REVISITING SUSTAINABLE DEVELOPMENT THROUGH FINANCIAL INCLUSION AND GREEN FINANCE: INSIGHTS FROM BAYESIAN REGRESSION

REVISITANDO O DESENVOLVIMENTO SUSTENTÁVEL ATRAVÉS DA INCLUSÃO FINANCEIRA E DAS FINANÇAS VERDES: INSIGHTS DA REGRESSÃO BAYESIANA

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Abstract

This study investigates the combined effects of financial inclusion and green finance on sustainable development across countries with different levels of financial development during the period 2005 to 2023. Composite indices of financial inclusion and green finance are constructed using principal component analysis, while countries are classified based on the International Monetary Fund Financial Development Index. A Bayesian regression approach is employed to account for parameter uncertainty and ensure robust inference. The results indicate that financial inclusion positively influences sustainable development in both financially developed and financially less developed countries, with a stronger effect in the latter group. Moreover, the interaction between financial inclusion and green finance further enhances sustainable development, particularly in financially less developed economies. These findings suggest that integrating inclusive finance with green financial policies is crucial for achieving sustainable development, especially in countries with shallow financial systems.

Keywords: Financial Inclusion. Green Finance. Sustainable Development.

***Resumo**

Este estudo investiga os efeitos combinados da inclusão financeira e das finanças verdes no desenvolvimento sustentável em países com diferentes níveis de desenvolvimento financeiro durante o período de 2005 a 2023. Índices compostos de inclusão financeira e finanças verdes são construídos utilizando análise de componentes principais, enquanto os países são classificados com base no Índice de Desenvolvimento Financeiro do Fundo Monetário Internacional. Uma abordagem de regressão Bayesiana é empregada para levar em conta a incerteza dos parâmetros e garantir inferências robustas. Os resultados indicam que a inclusão financeira influencia positivamente o desenvolvimento sustentável tanto em países financeiramente desenvolvidos quanto em países financeiramente menos desenvolvidos, com um efeito mais forte neste último grupo. Além disso, a interação entre inclusão financeira e finanças verdes aprimora ainda mais o desenvolvimento sustentável, particularmente em economias financeiramente menos desenvolvidas. Essas descobertas sugerem que a integração de finanças inclusivas com políticas financeiras verdes é crucial para alcançar o desenvolvimento sustentável, especialmente em países com sistemas financeiros frágeis.*

Palavras-chave: *Inclusão Financeira. Finanças Verdes. Desenvolvimento Sustentável.*

1 INTRODUCTION

A growing body of literature has examined the determinants of sustainable development by emphasizing the role of economic development while simultaneously reducing environmental pollution. Existing studies explore the coordination between green finance and the green economy in promoting sustainable development (Liu *et al*., 2020), the strengthening of green finance to support green growth (Desalegn and Tangl, 2022), and the development of green finance to ensure environmental sustainability (Fu and Irfan, 2022). Other strands of research investigate the role of foreign direct investment in green financial systems (Chai *et al*., 2021), the relationship between renewable energy and human development (Sasmaz *et al*., 2020), and the use of renewable energy in transportation as a means of reducing environmental pollution (Buonocore *et al*., 2019). Further evidence shows that green finance contributes to poverty reduction (Jiang *et al*., 2020), lowers energy intensity through financial development and green finance (Lv *et al*., 2022), and reduces carbon emissions (Zhang *et al*., 2022). A common feature of these studies is their focus on the economic and social dimensions of sustainability, with external drivers such as green finance, green energy, environmentally related technological progress, and pollution mitigation acting as key transmission mechanisms.

Financial inclusion has also emerged as a powerful driver of sustainable development, particularly in emerging economies. Financial inclusion refers to the expansion of both the quality and quantity of financial products, services, and instruments that enable individuals and firms to access formal financial systems more easily (Jungo *et al*., 2022b). The United Nations 2030 Agenda for Sustainable Development recognizes financial inclusion as an important tool for poverty reduction and economic growth. In a similar vein, green finance encompasses financial products and services designed to support environmental sustainability by channeling resources toward environmentally responsible activities (Jiang *et al*., 2020).

When these two approaches are combined, their benefits can be amplified. Green finance can create new investment opportunities for environmentally sustainable projects, while financial inclusion ensures that such investments reach a broader segment of households and firms. This interaction can foster inclusive and sustainable green growth. However, much of the existing literature examines these channels in isolation, such as studies focusing on financial inclusion and renewable energy (Cui *et al*., 2022) or

financial inclusion and technological development (Ahmad *et al*., 2022). Related research on green finance and green growth includes studies on green finance and agriculture (Mo *et al*., 2023), government investment and green growth (Feng *et al*., 2022), and the impact of foreign direct investment on green growth (Yue *et al*., 2016). This study addresses this gap by jointly examining the roles of green finance and financial inclusion in promoting sustainable development.

