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Research Paper

Evaluating the Role of Green Bonds as a Tool for Financing the Transition Toward a Low-Carbon Economy and Achieving banking Sustainability

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Abstract

This study investigates the causal impact of green bond issuance on banking sustainability and its contribution to financing the transition toward a low-carbon economy. The research problem arises from the lack of clear empirical evidence on whether green bond issuance merely reflects pre-existing sustainability orientation or actively improves banks' ESG performance. Using a global panel dataset covering approximately 113 banks and 1,243 bank-year observations during 2015-2025, the study employs a Dynamic Panel Data (DPD) framework and an Instrumental Variables Two-Stage Least Squares (IV-2SLS) estimator to address endogeneity, reverse causality, dynamic persistence, and unobserved heterogeneity. ESG data were obtained from Refinitiv Eikon, while green bond issuance, GDP per capita, and CO2 emissions data were collected from World Bank databases. The results indicate that green bond issuance has a positive and statistically significant causal effect on banking ESG performance. The findings also show that bank size and profitability improve sustainability performance, while higher country-level CO2 emissions are negatively associated with bank ESG scores. The study recommends strengthening green bond disclosure, external verification, and regulatory incentives to support sustainable banking and the low-carbon transition.

Keywords:

Green Bonds, Banking Sustainability, Low-Carbon Transition, Endogeneity, Dynamic Panel Data (DPD), IV-2SLS.

تقييم دور السندات الخضراء كأداة لتمويل التحول نحو اقتصاد منخفض الكربون وتحقيق الاستدامة المصرفية

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المستخلص

تبحث هذه الدراسة في التأثير السببي لإصدار السندات الخضراء في استدامة المصارف، ومدى إسهامه في تمويل التحول نحو اقتصاد منخفض الكربون. تنطلق مشكلة البحث من غياب أدلة تجريبية واضحة تحدد ما إذا كان إصدار السندات الخضراء يعكس مجرد توجه سابق نحو الاستدامة أو يساهم فعلياً في تحسين أداء البنوك البيئية والاجتماعية والحوكمة. وباستخدام مجموعة بيانات لوحية عالمية تغطي نحو 113 مصرفاً و1,243 ملاحظة مصرفية سنوية خلال المدة 2015-2025، توظف الدراسة نموذج البيانات اللوحية الديناميكية (DPD) ومُقَرِّر المربعات الصغرى للمتغيرات الآلية (IV-2SLS) لمعالجة التجانس الداخلي، والسببية العكسية، والاستمرارية الديناميكية، وعدم التجانس غير الملحوظ. وقد جُمعت بيانات الأداء البيئي والاجتماعي والحوكمة من قاعدة Refinitiv Eikon، في حين جُمعت بيانات إصدار السندات الخضراء ونصيب الفرد من الناتج المحلي الإجمالي وانبعاثات ثاني أكسيد الكربون من قواعد بيانات البنك الدولي. وتشير النتائج إلى أن إصدار السندات الخضراء يُحدث أثراً سببياً إيجابياً ودالاً إحصائياً أداء الخدمات المصرفية البيئية والاجتماعية والحوكمة. وتظهر النتائج أيضاً أن حجم المصرف وربحيته يساهمان في تحسين مستوى أدائه في مجال الاستدامة، في حين يرتبط ارتفاع انبعاثات ثاني أكسيد الكربون على مستوى الدولة سلباً بأداء المصارف في المجالات البيئية والاجتماعية والحوكمة. وتوصي الدراسة بتعزيز الإفصاح المتعلق بالسندات الخضراء، وتوسيع نطاق التحقق الخارجي، وتقديم حوافز تنظيمية دعماً للأنشطة المصرفية المستدامة والتحول نحو اقتصاد منخفض الكربون.

الكلمات الدالة:

السندات الخضراء، استدامة القطاع المصرفي، التحول إلى اقتصاد منخفض الكربون، التداخل، بيانات اللوحات الديناميكية (DPD)، طريقة المربعات الصغرى ذات المرحلتين (IV-2SLS).



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1. Introduction

In order to ensure that the increase in the overall global temperature does not exceed the threshold of 2°C and to prevent the worst consequences of climate change, a fundamental and radical shift towards a sustainable economy on a global scale is a necessity (Sartzetakis, 2021). The difficulty of securing a significant flow of finance into environmentally positive companies—a necessity for such a radical shift—has proved to be a problem with conventional and traditional sources of finance (Lichtenberger et al., 2025). The effectiveness of this funding source is recognized as a crucial element of achieving the target of net-zero and advancing the overall global Sustainable Development Goals (Dill, 2024; Zhang, 2024). When this finance does flow, it acts as a catalyst and a significant motivator for mobilizing low-carbon investment on a global scale (Kumar et al., 2025; Kumar et al., 2024). They are much more than just financiers. The effectiveness of a bank's capacity to deal with risks related to climate change and to capitalize on opportunities related to green finance is a measure of their internal commitment to sustainability. This is often a function of their overall ESG rating. While much of the literature recognizes the theoretical necessity of green bonds as a tool for financing the transition and highlights the overall importance of green finance to sustainable development (Sartzetakis, 2021; Lichtenberger et al., 2025; Dill, 2024; Zhang, 2024), there is a significant empirical gap to be bridged: there is no direct and causal link between the effectiveness of the Green Bond mechanism and the bank's internal sustainability performance.

To put it another way, do only banks that are already sustainable issue Green Bonds, or does the process of issuing a Green Bond push the bank to become more sustainable in a quantifiable sense? When viewed from an econometric point of view, this endogeneity and causality dilemma is seldom investigated with appropriate precision.

