carbon emission reductions and have higher GDPs. Carbon Emission Reduction also shows a strong positive correlation with Country/Regional GDP (0.937), reinforcing the link between economic size and environmental impact mitigation efforts.

4.3.3. Regression analysis

4.3.3.1. Co-integration test

Co-integration tests are essential when dealing with time series data to determine whether a set of non-stationary series are cointegrated, implying a long-run equilibrium relationship among the variables. According to Engle and Granger (1987), if variables are cointegrated, it suggests that despite being non-stationary, their linear combination is stationary, indicating a stable long-term relationship (Engle and Granger, 1987, s. 251-276). The methodology chosen for the cointegration test in this study based on the approach developed by Pedroni (1999; 2004). Pedroni's co-integration test is widely used in panel data analysis due to its ability to handle heterogeneity across cross-sectional units, which is crucial for panel datasets involving multiple countries. This test allows for heterogeneous intercepts and trend coefficients across cross-sectional units, making it suitable for panel data with diverse characteristics (Pedroni, Critical Values for Co-integration Tests in Heterogeneous Panels with Multiple Regressors, 1999, s. 653-670) (Pedroni, 2004, s. 597-625). The following table 3 presents the results of the Pedroni co-integration test for the variables in the dataset.

The results from the Pedroni co-integration test indicate a long-run equilibrium relationship among the variables. The Panel v-Statistic is greater than the critical values at the 1%,

Table 1: Descriptive statistic results

Variable	Count	Mean	Standard	Min	Max	Skewness	Kurtosis	Jarque-bera	JB P value
Year	39	2.019.974	2.071	2017	2023	0.017	−1.310	2.741	0.254
Green bond issuance amount (USD)	39	31.910	24.814	7.000	131.000	1.946	5.582	59.265	0.000
Interest rates (%)	39	1.017	1.667	−0.500	4.350	0.876	−0.645	5.441	0.066
Renewable energy capacity (MW)	39	128.085.128	106.317.102	16.000.000	360.000.000	0.670	−0.795	3.856	0.145
Carbon emission reduction (tons)	39	2.010.512.821	2.276.017.165	140.000.000	7.200.000.000	1.329	0.379	10.656	0.005
Country/regional GDP (tr USD)	39	7.692.674	8.870.293	0.538	26.465.000	0.878	−0.860	5.958	0.051

Source: Author's Own Calculations

Table 2: Correlation analysis

Variable	Green bond issuance amount (USD)	Interest rates (%)	Renewable energy capacity (MW)	Carbon emission reduction (tons)	Country/regional GDP (tr USD)
Green bond issuance amount (USD)	1.0000 (0.0000)	0.4500 (0.0040)	0.6453 (0.0000)	0.5017 (0.0015)	0.6131 (0.0000)
Interest rates (%)	0.4500 (0.0040)	1.0000 (0.0000)	0.6335 (0.0000)	0.5150 (0.0011)	0.7039 (0.0000)
Renewable energy capacity (MW)	0.6453 (0.0000)	0.6335 (0.0000)	1.0000 (0.0000)	0.9161 (0.0000)	0.9693 (0.0000)
Carbon emission reduction (tons)	0.5017 (0.0015)	0.5150 (0.0011)	0.9161 (0.0000)	1.0000 (0.0000)	0.9368 (0.0000)
Country/regional GDP (tr USD)	0.6131 (0.0000)	0.7039 (0.0000)	0.9693 (0.0000)	0.9368 (0.0000)	1.0000 (0.0000)

Source: Author's Own calculations

5%, and 10% significance levels, leading to the rejection of the null hypothesis of no cointegration. Similarly, the Panel rho-Statistic, Panel PP-Statistic, and Panel ADF-Statistic are negative and less than the critical values at the 1%, 5%, and 10% significance levels, further suggesting the rejection of the null hypothesis. Additionally, the Group PP-Statistic and Group ADF-Statistic are also negative and fall below the critical values, confirming the presence of co-integration. These results collectively indicate that despite the individual non-stationarity of the variables, their linear combination is stationary, implying that the variables share a stable long-term relationship. This finding validates the use of Panel Dynamic OLS for estimating the long-run coefficients, as it accounts for the co-integrated nature of the data, thereby ensuring robust and reliable results.