Moreover, empirical studies on sustainable development largely rely on traditional frequentist econometric methods. These approaches are based on restrictive assumptions that may not hold in practice, potentially leading to imprecise inference and prediction. Frequentist methods treat parameters as unknown but fixed values, even though they may change as sample information evolves. In contrast, the Bayesian approach treats parameters as random variables characterized by probability distributions, allowing uncertainty to be explicitly quantified. This study adopts a Bayesian framework to examine the effects of financial inclusion and green finance on sustainable development.

In addition, recent evidence from Van & Le Quoc (2024) indicates that the degree of financial inclusion varies with the level of financial development. Countries with high financial development tend to exhibit more inclusive financial systems than those with low financial development, implying that the impact of financial inclusion on sustainable development may differ across these groups. Motivated by this insight, the present study investigates two groups of countries with low and high levels of financial development to compare the underlying drivers of sustainable development and to derive policy relevant implications for each group.

The remainder of the study is organized as follows. Section 2 presents the theoretical background and a review of related studies. Section 3 describes the variables and outlines the Bayesian regression methodology. Section 4 reports the empirical results. Section 5 concludes with policy implications and discusses the limitations of the study.

2 LITERATURE REVIEW

2.1 The relationship between financial inclusion, green finance, and sustainable economic development

The relationship between economic growth and environmental quality is inherently complex. On the one hand, economic growth tends to increase the demand for energy and natural resources, which may lead to higher levels of environmental pollution (Grossman and Krueger, 1995). As industrial activities expand and population concentration in urban areas intensifies, air and water pollution often rise accordingly. On the other hand, economic growth also creates conditions that facilitate technological progress, which can mitigate the adverse environmental effects associated with growth (Porter and van der Linde, 1995). Increased investment in renewable energy sources such as wind and solar power can reduce reliance on fossil fuels and lower the environmental costs of economic expansion.

The first dimension of this trade off has been partially addressed through the development of alternative measures to traditional gross domestic product. The United Nations Economic and Social Commission for Asia and the Pacific has encouraged the use of green gross domestic product as a more comprehensive indicator that integrates environmental costs and natural resource depletion into the production process of national economies (ESCAP, 2013). By accounting for environmental externalities, green GDP corrects the limitations of conventional GDP and provides a more accurate reflection of development under environmental constraints, thereby supporting sustainable development objectives (United Nations Statistical Institute, 1993).

The second dimension requires external drivers that can stimulate investment in environmentally sustainable activities. These drivers operate primarily through financial transmission channels, including green credit, public research and development expenditure for environmental protection, and green investment. Collectively, these instruments form the green financial system, which mobilizes financial resources toward projects that support environmental sustainability and long term economic development (Midilli *et al*., 2006; Desalegn and Tangl, 2022; Guo *et al*., 2022).

This framework highlights the central role of green finance in reconciling economic growth with environmental sustainability, while also providing a foundation

for examining how financial inclusion can complement green finance in promoting sustainable economic development.

2.1.1 The interaction between financial inclusion and green finance as a driver of sustainable growth

Access to green finance varies substantially across countries, particularly between economies with high and low levels of financial development. In financially advanced economies such as the United States, the United Kingdom, and Japan, well developed financial systems, large capital markets, and higher levels of financial inclusion enable economic agents to access green financial resources more effectively than in less developed financial systems. These countries have also established more mature green financial mechanisms, including green credit, green loans, and green insurance products. By 2020, green bond issuance in financially developed economies reached a record level of approximately 270 billion US dollars, providing strong financial support for sustainable growth (Climate Bonds Initiative, 2019).

In financially developed economies, financial inclusion is widely regarded as an important pillar of sustainable development. By ensuring access to financial services for all segments of society, particularly low income groups, financial inclusion fosters a more competitive business environment, encourages investment, and supports sustainable development outcomes (Tufail *et al*., 2022). Given that agriculture accounts for only a small share of gross domestic product in these economies, typically between 1 and 5 percent (World Bank, 2019), the strategic integration of financial inclusion and green finance primarily aims to channel capital toward large scale green projects and advanced technologies that reduce carbon emissions. Investment in renewable energy has therefore been consistently prioritized as a core component of sustainable growth strategies in financially developed countries (Midilli *et al*., 2006).

However, evidence from emerging economies such as Brazil, Russia, India, China, and South Africa suggests that financial inclusion may contribute to environmental degradation if financial expansion is not carefully regulated. Uncontrolled financial activities can intensify resource exploitation and exacerbate pollution and climate change risks (Ahmad *et al*., 2022). Moreover, empirical studies focusing on ASEAN countries indicate that rising financial inclusion may increase carbon emissions when it is not

aligned with environmental objectives (Ahmad *et al*., 2022). When financial inclusion is combined with green finance, however, financial activities are more likely to be directed toward environmentally responsible investments, thereby supporting sustainable development.