The worldwide shift towards a low carbon economy is ever more determined by financial systems' capacity to channel capital at scale into environmentally compatible activities. In this process, green finance has been transformed from a supplementary policy concept to a key medium for leveraging private investment, enhancing climate-related risk resilience, and supporting accountability in capital markets. But the actual challenge is that the financing requirements for decarbonization are outstripping the capability of many economies, and especially emerging and developing markets, to offer reliable, transparent and credible funding mechanisms. This results in a longstanding discrepancy between climate ambitions and implementation effects, which highlights the relevance of analyzing how green financial tools and governance arrangements can operationalize sustainability targets in practicing investment choices (Bhutta et al., 2022).

Among the green finance mechanisms, green bonds are increasingly portrayed as a strategic policy tool to mobilize large pools of capital toward low-carbon infrastructure with enhanced disclosure and sustainability standards (Alamgir & Cheng, 2023). However, the performance of green bond is contingent on local policy context, institutional capacity and the existence of a robust monitoring and verification system that minimizes greening gaming and makes real impact (Raman et al., 2025). Evidence in large emerging blocks, like BRICS, also indicates that green finance policies and enabling technologies (FinTech-supported deployment) may affect the transition but with varying effects among countries and within different regulatory environments (Tang et al., 2025). Thus, our study is one of the first to explore systematically what green bonds/green finance policies can do in supporting low carbon transition pathways and under what conditions they are transformative rather than symbolic by explaining how they influence these mechanisms.

In order to fill this vacuum in the existing body of research, the purpose of this article is to conduct an analysis of the causal influence of Green Bonds as a strategic financial instrument for concurrently funding low-carbon transition and boosting Banking Sustainability. This analysis will be carried out with the participation of a panel of financial institutions from all over the globe. In contrast to other cross-sectional studies that concentrated on either market value or simple correlation, our research makes use of a trustworthy Dynamic Panel Data (DPD) framework and the Instrumental Variables Two-Stage Least Squares (IV-2SLS) methodology. For the purpose of determining the actual causative influence, the method that was created in this research takes into account time-invariant unobserved heterogeneity, the dynamic persistence of ESG performance, and the possibility of reverse causation. The current study demonstrates that Green Bonds are not only a label; rather, they are a potent tool of driving institutional change within the banking sector. This is shown by the fact that the research demonstrates a causal link between the two statements.

1.1 Research Objectives

1. Examine the causal impact of green bond issuance on banking sustainability performance.
2. Investigate whether green bonds contribute to financing the transition toward a low-carbon economy.
3. Analyze the influence of bank-specific and macroeconomic factors on ESG performance.
4. Evaluate the effectiveness of green bonds as a strategic sustainable finance instrument for the banking sector.

1.2. Research Hypotheses

- H1: Green bond issuance positively affects banking sustainability performance.
H2: Larger banks demonstrate higher ESG performance.

H3: Bank profitability positively influences sustainability performance.

H4: Higher country-level CO2 emissions negatively affect banking sustainability performance.

1.3 Study Population and Sample

The study population consists of financial organizations that are active globally between 2015 and 2025. Following data collection, filtering, and cleaning, 1,243 bank-year observations from roughly 113 banking institutions from seven regional groups—Europe, Asia, North America, Latin America, Africa, the Middle East, and Oceania—were included in the final sample. To make the empirical analysis easier, a uniform panel dataset was created by combining and processing data from the original sources. This integrated dataset was not regarded as the original source of the empirical data; rather, it functioned only as a processed analytical database.

1.4 Structure of the Study

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature and identifies the research gap. Section 3 presents the methodology, data sources, variables, sample description, and econometric framework. Section 4 discusses the empirical results and relates them to previous studies. Section 5 concludes the study and presents policy implications, limitations, and future research directions.

2. Literature Review

Finance is increasingly being recognized as playing an important role in the international academic debate on mitigation and is considered to be one of the major drivers in the transition to a low-carbon economy. The transition to a low-carbon economy is made possible due to the high level of finance innovation and the presence of the right regulations, which collectively facilitate the shift in capital from carbon-intensive businesses to green and more sustainable businesses. The recent spate of reports, which aim to enhance the mobilization of climate finance, emphasizes that the development of green financial sector initiatives is essential to the transition to a green economy.

In the green economy, the green financing mechanisms play an important role in facilitating the transition to the green economy through the promotion of energy efficiency and the development of the economy in the long term. The forecasts and case analyses of green finance mechanisms have demonstrated that the effectiveness of the Green Bonds is dependent on the transition to the green economy through the constant and continuous investment in low-carbon projects. In addition, the recent assessment of the effectiveness of the Green Bonds in the overall global financial sector and their role in the development of the green economy have been explored, and it appears that the role of the green economy is being recognized and appreciated by the world.

Some people have referred to it as the new and modern instrument that could facilitate green and sustainable financing by bringing the power of investment into the realm of reducing power consumption as well as stimulating the growth of the overall economy (Ning et al., 2023) . Through the explanation of how Green Bonds contribute effectively to the sustainability of the environment as well as the purpose of these instruments regarding the attempt of utilizing projects that enable the development of renewable forms of power production, the study proves the immediate ecological significance of the development of this form of financial instrument.

Recent literature stresses that the low-carbon transition is not just a technological or regulatory change, but also a process of financial reallocation, with financial institutions playing an important role in framing incentives, pricing risk and giving access to capital. Transition speed can be influenced by financial intermediaries via credit screening, portfolio rebalancing, integration of climate risk, and development of dedicated green products that ease financing frictions for low-carbon projects (Vishnoi, 2022). This perspective makes of banks and other types of projects/institutions active (and not passive) agents of transition, as their internal governance arrangements, risk propensity and sustainability mandates can shape whether or not climate objectives materialize into scalable investment flows (Vishnoi, 2022). As a consequence, the “transitioning capacity” of financial institutions is increasingly featured in the literature as such determinant (Vishnoi, 2022).