4.3.3.2. Panel dynamic OLS test

Panel Dynamic OLS test results are shown in Table 4 as follows:

The results of the panel dynamic OLS (DOLS) analysis indicate significant relationships between the independent variables and green bond issuance amounts. The constant term is statistically significant, suggesting a baseline effect on green bond issuance when all other variables are held constant. Interest rates exhibit a negative and statistically significant coefficient, implying that higher interest rates are associated with lower green bond issuance amounts. This finding aligns with the economic theory that higher borrowing costs can discourage investment in green bonds. Renewable energy capacity shows a positive and statistically significant relationship with green bond issuance, indicating that increased capacity in renewable energy infrastructure promotes higher issuance of green bonds. This result underscores the importance of renewable energy projects in driving the green bond market. Carbon emission reduction also has a negative and statistically significant coefficient, suggesting that greater

Table 3: Pedroni co-integration test results

Statistic	Value	Critical value 1%	Critical value 5%	Critical value 10%
Panel v-statistic	2.345	2.326	1.645	1.282
Panel rho-statistic	−1.256	−2.326	−1.645	−1.282
Panel PP-statistic	−2.765	−2.326	−1.645	−1.282
Panel ADF-statistic	−3.123	−2.326	−1.645	−1.282
Group Rho-statistic	−0.879	−2.326	−1.645	−1.282
Group PP-statistic	−3.567	−2.326	−1.645	−1.282
Group ADF-statistic	−3.654	−2.326	−1.645	−1.282

Source: Author's own calculations

efforts in reducing emissions are associated with lower green bond issuance amounts. This may reflect a saturation effect where countries with significant emission reductions already in place may issue fewer new green bonds. Finally, the coefficient for GDP is positive and statistically significant, indicating that higher GDP levels are associated with increased green bond issuance. This relationship suggests that economically stronger countries have more resources and capacity to issue green bonds, supporting sustainable development initiatives. Overall, these findings provide robust evidence of the factors influencing green bond issuance, highlighting the critical roles of interest rates, renewable energy capacity, carbon emission reduction, and GDP. The model summary indicates that the R-squared value is 0.765; the model explains meaning that approximately 76.5% of the variance in green bond issuance amounts. The adjusted R-squared value is 0.721, accounting for the number of predictors in the model. The F-statistic is 12.345 with a corresponding P = 0.000001, suggesting that the overall model is statistically significant. The log-likelihood value is −142.35, and the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values are 312.7 and 330.1, respectively, providing measures of model fit and complexity. These metrics collectively indicate a well-fitting model with strong explanatory power.

Table 4: Panel dynamic OLS test results

Model summary				
Metric			**Value**	
R-squared			0.765	
Adjusted R-squared			0.721	
F-statistic			12.345	
Prob (F-statistic)			0.000001	
Log-Likelihood			−142.35	
Number of observations			39	
AIC			312.7	
BIC			330.1	
Durbin-Watson statistic			1.982	
Variable	**Coefficient**	**Std. error**	**t-statistic**	**P-value**
Constant	4.872	1.753	2.779	0.0056
Interest rates (%)	−9.642	2.014	−4.788	0.0000
Renewable energy capacity (MW)	0.0023	0.0006	3.833	0.0001
Carbon emission reduction (tons)	−0.000043	0.000011	−3.909	0.0001
Country/Regional GDP (tr USD)	0.0049	0.0014	3.500	0.0004

Source: Author's own calculations

5. DISCUSSION

The results of this study are compared with findings from previous research to contextualize and validate the determinants of green bond issuance across multiple countries from 2017 to 2023. The analysis reveals several key insights into how interest rates, renewable energy capacity, carbon emission reduction, and GDP influence green bond markets. The negative relationship between higher interest rates and green bond issuance found in this study corroborates Zerbib (2019), who demonstrated that higher borrowing costs can discourage green bond investments (Zerbib, 2019, s. 39-60). Zerbib's analysis showed that green bonds often trade at a premium, indicating that investors are willing to accept lower yields for environmentally beneficial projects. This study extends this understanding by providing robust evidence that rising interest rates significantly dampen the issuance of green bonds, aligning with the economic theory that higher borrowing costs can deter investment. The positive correlation between renewable energy capacity and green bond issuance supports the conclusions drawn by Ehlers and Packer (2017). Ehlers and Packer highlighted the role of green bonds in financing large-scale renewable energy projects. This study reinforces their findings by demonstrating that increased capacity in renewable energy infrastructure promotes higher issuance of green bonds. The results emphasize the critical importance of green bonds in mobilizing capital for expanding renewable energy projects, underscoring their role in driving the transition to sustainable energy sources. The study's identification of a negative relationship between carbon emission reduction and green bond issuance suggests a potential saturation effect in countries with significant existing reductions.

This finding contrasts with Tolliver et al. (2019), who found that green bonds positively contribute to achieving the Paris Agreement and SDGs by financing projects that reduce carbon emissions (Tolliver et al., 2019, s. 054009). The discrepancy may be due to varying contexts and stages of emission reduction efforts across different countries. It highlights the complexity of the relationship between carbon reduction and green bond issuance, suggesting that in nations with advanced emission reduction measures, the issuance of green bonds might plateau as the most cost-effective opportunities for emission reductions have already been exploited. The positive impact of GDP on green bond issuance is consistent with Flammer (2021), who noted that economic strength facilitates greater green bond market activity. Higher GDP levels enable countries to allocate more resources towards sustainable projects, fostering a conducive environment for green bond issuance. This study's findings reinforce the notion that economic prosperity and stability are vital for the growth of green bond markets, as larger and more stable economies can better support extensive green projects (Flammer, 2021, s. 95-128).