In contrast, countries with low levels of financial development, including many economies in Africa and Southeast Asia, often face underdeveloped financial systems, smaller capital markets, and lower degrees of financial inclusion. These structural constraints limit access to green finance and hinder the adoption of environmentally sustainable technologies. In addition, weak regulatory frameworks and institutional capacity further restrict the development of green financial mechanisms in these economies. Limited access to green finance therefore represents a major barrier to sustainable development in financially less developed countries (Green Climate Fund).

According to reports by the International Fund for Agricultural Development, many financially less developed countries continue to face persistent challenges in accessing formal financial services, with a severe shortage of green financial products. In response, international and regional institutions such as the International Finance Corporation and the Asian Development Bank have begun to promote inclusive green financial products targeted at small and medium sized enterprises and households in these economies. By integrating green finance with financial inclusion, microfinance institutions can provide funding for environmentally sustainable economic activities, reduce financial inequality, and enable smaller firms and households to access the capital required for productive investment.

This integration also facilitates the transition toward sustainable business models by encouraging the adoption of cleaner production systems and the development of green products. World Bank data indicate that in financially less developed countries, agriculture accounts for around 25 percent of gross domestic product, while approximately 22 percent of the population lives below the poverty threshold (World Bank, 2019; UNDP, 2020). As a result, the combined role of financial inclusion and green finance is particularly important for rural communities and low income households, especially in supporting green agricultural projects. Nevertheless, the limited depth of financial inclusion in these countries continues to constrain access to green finance.

Overall, this discussion highlights substantial differences in the mechanisms through which financial inclusion and green finance contribute to sustainable

development across countries with different levels of financial development. Access to inclusive financial services remains more limited in financially less developed economies than in financially advanced ones. This study therefore seeks to clarify the underlying drivers and the magnitude of the joint effects of financial inclusion and green finance on sustainable development across these two groups of countries.

2.2 Review of related studies

From a thematic perspective, existing studies on financial inclusion and green finance largely focus on isolated objectives rather than their joint effects on sustainable development. One strand of the literature examines financial inclusion as a mechanism for enhancing macroeconomic and financial stability (Ahamed and Mallick, 2019; Ahmad, 2018; Barik and Pradhan, 2021; Danisman and Tarazi, 2020; Jungo *et al*., 2022a; Vo *et al*., 2019). Another group of studies emphasizes the role of financial inclusion in improving monetary policy effectiveness and stability (Akanbi *et al*., 2020; Arshad *et al*., 2021; Jungo *et al*., 2022b; Maher, 2022; Oleschak, 2021; Ridwan, 2022). A related strand links financial inclusion to sustainable development outcomes, particularly poverty reduction and social inclusion (Ade Soyemi *et al*., 2020; Adegbite and Machethe, 2020; Arshad *et al*., 2021; Ozili, 2022; Tay *et al*., 2022). More recent studies have extended this literature to environmental dimensions by examining the relationship between financial inclusion and renewable energy consumption (Cui *et al*., 2022) and between financial inclusion and technological innovation (Ahmad *et al*., 2022).

In parallel, a separate body of research investigates the role of green finance in promoting sustainable development. These studies analyze the links between green finance and agricultural sustainability (Mo *et al*., 2023), government investment and sustainable development outcomes (Feng *et al*., 2022), foreign direct investment and green growth (Yue *et al*., 2016), poverty reduction effects of green finance (Jiang *et al*., 2020), renewable energy consumption (Li *et al*., 2022), energy intensity (Lv *et al*., 2022), and the broader nexus between energy use and sustainable development (He *et al*., 2022). Despite their valuable contributions, these strands of literature remain largely disconnected, as most studies examine either financial inclusion or green finance in isolation. Empirical evidence on their joint impact on sustainable development remains limited.

From a measurement perspective, financial inclusion is commonly constructed using principal component analysis based on multiple indicators of financial access and usage. Typical indicators include the number of commercial bank branches per thousand square kilometers, the number of branches per adult population, the density of automated teller machines per geographic area, and the number of automated teller machines per adult population (Ahamed and Mallick, 2019; Ahmad, 2018; Barik and Pradhan, 2021; Danisman and Tarazi, 2020; Jungo *et al*., 2022a; Vo *et al*., 2019). In contrast, there is no unified measurement framework for green finance, largely due to data limitations. For example, Liu *et al*. (2020) construct a green finance index for China based on green credit, green insurance, green investment, and green growth indicators. He *et al*. (2022) measure green growth at the provincial level in China using indicators related to economic scale, economic structure, environmental pollution, economic benefits, and resource allocation efficiency.

In the context of Bangladesh, Rahman *et al*. (2022) employ content analysis to construct a green finance index based on nine criteria, including energy conservation, waste management, renewable energy, alternative energy, recyclable product manufacturing, green construction, environmental scale, sustainability performance, and green financial policies. Similarly, Jiang *et al*. (2022) develop a composite green finance index for China using three main dimensions, economic, financial, and environmental, which together include seventeen sub indicators. Lv *et al*. (2022) measure green finance using four core components: green credit, green insurance, green investment, and government support for environmental protection. Overall, most existing measures of green finance rely on country specific or sub national data, with limited applicability in cross country settings.