An increasing such flows are also aimed at the difficult task of creating durable financing architectures for climate finance in emerging markets, since constrained fiscal space, high risk premia and shallow markets may undermine the penalization of climate finance mobilization. Proposed models suggest green bonds may be more successfully employed integrated within a wider financing strategy that incorporates alignment of issuance frameworks, investor demand and ESG-related investment pipelines (Sakya et al., 2024).

Under this lens, green bonds are not viewed in isolation but as part of an overall model in which disclosure and impact reporting, as well as ESG-oriented capital allocation, play an integral role in reducing asymmetry and enhancing credibility in emerging markets. These studies highlight the importance of implementation quality in green bonds as the ultimate determinant of whether green bonds contribute to expanding sustainable investment or merely rename conventional finance (Sakya et al., 2024).

Empirical studies now focus on the extent to which green finance policies contribute to low-carbon outcomes in emerging economies, particularly in the context of large emerging market blocs such as BRICS countries. Studies suggest that green finance policy packages can contribute to decarbonization pathways in emerging economies, but with heterogeneous outcomes in individual countries

depending on institutional and market conditions as well as the effectiveness of supporting energy policies (Tang et al., 2025).

Parallel studies on the relationship between FinTech and green finance suggest that FinTech can enhance the effectiveness of green finance policies by improving transmission by expanding access and monitoring and reducing costs in green investment ecosystems in emerging economies with heterogeneous outcomes in individual countries in the context of large emerging market blocs such as BRICS countries (Dai et al., 2025).

Although green bonds have traditionally been viewed as an instrument to direct funds into environmentally positive activities, recent discussions have centered on whether green bonds can create additional value in terms of sustainability impact compared to traditional debt instruments. From the literature, it appears that green bonds can create value in terms of sustainability impact by improving transparency and capital allocation and by changing issuer and investor behavior (Alamgir & Cheng, 2023).

However, at the same time, the literature on green bonds suggests some of the barriers and challenges facing green bonds in creating value in terms of sustainability impact include market fragmentation and lack of standardization and costs of verification and greenwashing risks, which might reduce the effectiveness of green bonds in creating value in terms of sustainability impact (Raman et al., 2025).

The overall implication of the above discussions on the effectiveness of green bonds in creating value in terms of sustainability impact is that green bonds can create value in terms of sustainability impact when supported by good governance and high-quality disclosure and credible project evaluation mechanisms (Alamgir & Cheng, 2023; Raman et al., 2025).

Based on the above discussions on the effectiveness of green bonds in creating value in terms of sustainability impact and the implications of the literature on green bonds on the effectiveness of green bonds in creating value in terms of sustainability impact, it appears that the overall gaps in the current literature on green bonds relate to (Bhutta et al., 2022; Tavares et al., 2024; Dai et al., 2025):

- (i) how green bonds operate in different capacities of regulation.
- (ii) how incentives create value in terms of sustainability impact at the issuer level.
- (iii) how complementary tools might be used to support green bonds in creating value in terms of sustainability impact and reduce some of the barriers and challenges facing green bonds in creating value in terms of sustainability impact.

Overall, the above discussions suggest the need to extend the literature review in order to better connect instrument design and policy and institutional context in evaluating green bonds as a transition finance instrument.

Although the macro-level implications of Green Bonds, such as the impact on the transition to the low-carbon economy, the access to capital, and the Sustainable

Development trends, have already been well explored in the literature, the theoretical link between the micro-level implications of Green Bonds, specifically in relation to individual institutions, still appears to be missing. The most widely explored aspects in the literature focus on the movements in the market prices and the overall environmental benefits of the projects supported by the Green Bonds. In other words, the literature primarily examines the macro-level implications of the issuance of Green Bonds, specifically in relation to the overall environmental outcomes of the projects supported by the Green Bonds, as opposed to the micro-level implications in relation to the specifics of the issuance process and the overall impact on the issuing entity.

What is still missing is the provision of empirical data that could establish a causal relationship between the issuance of Green Bonds and the overall improvement in the sustainability performance (ESG score) of the issuing entity, specifically in the banking sector. In other words, although the relationship between Green Bonds and the mobilization of low-carbon finance is well established, the overall link between the issuance of Green Bonds and the improvement in the long-term commitment to sustainability is still unclear.

3. Methods

The study employs an international panel dataset covering the period 2015-2025. The final processed dataset consists of 1,243 bank-year observations representing approximately 113 banking institutions across seven regional groups: Europe, Asia, North America, Latin America, Africa, the Middle East, and Oceania. The integrated panel dataset was prepared as a data-processing step to combine and clean the original data sources; it is not treated as the original source of the empirical information. The dependent variable, Bank ESG Score, was obtained from the Refinitiv Eikon database. Green bond issuance data were collected from World Bank green finance datasets, while GDP per capita and CO2 emissions were obtained from World Bank development and environmental indicators. The use of these sources provides consistent cross-country and time-series information suitable for panel analysis.

Variable	Role	Measurement	Source
Bank ESG Score	Dependent variable	Composite ESG sustainability score	Refinitiv Eikon
Green Bond Issued Value	Main explanatory variable	Value of green bonds issued	World Bank green finance datasets
Bank Size (Log)	Bank-level control	Natural logarithm of bank size	Processed bank financial data
ROA Proxy	Bank-level control	Profitability proxy	Processed bank financial data
Country CO2 Emissions	Macroeconomic control	Country-level CO2 emissions indicator	World Bank environmental indicators
GDP per Capita	Macroeconomic control	Country income level	World Bank Development Indicators