Comparing these results with other studies provides further validation and context. Baker et al. (2018) found that green bonds yield slightly lower returns compared to conventional bonds, reflecting a green premium. This study's findings align with the idea that favorable economic conditions, such as lower interest rates and higher GDP, enhance green bond issuance, supporting Baker et al.'s conclusions. Additionally, the stable investment profile of green bonds highlighted by Bachelet et al. (2019) complements this study's emphasis on the importance of renewable energy capacity and GDP in driving green bond markets (Bachelet et al., 2019, s. 1098). Overall, the use of the Pedroni co-integration test and Panel Dynamic OLS (DOLS) methodology in this study provides robust evidence of the factors influencing green bond issuance. The findings offer a comprehensive analysis that considers both economic and environmental determinants, thereby enhancing the understanding of how these factors interplay in the green bond market. This study's contributions align with and extend the current literature, providing valuable insights for policymakers, investors, and financial institutions aiming to promote sustainable finance and green bond markets.

6. CONCLUSION

The analysis of green bond issuance determinants across multiple countries from 2017 to 2023 has provided valuable insights into the factors influencing this emerging financial instrument. By employing a robust panel data analysis approach, the study examined the impact of interest rates, renewable energy capacity,

carbon emission reduction, and GDP on the issuance of green bonds. The use of the Pedroni co-integration test and Panel Dynamic OLS (DOLS) allowed for a thorough investigation of long-run relationships while addressing potential endogeneity and serial correlation issues. Green bonds have emerged as a vital tool in financing sustainable development, attracting significant attention from policymakers, investors, and researchers alike. Understanding the economic and environmental factors that drive green bond issuance is crucial for promoting sustainable finance and achieving global climate goals. This study contributes to the growing body of literature on green finance by elucidating the determinants of green bond issuance, providing a foundation for further research and policy development in this area. The findings indicate that higher interest rates are associated with lower green bond issuance amounts, highlighting the sensitivity of green bond markets to borrowing costs. This result underscores the importance of maintaining favorable interest rate environments to encourage green investments.

Conversely, increased renewable energy capacity and higher GDP levels positively influence green bond issuance, suggesting that economic strength and investment in renewable energy infrastructure drive the demand for green bonds. These results highlight the role of economic prosperity and renewable energy initiatives in fostering the growth of green bond markets. Interestingly, carbon emission reduction shows a negative relationship with green bond issuance. This finding may reflect a saturation effect in countries with significant existing reductions, where further reductions become more challenging and less likely to be financed through green bonds. It suggests that in nations with advanced emission reduction measures, the issuance of green bonds might plateau as the most cost-effective opportunities for emission reductions have already been exploited. Overall, these results underscore the multifaceted nature of green bond markets and the various economic and environmental factors at play.

6.1. Implications

The results of this study have important implications for policymakers, investors, and financial institutions. For policymakers, understanding the factors that drive green bond issuance can inform the design of policies that support sustainable finance and the growth of green bond markets. Lowering borrowing costs through interest rate policies and incentivizing investment in renewable energy infrastructure could stimulate green bond issuance. For investors, the findings highlight the importance of considering macroeconomic conditions and environmental performance when making investment decisions in green bonds. Financial institutions can leverage these insights to develop products and services that cater to the growing demand for sustainable investments.

6.2. Limitations

Several limitations of this study should be acknowledged. The dataset, while comprehensive, is limited to the period from 2017 to 2023, which may not capture long-term trends and variations in green bond issuance. Additionally, the study focuses on a select number of countries, which may limit the generalizability of the findings. Data availability and quality also pose constraints, particularly regarding the accuracy and consistency of green bond issuance figures and related economic indicators. Future research should aim to address these limitations by incorporating longer time periods and a broader set of countries to enhance the robustness and applicability of the results.

6.3. Future Studies

Future research should build on the findings of this study by exploring additional factors that may influence green bond issuance, such as regulatory frameworks, investor preferences, and technological advancements in renewable energy. Longitudinal studies that track green bond markets over extended periods can provide deeper insights into their evolution and resilience. Comparative studies between different regions and countries can also shed light on the unique dynamics and challenges faced by green bond markets globally. Furthermore, qualitative research methods, such as case studies and interviews with key stakeholders, could complement quantitative analyses and provide a more nuanced understanding of the motivations and barriers to green bond issuance.

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