Regarding research scope and methodology, data constraints in measuring green finance have restricted most studies to national or sub national analyses, particularly within China. Empirical approaches vary widely, including entropy based indices (Jiang *et al*., 2020), vector autoregressive models at the provincial level (Wang, 2021), propensity score matching techniques (Huang and Zhang, 2021), and spatial econometric models (Lv *et al*., 2022; Wu *et al*., 2023). Moreover, the majority of studies examining the relationship between financial inclusion, green finance, and sustainable development rely on frequentist econometric methods. These approaches often require strong

assumptions that may not hold in practice, thereby limiting the reliability of inference and prediction.

Although several studies have highlighted the strengths and limitations of Bayesian methods (Gelman and Hill, 2006; Kruschke, 2014), a key advantage of the Bayesian framework is that estimation accuracy is less sensitive to sample size. In addition, Bayesian methods can address common econometric challenges such as autocorrelation, heteroskedasticity, and endogeneity (Dinh, 2025a, 2025b; Kim & Le Quoc, 2024; Khoi & Dinh, 2025; Huy & Dinh, 2025a, Huy & Dinh, 2025b). For these reasons, this study adopts a Bayesian approach to examine the joint effects of financial inclusion and green finance on sustainable development.

3 DESCRIPTION OF VARIABLES AND RESEARCH METHODOLOGY

3.1 Measurement of research variables

3.1.1 Green finance

Following Oanh and Dinh (2024) and Dinh *et al*. (2024), green finance is measured using three core components: green credit, green investment, and government green support, as summarized in Table 2. Green credit is captured by two sub indicators, namely credit to the agricultural sector and credit to the renewable energy sector. Green investment and government support are proxied by public research and development expenditure on renewable energy and public research and development expenditure on environmental protection, respectively. This construction reflects the key financial channels through which resources are mobilized toward environmentally sustainable activities.

3.1.2 Financial inclusion

Consistent with prior studies such as Vo *et al*. (2019) and Jungo *et al*. (2022a, 2022b), financial inclusion is constructed as a composite index based on six indicators representing both demand side and supply side dimensions of the financial system. The demand side dimension captures financial usage and includes outstanding bank credit and

outstanding bank deposits. The supply side dimension reflects access to financial services and includes the number of commercial bank branches per thousand square kilometers, the number of commercial bank branches per one hundred thousand adults, the number of automated teller machines per thousand square kilometers, and the number of automated teller machines per one hundred thousand adults. Detailed descriptions of the green finance and financial inclusion indicators are provided in Appendix 1.

3.1.3 Sustainable development

Sustainable development is measured using the Sustainable Development Goals Index, which integrates seventeen indicators corresponding to the United Nations Sustainable Development Goals (United Nations Department of Economic and Social Affairs, 2022). This index has been validated by the Joint Research Centre of the European Commission and is widely used to assess multidimensional sustainable development performance across countries (Schmidt Traub *et al*., 2017; European Commission *et al*., 2019). The full list of indicators is reported in Appendix 2.

In addition to the main explanatory variables, several control variables are included to account for macroeconomic and structural conditions. These include the urban population ratio, trade openness, the inflation rate, population growth, and annual economic growth. Definitions and data sources for all variables are reported in Table 4.

Empirical models

To examine the relationship between financial inclusion, green finance, and sustainable development, the following baseline models are estimated:

$$\text{SDGI}_{i,t} = \beta_o + \beta_1 FI_{i,t} + \beta_x X_{i,t} + \varepsilon_{i,t} \qquad (1)$$

$$\text{SDGI}_{i,t} = \beta_o + \beta_1 FI_{i,t} + \beta_2 GF * FI_{i,t} + \beta_x X_{i,t} + \varepsilon_{i,t} \qquad (2)$$

where:

$i = 1, 2, \ldots N$ denotes countries and $t = 1, 2, \ldots T$ denotes time. $X_{i,t}$ represents the vector of control variables, and εi,t is the error term.

Table 1

Description of variables

Variable	Symbol	Measurement	References	Data source
Dependent variable				
Sustainable development	SDGI	Composite index based on seventeen indicators listed in Appendix 1 (score)	Dinh (2025c, 2025d); Dinh *et al.* (2025); Van *et al.*, (2025a, 2025b); Tuyet & Dinh (2025); Quoc *et al.* (2025b, 2025c); Quoc & Quoc (2025)	SDGI
Independent variable				
Green finance	GF	Constructed using principal component analysis based on indicators reported in Appendix 2	Authors calculation based on studies summarized in Appendix 2	Authors
Financial inclusion	FI	Constructed using principal component analysis based on indicators reported in Appendix 2	Authors calculation based on studies summarized in Appendix 2	Authors
Control variables				
Urban population	UR	Urban population as a share of total population (percent)	Nguyen Quoc *et al.* (2025); Quoc *et al.* (2025a)	WDI
Trade openness	OPE	Total exports plus imports as a share of gross domestic product	Nguyen Quoc *et al.* (2025); Quoc *et al.* (2025a)	WDI
Inflation rate	INF	Annual growth rate of consumer price index (percent)	Le Quoc *et al.* (2025); Le Quoc (2024); Huy *et al.* (2023a, 2023b); Huy & Tam (2025)	WDI
Population growth	POP	Annual population growth rate (percent)	Saydaliev and Chin (2022); Huy & Loan (2022);	WDI
Economic growth	TGDP	Annual growth rate of gross domestic product (percent)	Nguyen Quoc *et al.* (2025); Quoc *et al.* (2025a)	WDI

Source: Authors compilation.