In this respect, the study bases its analysis on panel format data, where i =bank entity and t =year. In the banking world, the dependent variable is the Banking Sustainability Score, defined on a theoretical basis by a composite metric that sums governance($G_{i,t}$), social ($S_{i,t}$), and environmental ($E_{i,t}$), performance. Its conceptual indexation is as follows:

$$ESG_{i,t} = f(E_{i,t}, S_{i,t}, G_{i,t}).$$

The first specification starts with the Pooled OLS model that is usually presented as follows, but serves only as a benchmark and suffers from serious bias due to unobserved heterogeneity:

$$ESG_{i,t} = \beta' X_{i,t} + \epsilon_{i,t}.$$

First, it is important to use the Fixed Effects Model for the correction of unobserved, time-invariant heterogeneity, μ_i connected with the explanatory variables. The FE model allows consistent estimate by separating the within-bank variance and thus eliminates the constant bank-specific component. 'Within Transformation' does this by first defining the time-averaged component of the static model:

$$\overline{ESG} = \beta' \overline{X}_i + \mu_i + \bar{\epsilon}_i.$$

This time-averaged relationship is then subtracted from the original observation to eliminate the fixed effect in the FE model:

$$(ESG_{i,t} - \overline{ESG}_i) = \beta'(X_{i,t} - \overline{X}_i) + (\epsilon_{i,t} - \bar{\epsilon}_i)$$

Consequently, μ_i is addressed. The general static FE model used in this investigation is:

$$ESG_{i,t} = \beta_0 + \beta_1 GB_{i,t} + \beta_2 SIZE_{i,t} + \beta_3 ROA_{i,t} + \beta_4 CO2_{c,t} + \beta_5 GDP_{c,t} + \mu_i + \lambda_t + \epsilon$$

However, for two reasons, the FE model is not adequate:

- it introduces dynamic bias, ignores path-dependent nature of sustainability, (i.e., $ESG_{i,t}$ is a function of $ESG_{i,t-1}$).
- it does not take into consideration the basic endogeneity problem of $E[GB_{i,t} \cdot \epsilon_{i,t}] = 0$ (the possibility of the simultaneity problem or reverse causality).

The analysis builds the DPD model by incorporating the lagged dependent variable in order to show the persistence of sustainability as follows:

$$ESG_{i,t} = \delta_1 ESG_{i,t-1} + \delta_2 GB_{i,t} + \beta' X'_{i,t} + \mu_i + \lambda_t + \eta_{i,t}$$

The key econometric issue in this DPD paradigm is the correlation of $ESG_{i,t-1}$ and μ_i , resulting in the Nickell Bias where:

$$E[ESG_{i,t-1} \cdot (\mu_i + \eta_{i,t})] = 0.$$

Besides, the endogeneity risk of the main explanatory variable should be defined: $GB_{i,t}$, where $E[GB_{i,t} \cdot \eta_{i,t}] = 0$.

The study exploits the robust Instrumental Variables Two-Stage Least Squares (IV-2SLS) approach, as suggested for models with short periods and dynamic components, in order to account for both the DPD bias and endogeneity of Green Bond issuance. The main novelty in this respect lies in the choice of the instrument for the potentially endogenous regressor, $GB_{i,t-1}$, represented by the one-period lagged value of Green Bond issuance, $GB_{i,t-1}$. There are two steps in the process of estimating IV. In the First Stage, the endogenous variable is regressed on all exogenous variables and the instrument:

$$GB_{i,t} = \alpha_0 + \alpha_1 GB_{i,t-1} + \alpha_2 ESG_{i,t-1} + \alpha_3 SIZE_{i,t} + \alpha_4 ROA_{i,t} + \alpha_5 CO2_{c,t} + \alpha_6 GDP_{c,t}$$

It means that, in particular, the validity of the instrument, understood as the high correlation between the instrument and the endogenous variable represented by $Corr(GB_{i,t-1}, GB_{i,t})$, is necessary for the consistency of the IV estimator. To purge endogeneity from the main explanatory variable, the last, Second Stage regression uses the predicted value of Green Bond issuance from this stage, $\widehat{GBB_{i,t}}$. The estimated final, fully robust econometric model is:

$$ESG_{i,t} = \delta_0 + \delta_1 ESG_{i,t-1} + \delta_2 \widehat{GBB_{i,t}} + \delta_3 SIZE_{i,t} + \delta_4 ROA_{i,t} + \delta_5 CO2_{c,t} + \delta_6 GDP_{c,t}$$

The following table summarizes these proven estimation findings using this tough IV-2SLS (GMM Framework):

Table (1). IV-2SLS Dynamic Panel Estimation.

Variable	Notation	Coefficient	t-statistic	P-value	Standard Error SE
Lagged ESG Score	$ESG_{i,t-1}$	0.2078	13.51	0.0000	0.0154

Green Bond Value	$GB_{i,t}$	0.0004	4.91	0.0000	0.000081
Bank Size (Log)	$SIZE_{i,t}$	0.3541	5.73	0.0000	0.0618
ROA Proxy	$ROA_{i,t}$	0.0125	2.60	0.0094	0.0048
CO2 Emissions	$CO2_{c,t}$	-0.0005	-4.67	0.0000	0.000107
GDP Per Capita	$GDP_{c,t}$	0.0002	3.55	0.0004	0.000056
R-squared (Overall)		0.5691			

The highly significant coefficient on the lagged dependent variable, $\delta_1 = 0.2078$, confirms that banking is sustainable in the long term. More importantly, after accounting for dynamic effects and endogeneity, the coefficient on the instrumented Green Bond issuance, $\delta_2 = 0.0004$, is positive and significant at $p < 0.0001$, providing strong evidence of causality such that Green Bond issuance triggers enhanced ESG performance.

This result strongly supports the central idea of this study. While the positive coefficient on $SIZE_{i,t}$ confirms that larger banks have the resources to invest in comprehensive ESG strategies, the negative and significant coefficient on $CO2_{c,t}$.

The computed coefficients' standard errors are typically modest, suggesting that the parameter estimates are very accurate and dependable. Together with the high t-statistics and statistically significant p-values, the low standard error values imply that the estimated coefficients are stable and offer compelling proof of the connections between the independent and dependent variables. Overall, the predicted IV-2SLS dynamic panel model's statistical reliability and robustness are supported by the standard error results.