3.2 Data and research methodology

3.2.1 Data

This study uses the Financial Development Index compiled by the International Monetary Fund. Based on this dataset, the average level of financial development across

all countries is computed over the period from 2005 to 2023. Countries whose average financial development index during this period exceeds the global mean are classified as financially developed countries, while those with an average index below the global mean are classified as financially less developed countries. Applying this classification criterion yields a sample consisting of fourteen financially less developed countries and eleven financially developed countries. The list of countries included in each group is reported in Appendix 3.

3.2.2 Research methodology and empirical framework

This study is based on the Financial Development Index compiled by the International Monetary Fund. Using this dataset, the average level of financial development across all countries is calculated for the period from 2005 to 2023. Countries whose average financial development index over this period exceeds the global average are classified as financially developed economies, while those with an average index below the global mean are classified as financially less developed economies. Based on this classification, the sample is divided into two groups consisting of fourteen financially less developed countries and eleven financially developed countries. The list of countries included in each group is reported in Appendix 3.

Financial inclusion and green finance cannot be adequately represented by single indicators, as no single variable can fully capture their multidimensional nature. Consequently, multiple indicators are commonly employed to measure these concepts, as summarized in Appendix 2. In this study, composite indices for financial inclusion and green finance are constructed using principal component analysis. This statistical technique applies an orthogonal transformation to convert a set of correlated variables into a smaller number of uncorrelated components, thereby maximizing the variance explained by the extracted components. The empirical analysis is conducted within a Bayesian framework. In Bayesian statistics, observed data are combined with prior information to derive posterior distributions of model parameters, and empirical results are interpreted in terms of probability distributions rather than point estimates. An important advantage of this approach is that estimation accuracy does not depend critically on large sample sizes, making it particularly suitable for studies with limited cross sectional and time series observations (Zondervan Zwijnenburg *et al*., 2017). The

Bayesian and frequentist approaches are grounded in fundamentally different statistical philosophies. The Bayesian framework treats the observed sample as fixed and the model parameters as random variables characterized by probability distributions. Posterior distributions are obtained by updating prior beliefs with observed data and are used directly for inference. In contrast, frequentist methods assume that the data are random draws from a hypothetical repeated sampling process, while model parameters are unknown but fixed constants. Inference is therefore based on the sampling distribution of estimators rather than on the conditional distribution of parameters given the observed data. In essence, Bayesian analysis addresses research questions by evaluating the probability distribution of parameters conditional on the observed sample.

4 RESULTS

4.1 Results of principal component analysis

Table 2 reports the results of the principal component analysis used to construct the financial inclusion and green finance indices. For the financial inclusion index, the largest positive loadings are observed for outstanding bank deposits and outstanding bank credit, indicating that financial usage plays a dominant role in explaining cross country variation in financial inclusion. This suggests that economies with deeper banking intermediation, reflected in higher levels of deposits and credit relative to economic activity, tend to exhibit higher levels of financial inclusion. In contrast, the indicators capturing physical access to financial services, including automated teller machine density and commercial bank branch density, display negative loadings. This pattern may reflect spatial saturation effects in financially developed systems, where an expansion in physical banking infrastructure does not necessarily translate into broader or more effective financial inclusion. Instead, financial inclusion in such contexts appears to be driven more by the intensity of financial usage than by the sheer number of access points. Overall, the PCA results indicate that financial inclusion is primarily associated with the depth and utilization of financial services rather than with their physical availability. For the green finance index, public environmental research and development expenditure exhibits the largest positive loading, highlighting the central role of government support in promoting green financial development. Credit directed toward the agricultural sector

also contributes positively, suggesting that green finance in many countries is closely linked to environmentally related activities in agriculture. In contrast, public research and development expenditure for renewable energy displays a negative loading, which may reflect trade offs in government budg*et al*location between environmental protection and renewable energy investment. The loading for credit to renewable energy remains relatively small, indicating that green credit allocation to this sector is still limited or uneven across countries. Taken together, the PCA results confirm that both financial inclusion and green finance are multidimensional constructs driven by distinct underlying components. Financial inclusion is dominated by financial usage indicators, while green finance is largely shaped by government environmental support and sector specific credit allocation. These composite indices therefore provide a suitable foundation for the subsequent Bayesian regression analysis examining their joint effects on sustainable development.

Table 2

Results of principal component analysis

FI	ATM	ATMKM	DCB	LCB	CBP	CBBP
Loading	−0.185	−0.185	−0.172	0.645	0.618	−0.238
GF	TDN	TDL	NS1	NS2		
Loading	0.421	−0.038	−0.563	0.689		

Source: Authors

4.2 Bayesian regression results

4.2.1 Descriptive statistics

Table 3 reports the descriptive statistics for financially less developed countries and financially developed countries. Several systematic differences emerge across the two groups. On average, sustainable development outcomes are more favorable in financially developed countries, as reflected by a higher mean value of the sustainable development index. In addition, the dispersion of sustainable development is lower in financially developed countries, indicating more stable and consistent performance across time and across countries within this group.

Green finance also exhibits clear heterogeneity. Financially developed countries display a higher average level of green finance, reflecting stronger institutional capacity,

more mature green financial instruments, and greater government support for environmentally oriented investment. Although the variability of green finance is substantial in both groups, the wider range observed in financially less developed countries suggests uneven access to green financial resources and a higher degree of cross country disparity.

A pronounced gap is also observed for financial inclusion. The average level of financial inclusion in financially developed countries is nearly twice that of financially less developed countries, highlighting the role of financial system depth and access in shaping inclusive economic participation. The larger standard deviation in financially developed countries indicates heterogeneity in the intensity of financial inclusion, driven by differences in market structure and institutional quality.

The descriptive evidence suggests that higher levels of financial development are associated with stronger sustainable development performance, deeper financial inclusion, and more advanced green finance systems. These differences provide empirical motivation for the subsequent Bayesian regression analysis, which examines whether the effects of financial inclusion and green finance on sustainable development vary systematically across countries with different levels of financial development.

Table 3

Descriptive statistics for the period 2005–2023

Variable	Financially less developed countries				Financially developed countries			
	Mean	Std. Dev.	Minimum	Maximum	Mean	Std. Dev.	Minimum	Maximum
SGDI	65.92	5.62	52.8	75.6	69.84	4.51	59.1	76.9
GF	16.78	19.35	−6.90	184.2	23.48	19.72	−4.80	156.3
FI	27.85	16.94	1.1	97.4	54.62	34.15	4.3	125.8
UR	55.1	12.98	21.4	76.9	63.48	17.92	30.2	88.4
OPE	86.2	25.4	26.9	148.6	91.35	40.8	25.1	195.3
INF	6.08	6.72	−1.20	50.8	4.02	3.05	−1.10	20.4
POP	0.39	1.05	−1.60	2.3	0.86	1.41	−1.00	9.2
GDP	4.11	4.68	−13.50	31.2	4.32	2.84	−6.10	13.4

Source: Authors

4.2.2 Bayesian regression results

Table 4

Bayesian regression results

Variables	Financially less developed countries				Financially developed countries			
	Equation (2)		Equation (3)		Equation (2)		Equation (3)	
	Mean	MCSE	Mean	MCSE	Mean	MCSE	Mean	MCSE
UR	0.2038	0.0002	0.2061	0.0002	0.1469	0.0002	0.1458	0.0002
OPE	0.0449	0.0001	0.0396	0.0001	0.0531	0.0001	0.0527	0.0001
INF	−0.0574	0.0003	−0.0561	0.0003	−0.3652	0.0009	−0.3660	0.0009
POP	−2.7426	0.0020	−2.6159	0.0020	−1.3318	0.0022	−1.3395	0.0022
TGDP	−0.1654	0.0014	−0.1719	0.0014	0.0216	0.0006	0.0269	0.0006
FI	0.0648	0.0001	0.0749	0.0002	0.0116	0.0001	0.0109	0.0001
FI*GF			0.0015	0.0000			0.0001	0.0000
Average acceptance rate	0.8644		0.8344		0.8164		0.8264	
Minimum efficiency	0.1355		0.1344		0.1366		0.1410	

Source: Authors

The Bayesian regression results reported in Table 4 provide several important insights into the role of financial inclusion and its interaction with green finance in shaping sustainable development outcomes across countries with different levels of financial development.

In Equation (2), the coefficient of financial inclusion is positive in both groups of countries, indicating that greater financial inclusion is generally associated with improved sustainable development performance. However, the magnitude of this effect differs markedly between the two groups. In financially less developed countries, financial inclusion exhibits a relatively large positive coefficient of 0.0648 with a very small Monte Carlo standard error, suggesting a strong and precisely estimated effect. This finding implies that expanding access to and usage of financial services in financially constrained systems generates substantial sustainability gains. In such contexts, financial inclusion alleviates credit constraints faced by households and small firms, facilitates investment in human capital and productive activities, and enhances resilience to income and climate related shocks. Because baseline levels of financial access are low, marginal improvements in inclusion tend to produce larger development benefits.