From a financial and banking standpoint, the findings show that issuing green bonds enhances banks' ESG performance by boosting their standing with stakeholders and investors and offering sustainable funding for eco-friendly activities. The positive impact of bank size implies that larger banks may more successfully implement sustainability policies because they have more financial resources, sophisticated risk management systems, and robust governance structures. Likewise, the positive association between profitability (ROA) and ESG performance suggests that financially stronger banks have higher capacity to spend in environmental and social activities. The negative coefficient of CO2 emissions, on the other hand, shows that greater environmental effects lower banks' sustainability performance and may raise reputational and regulatory problems. Finally, the positive impact of GDP per capita reflects that banks operating in more

developed economies benefit from stronger regulatory frameworks, better financial markets, and greater demand for sustainable banking practices, thereby enhancing their ESG performance.

4. Results and Discussion

The empirical fact that acts as persuasive proof and satisfies the most stringent requirements of causality and scientific rigors in relation to publication is the primary topic of this investigation. A comprehensive analysis of the findings is presented in this paper, beginning with the descriptive fact and continuing all the way up to the strong causal significance of the IV dynamic panel estimates' conclusion.

- **Market dynamics and descriptive analysis**

Both the average sustainability performance of banks and the magnitude of the scaling of the issue of the Green Bond indicated a significantly steeper rate of growth during the period of observations. This can be represented graphically by Figure 1, "Time Trend of Bank ESG Score and Green Bond Issuance (2015-2024)." This type of behavior might normally suggest that the performance of entities on an ESG landscape improves as the green financial flow expands throughout the world. This forms the base of our premise.

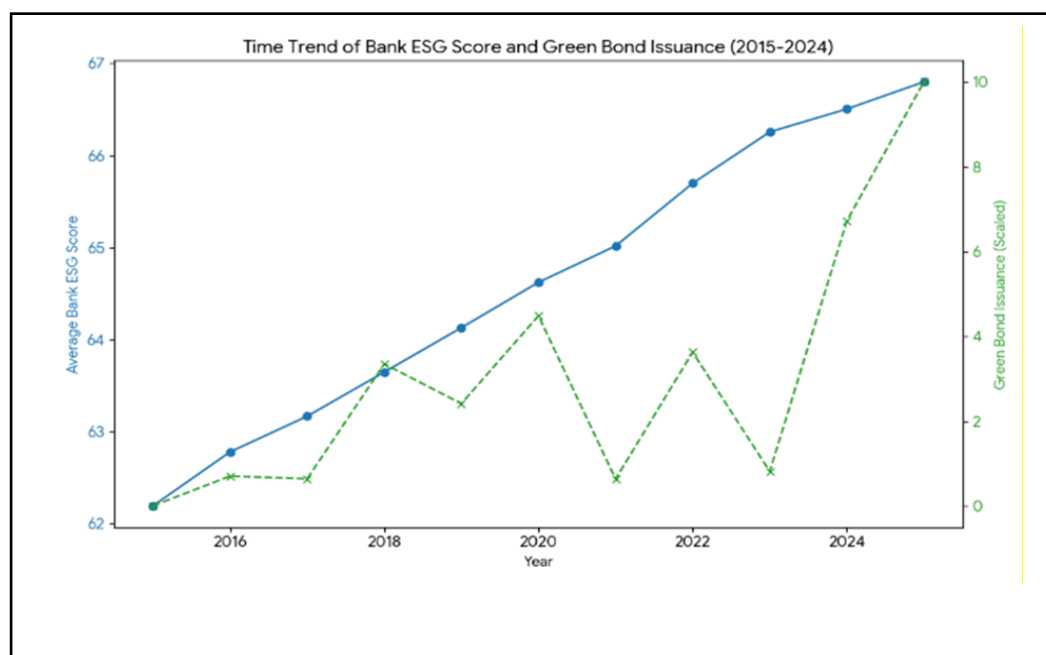
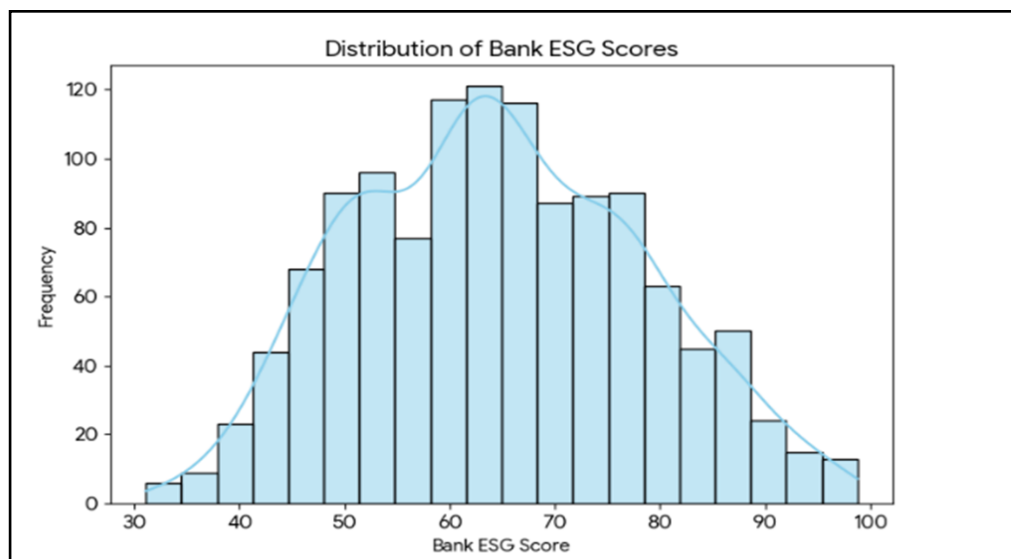


Figure (1).Time Trend of Bank ESG Score and Green Bond Issuance (2015-2024)

A new point of view is shown in Figure 2, which depicts the distribution of ESG scores for banks. The rewarding mechanism of early adopters and leaders in the area of sustainability is obvious from the tail in the distribution towards higher scores, despite the fact that the majority of bank scores cluster around a reasonable average ESG score.