By contrast, in financially developed countries, the coefficient of financial inclusion is considerably smaller, at 0.0116, although it remains positive and statistically stable. This weaker effect is consistent with a saturation argument. In economies where

financial access is already widespread, further expansion of financial inclusion yields diminishing marginal returns for sustainable development. At this stage of development, the composition and allocation of financial flows become more important than the mere expansion of access. Financial inclusion alone is therefore insufficient to generate sizable sustainability gains unless it is complemented by mechanisms that direct financial resources toward environmentally and socially productive uses.

When the interaction term between financial inclusion and green finance is introduced in Equation (3), the role of financial inclusion changes in a meaningful way. In financially less developed countries, the coefficient of financial inclusion increases from 0.0648 to 0.0749, indicating that the development impact of inclusive finance is amplified when it operates alongside green finance. This result suggests that financial inclusion acts as a transmission mechanism through which green finance can reach a broader base of economic agents, including small enterprises, rural households, and the agricultural sector. In these economies, green finance initiatives that are not supported by inclusive financial systems may fail to scale effectively, while inclusive finance without a green orientation may stimulate economic activity at the expense of environmental quality. The interaction between the two therefore enhances the overall contribution to sustainable development.

In financially developed countries, the coefficient of financial inclusion decreases slightly from 0.0116 to 0.0109 after accounting for the interaction term. This pattern implies that a portion of the effect previously attributed to financial inclusion operates indirectly through green finance channels. In advanced financial systems, where inclusion is already high, green finance plays a more decisive role in determining whether financial resources contribute to sustainability objectives. Financial inclusion remains relevant, but its independent effect is relatively modest once the green orientation of finance is explicitly considered.

The interaction term between financial inclusion and green finance is positive in both groups, with a coefficient of 0.0015 in financially less developed countries and 0.0001 in financially developed countries. Although the absolute magnitude of the interaction effect is small, its economic interpretation is meaningful. The larger interaction effect in financially less developed countries highlights a strong complementarity between inclusive financial systems and green financial mechanisms. In these settings, green finance provides environmental direction to capital flows, while

financial inclusion ensures that such flows are accessible to a wide range of economic actors. In financially developed countries, the smaller interaction effect suggests that complementarity still exists but is weaker, as green finance can operate effectively even in the absence of further gains in financial inclusion.

From a Bayesian diagnostic perspective, the average acceptance rates range from 0.8164 to 0.8644, indicating good mixing and convergence of the sampling algorithm. The minimum efficiency values are consistently above acceptable thresholds, further confirming the reliability of the posterior estimates. The very small Monte Carlo standard errors for the key coefficients reinforce the stability of the results and strengthen confidence in the inferred relationships.

The findings underscore three key points. First, financial inclusion contributes positively to sustainable development across countries, but its impact is stronger in financially less developed economies. Second, green finance enhances the effectiveness of financial inclusion, particularly where financial systems are shallow and access constraints are binding. Third, sustainable development strategies should not treat financial inclusion and green finance as separate policy domains. Instead, their joint implementation is crucial, especially in financially less developed countries, where inclusive green finance can generate substantial and mutually reinforcing economic, social, and environmental benefits.

5 CONCLUSION AND POLICY IMPLICATIONS

5.1 Conclusion

This study examines the roles of financial inclusion and green finance in promoting sustainable development, with particular attention to differences between financially less developed and financially developed countries. Using composite indices constructed through principal component analysis and a Bayesian regression framework, the analysis provides robust evidence on how inclusive and green financial systems jointly shape sustainable development outcomes. The empirical results indicate that financial inclusion has a positive effect on sustainable development in both groups of countries. However, the magnitude of this effect is substantially larger in financially less developed countries, where improvements in access to and usage of financial services

generate strong development gains. In contrast, the effect of financial inclusion is weaker in financially developed countries, suggesting diminishing marginal returns once a high level of financial access has been achieved. This finding highlights the importance of the stage of financial development in conditioning the development impact of financial inclusion. The results further reveal a positive and statistically stable interaction between financial inclusion and green finance. This interaction effect is particularly pronounced in financially less developed countries, indicating that the development benefits of financial inclusion are amplified when financial resources are directed toward environmentally sustainable activities. In such contexts, financial inclusion facilitates the transmission of green finance to households, small firms, and rural sectors, thereby strengthening the economic, social, and environmental dimensions of sustainable development. In financially developed countries, the interaction effect remains positive but is relatively smaller, reflecting the greater maturity of green financial markets and the reduced dependence on further gains in financial inclusion. From a methodological perspective, the Bayesian framework employed in this study offers reliable inference by explicitly accounting for parameter uncertainty and ensuring stable estimation even with moderate sample sizes. The high acceptance rates and low Monte Carlo standard errors confirm the robustness of the estimated relationships. Overall, the findings suggest that financial inclusion and green finance should be viewed as complementary rather than independent policy instruments. While financial inclusion provides the foundation for broad based economic participation, green finance determines the sustainability orientation of financial flows. Their joint development is therefore essential for achieving balanced and long term sustainable development, particularly in economies with lower levels of financial development.

5.2 Policy implications

The findings of this study offer several important policy implications for governments, financial regulators, and development institutions seeking to advance sustainable development through financial sector reforms.

For financially less developed countries, the results suggest that expanding financial inclusion should be a central pillar of sustainable development policy. However, policies that focus solely on broadening access to financial services may generate limited

or even adverse environmental outcomes if they are not aligned with green objectives. Policymakers should therefore integrate financial inclusion strategies with green finance frameworks. This can be achieved by promoting inclusive green credit schemes targeted at small and medium sized enterprises, rural households, and agricultural producers, particularly for investments in renewable energy, climate resilient agriculture, and pollution reducing technologies. Strengthening public support for environmental and renewable energy research and development can further enhance the effectiveness of inclusive green finance by lowering investment risks and encouraging private sector participation.

In addition, regulatory authorities in financially less developed countries should prioritize the development of institutional and regulatory infrastructures that support inclusive green finance. This includes establishing clear taxonomies for green activities, improving disclosure standards for environmental risks, and enhancing the capacity of financial institutions to assess and manage green investment risks. By doing so, policymakers can ensure that increased financial inclusion translates into sustainable rather than environmentally harmful economic activity.

For financially developed countries, the relatively smaller marginal effect of financial inclusion indicates that policy emphasis should shift from expanding access toward improving the quality and sustainability orientation of financial intermediation. Policymakers should focus on strengthening green financial markets, such as green bonds, green insurance, and sustainability linked lending, while ensuring that these instruments remain accessible to a broad range of firms and households. Enhancing incentives for private investment in green technologies and supporting innovation in green financial products can further reinforce the contribution of the financial sector to sustainable development.

Moreover, in financially developed economies, financial inclusion policies should be designed to complement green finance initiatives rather than operate independently. Aligning inclusive finance programs with climate and environmental objectives can help avoid misallocation of financial resources and ensure that inclusive growth remains consistent with long term sustainability goals.

At a broader level, the results highlight the importance of policy coordination. Sustainable development strategies should not treat financial inclusion and green finance as separate domains. Instead, an integrated policy approach is required, in which inclusive

financial systems provide the transmission channels for green investment, while green finance frameworks guide the direction of financial flows. International development organizations and multilateral financial institutions can support this process by facilitating knowledge sharing, providing technical assistance, and mobilizing concessional finance for inclusive green projects in financially less developed countries.

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APPENDIX

Appendix 1

17 indicators for calculating the SDGI

Sustainable Development Index (SDGI)		
Target 1	No Poverty	
Target 2	No Hunger	
Target 3	Good Health and Well-Being	
Target 4	Quality Education	
Target 5	Gender Equality	
Target 6	Clean Water and Sanitation	
Target 7	Affordable and Clean Energy	
Target 8	Decent Work and Economic Growth	
Target 9	Industry, Innovation and Infrastructure	**SDGINDEX.ORG**
Target 10	Reduced Inequalities	
Target 11	Sustainable Cities and Communities	
Target 12	Responsible Consumption and Production	
Target 13	Climate Action	
Target 14	Life Below Water	
Target 15	Life on Land	
Target 16	Peace, Justice and Strong Institutions	
Target 17	Partnerships for the Goals	

Appendix 2

Measurement indicators for green finance and financial inclusion

Main variable	Major component	Sub indicator	Measurement	Data source
Green finance (GF)	Green credit	Credit to agricultural sector (TDN)	Growth rate of credit provided to the agricultural sector (percent)	FAO OECD
		Credit to renewable energy sector (TDL)	Growth rate of credit provided to renewable energy activities (percent)	OECD
	Green investment	Public renewable energy research and development expenditure (NS1)	Public research and development budget for renewable energy as a share of total public energy research and development (percent)	OECD
	Government green support	Public environmental research and development expenditure (NS2)	Public research and development budget related to environmental protection	OECD

			as a share of total public research and development (percent)	
Financial inclusion (FI)	Outstanding bank credit (LCB)		Outstanding commercial bank credit as a share of gross domestic product	WDI FAS
	Outstanding bank deposits (DCB)		Outstanding commercial bank deposits as a share of gross domestic product	WDI FAS
	Bank branches per area (CBBP)		Number of commercial bank branches per 1000 square kilometers	WDI FAS
	Bank branches per population (CBP)		Number of commercial bank branches per 100000 adults	WDI FAS
	Automated teller machines per area (ATMKM)		Number of automated teller machines per 1000 square kilometers	WDI FAS
	Automated teller machines per population (ATM)		Number of automated teller machines per 100000 adults	WDI FAS

Source: Authors

Appendix 3

Classification of countries by level of financial development

Financially developed countries	Financially less developed countries
Bulgaria; Brazil; Chile; China; Croatia; Indonesia; Jordan; Mauritius; Thailand; Vietnam; South Africa.	Albania; Armenia; Azerbaijan; Bosnia and Herzegovina; Belarus; Bolivia; Georgia; Honduras; Cambodia; Moldova; Pakistan; Paraguay; Romania; Ukraine."

Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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