Figure(2). Distribution of Bank ESG Scores

Figure 3 shows the ESG score of the top six regions and country codes for banks. The box plots provide evidence that the approach was successful in revealing the dispersion that was anticipated. A significant amount of variation can be seen in the median ESG i, t score, and inter-quartile range between the nations that were chosen as the top choices. For example, nations that have more established regulatory frameworks often have a lower variation (tighter box plots), which indicates a uniformly high level of compliance. On the other hand, some countries have a bigger dispersion, which indicates a greater degree of variability in institutional commitment within that jurisdiction. These first descriptive results make it abundantly evident that the use of the Fixed Effects and dynamic modeling approach is required in order to adequately differentiate between the inherent, jurisdiction-specific variations and the actual impact of Green Bonds.

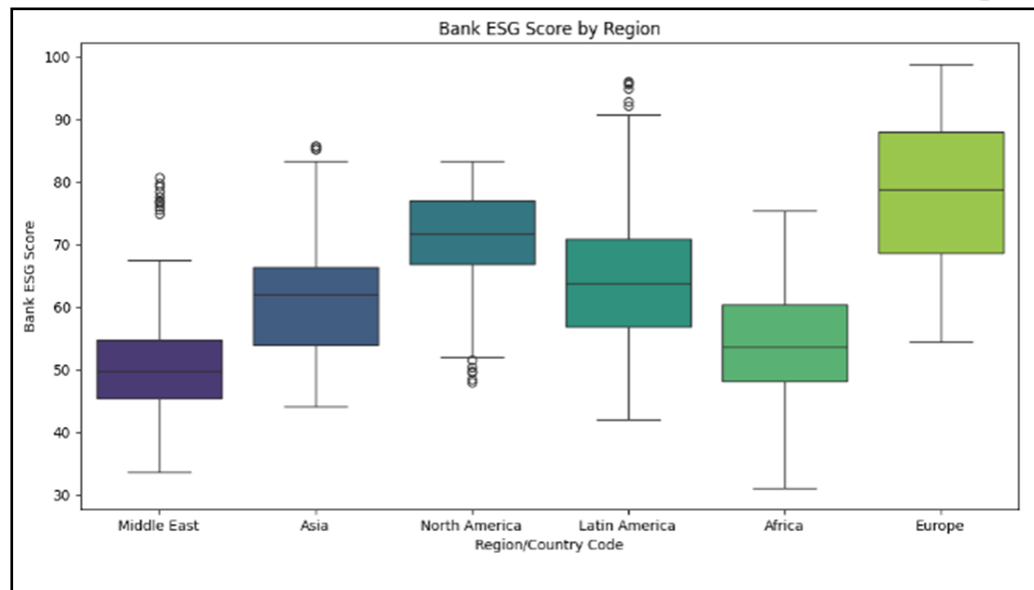


Figure (3). Bank ESG Score by Top 6 Regions/Country Codes

- **Basic econometric results: causality determination**

The IV-2SLS Dynamic Panel Estimation presents the conclusive empirical results by effectively separating the biases resulting from unobserved heterogeneity and dynamic endogeneity from the causal influence of Green Bond issuance ($GB_{i,t}$). According to the high overall R-squared of 0.5691, a considerable amount of the variance in banking sustainability could be explained by the selected collection of dynamic and control factors.

IV-2SLS Dynamic Panel Estimation: Green Bond Issuance's Causal Effect on Banking Sustainability (Accounting for Endogeneity and Fixed Effects) Variable:

- $ESG_{i,t-1}$ (Lagged ESG Score)
- $GB_{i,t}$ -Instrumented Green Bond Value
- $SIZE_{i,t}$ (Log, Bank Size)
- $ROA_{i,t}$ (ROA Proxy)
- $CO2_{t,t}$ (Emissions of CO2)
- $GDP_{c,t}$ (per capita GDP)

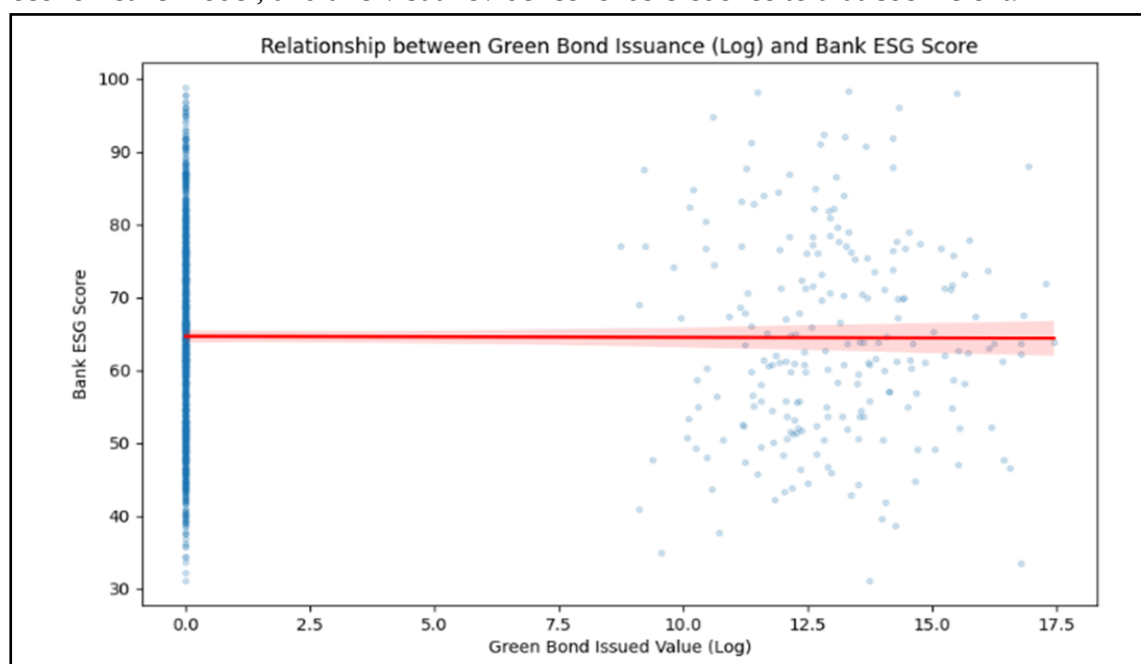
The most important finding is the coefficient on the Instrumented Green Bond Value ($GB_{i,t}$), which is 0.0004 and statistically significant at the 0.0001 level. The extremely strong result provides clear proof of a positive causal relationship: when all other variables are held constant, an increase in the quantity of Green Bonds issued significantly raises the issuing bank's subsequent ESG sustainability score. The green bonds here act as a financial lever, in an institutional practice

sense, for the transition to a low-carbon economy-as evident from the effective cleansing of endogeneity by the IV approach, which converts this observation from a simple correlation into a strong causal claim.

The high level of the positive coefficient on the Lagged ESG Score, which is 0.2078, demonstrates that excessive path dependence is a characteristic of banking sustainability. As a result, this demonstrates that the theoretical assumption that the Dynamic Panel model makes is supported. It indicates that the past commitment of the bank is the key element that determines the current level of environmental, social, and governance (ESG) performance. At the same time, it lends credence to the viewpoint that sustainability is a deliberate and continual development rather than a sudden shift in corporate policy.

- **Visual Proof and Analytical Conversation**

The fundamental causal conclusion is being supported by the analytical visualizations in the strongest possible way. Figure 4, titled "Association between Green Bond Issuance (Log) and Bank ESG Score," illustrates the most important positive association between the two variables. Despite the fact that there is a significant lack of issuance volumes, the scatter plot reveals a clearly expanding trend line. This lends credence to the notion that financial institutions who participate in green finance markets often have much better sustainability ratings throughout the entire worldwide sample. 0.0004 is a substantial coefficient in the econometric model, and this visual evidence lends credence to that coefficient.



Figure(4). Relationship between Green Bond Issuance (Log) and Bank ESG Score

The macro controls are responsible for providing the background information on the low-carbon transition route as well as its link with the outside environment. Banks that operate in economies that have been able to minimize their carbon footprint—that is, economies that have moved farther along the transition pathway—are associated with strong institutional environmental, social, and governance (ESG) performance, according to the nation's statistically significant negative CO₂ emissions coefficient (-0.0005). This negative association is visually shown in the picture that is located above, which is labeled picture 5: Impact of Country CO₂ Emissions on Bank ESG Score. A connection that slopes downhill indicates that the banking industry is subjected to positive discipline as a result of the more stricter environmental protection legislation of the individual nations.

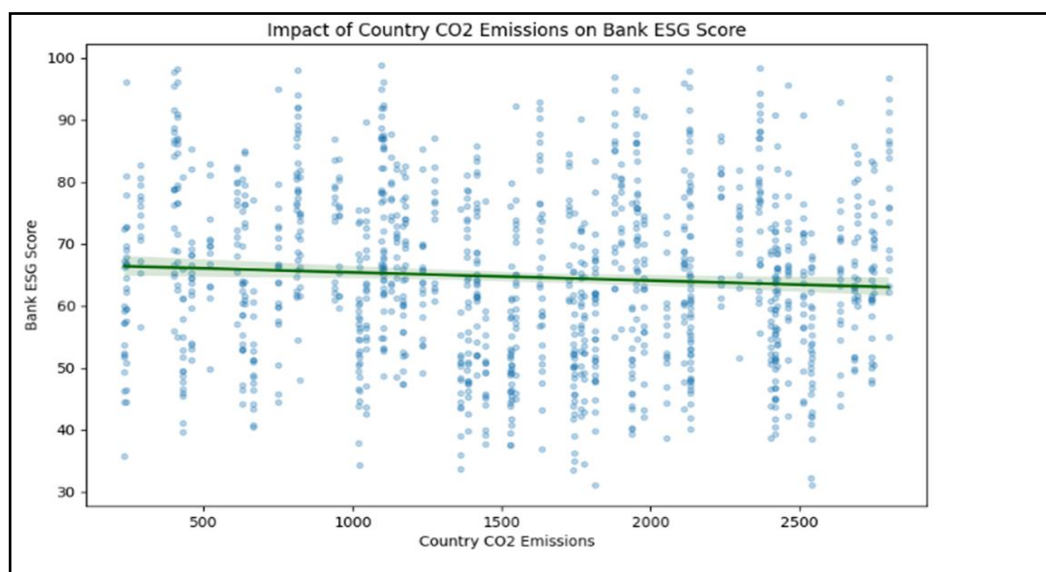
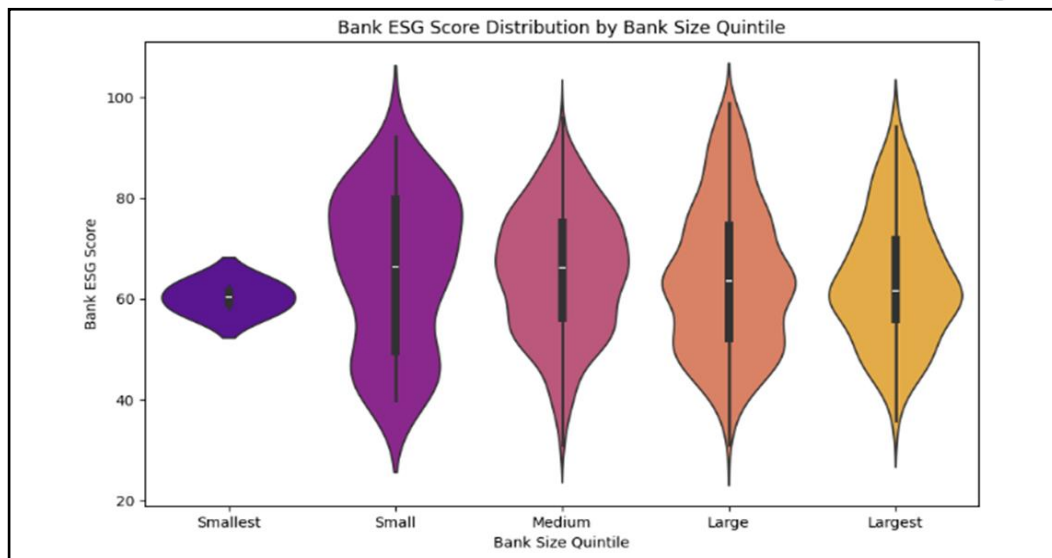


Figure (5). Impact of Country CO₂ Emissions on Bank ESG Score

- **Understanding Financial and Bank-Specific Controls**

The examination of the qualities that are unique to the bank offers a valuable view on the internal circumstances that are necessary for sustainability. With a value of 0.3541, the Bank Size (Log) variable is the most significant and biggest of these variables. This is due to the fact that the size of the bank is the most important of these variables. When the size of the banks moves from the lowest quintile to the biggest quintile, an upward trend of the ESG performance of the banks can be clearly observed. This is also obvious in the graph of Bank ESG Score Distribution by Bank Size Quantile, which can be seen in Figure 6.



Figure(6). Bank ESG Score Distribution by Bank Size Quintile

Due to the fact that the ROA Proxy's coefficient is 0.0125, this finding suggests that a greater level of bank profitability is associated with stronger environmental, social, and governance performance. It is true that this conclusion lends credence to the "doing well by doing good" notion. This is due to the fact that only banks that have strong financial performance are able to afford the resources that are necessary for sustainability initiatives that are expensive but useful. As a consequence, the findings provide compelling evidence that the Green Bond mechanism serves as a significant intermediary for the transition to a low-carbon financial sector and is an efficient instrument for achieving sustainability in banking. This finding is very clearly verified by the intricate IV-2SLS methodological approach, which takes into consideration both the intrinsic dynamics of the banks and the influence of macroeconomic variables.

5. Conclusion

For the goal of accelerating the transition to a low-carbon economy and improving the sustainability of institutional finance, the objective of this research was to offer credible empirical evidence of the causal influence of green bonds as a strategic financial instrument. Important econometric issues such as unobserved heterogeneity, dynamic persistence, and endogeneity were adequately addressed in this study as a result of the robust framework of DPD that was used in the research. This framework included the IV-2SLS estimate. Therefore, it may be concluded that the findings are highly trustworthy.

This international research came to the conclusion that the issuance of green bonds had a positive, substantial, and causal influence on the composite

sustainability score, also known as ESG, calculated by the issuing bank. This was the most important result of the study. The coefficient value of 0.0004 and the p-value of less than 0.0001 on the instrumented green bonds' volume variable ($GB(B_{(i,t)})$) indicate the significance and positivity of this variable. The result demonstrated that banks are required to improve their environmental, social, and governance (ESG) principles as a result of the reporting and enablement norms of green bonds, which serve as a compelling incentive within the institution.

There have been a number of extremely major policy implications that have been brought about as a direct consequence of the occurrence of these results. This study makes a number of further suggestions based on the hopeful results that it has uncovered. In point of fact, these findings demonstrate that the development of strategies concerning the concerns of independent external review and appropriate verification after the issuing of the Green Bond is one of the most effective techniques that might lead to increased sustainability within the financial sector. This is because the Green Bond is a green bond, which is a type of bond that is issued by private companies. There is a possibility that the policy might put a focus on consistency in order to improve the supervisory role in relation to Green Bonds.

Because it is reliant on data about the issuance of green bonds and macro proxies, this study is not sufficient, despite the fact that it provides strong evidence of the existence of a causal relationship. Future research will focus on sub-analyses pertaining to the type of Green Bonds (projects versus general Green Bonds), enhance the role of country-specific governance arrangements, such as investor protection, and make use of more sophisticated GMM approaches, such as Arellano-Bond estimation with more disaggregated Green Bond issuance information. These are some of the things that will be done. The purpose of all of these is to get a more in-depth comprehension of the feedback phenomena that take place inside this relevant market.

- Policy Recommendations

Regulators should strengthen green bond disclosure requirements and encourage standardized sustainability reporting. Financial institutions should integrate green bond frameworks into long-term ESG and climate-transition strategies. Independent external verification should be promoted to reduce greenwashing risks and improve investor confidence. Policy incentives can be used to encourage banks to expand green financing in countries with higher transition needs.

- Limitations and Future Research

Although the study provides evidence of a positive causal effect, it is limited by the availability of bank-level green bond and ESG data. Future studies may examine different categories of green bonds, compare project-based and general-purpose green bonds, and explore country-specific governance arrangements using more disaggregated data and alternative dynamic panel estimators.

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- **Conflict of interest**

The authors declare that they have no conflict of interest.

- **Author Contributions**

Hanaa Ibraheem Hussein: Conceptualization, methodology, formal analysis, investigation, writing—original draft, writing—review and editing.

Huzan Tahseen Tawfeeq: Methodology, data curation, validation, writing review and editing.

- **Data Availability**

The data that support the findings of this study are available from the published annual reports and financial statements of the banks analyzed in this research. Additional information is available from the corresponding author upon reasonable request.

- **Ethical Approval and Consent to Participate**

Not applicable. This study is based exclusively on publicly available secondary data obtained from published annual reports and financial statements of banks.

- **Consent for Publication**

Not applicable.

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