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Pathways to Green Growth: The Role of Green Finance in Developed and Developing Countries

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ABSTRACT

This study examines the dynamic relationship between green finance and green growth across 11 developed and 41 developing countries from 2005 to 2022. Green finance is measured using four key indicators: credit for agriculture, credit for renewable energy, public R&D spending on renewable energy, and public R&D spending on environmental protection. Green growth is represented by green GDP, which is proxied through adjusted net savings—calculated by combining net national savings and education expenditure, while subtracting energy, mineral, and forest depletion, as well as carbon dioxide emissions. Using a panel vector autoregression (PVAR) model, the study investigates how green finance affects green growth over time. The results show a clear divergence between country groups: in developed countries, green finance has a positive and stable impact on green growth. In contrast, in developing countries, the effect is more volatile and sometimes negative, likely due to weaker institutional capacity, inadequate policy frameworks, or inefficient allocation of green finance. These findings highlight the need for differentiated policy responses. Developing countries should focus on building robust legal and institutional foundations—such as implementing green taxonomies, enforcing mandatory environmental disclosures, and establishing standardized green bond regulations—to improve transparency and attract sustainable investment. Meanwhile, developed countries are encouraged to strengthen carbon pricing mechanisms, phase out fossil fuel subsidies, and provide stronger incentives for investments in renewable energy and clean technologies. Tailor-

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ing green finance policies to each country's context is crucial for supporting long-term sustainable development and environmental resilience.

Keywords: Green Finance; Green Growth; PVAR

1. Introduction

Green growth adjusts conventional GDP by incorporating the costs of environmental pollution, resource depletion (e.g., mining), and social externalities [1]. It emphasizes aligning economic expansion with environmental stewardship to conserve natural resources while reducing the negative impacts of economic activities on ecosystems [2]. As environmental challenges—such as deforestation, climate change, and ecosystem degradation—have intensified, the urgency of promoting green growth has increased significantly. In response, governments, international organizations, and businesses have collaborated more closely to support green growth by increasing investments in green infrastructure, renewable energy sources, and sustainable agricultural practices. These efforts help lower CO_2 emissions and mitigate the greenhouse effect. Within this framework, green finance has emerged as an essential mechanism for driving the global transition toward environmentally responsible development [3].

Scholars and policymakers have increasingly focused on the environmental impacts of green finance. These include financial instruments and mechanisms designed to promote sustainability and reduce the ecological footprint of economic activities [4]. Examples include green financial services and products, investments in renewable energy and energy efficiency, and funding for environmentally conscious projects [5]. However, the effectiveness of green finance varies widely across countries due to differences in economic development, institutional maturity, and the structure of financial systems. Its capacity to drive green growth depends on income levels, the presence of sectoral spillover effects, and national GDP priorities. In many cases, prioritizing economic expansion without integrating sustainability objectives has led to the overexploitation of resources, environmental degradation, and ecological imbalance. As a result, the relationship between green finance and green growth is not uniform and tends to diverge sharply between developed and developing nations.

There is an ongoing debate over the definition of green growth and green finance, primarily due to limitations in developing efficiency measures and difficulties in obtaining consistent data. As a result, research on the relationship between these concepts remains limited and often focuses on provincial-level analyses in countries such as China and the United States [5, 6]. Furthermore, most existing studies assess green finance and green growth as separate issues when evaluating environmental quality. For instance, Li et al. [7] investigate the link between green finance and renewable energy consumption, while Lv et al. [8] examine the impacts of green finance and development on energy density. In this study, we construct a composite measure of green finance by integrating three dimensions: green investment, green credit, and government support. We conceptualize the green financial system as comprising two components: green credit, which reflects the role of financial intermediaries (e.g., commercial banks, savings and loan institutions, and insurance companies), and green investment, which captures activities in green financial markets (e.g., trading green stocks and green bonds). In addition, government support is incorporated through public R&D programs and environmental budgets. This integrated framework constitutes a key contribution of our study.

Previous research has primarily focused on subnational contexts—such as provinces in China, Bangladesh, or Nigeria—when analyzing the relationship between green finance and green growth. However, most countries today are transitioning toward a green growth paradigm, albeit at different speeds and through diverse pathways depending on their development stage, resource endowments, and economic structures. These divergences are particularly pronounced between developed and developing countries [9]. To address this gap, our study expands the analytical scope by comparing the relationship between green growth and green finance across both groups. In doing so, we uncover divergent dynamics and provide tailored policy recommendations for each category of countries.

This study makes two key contributions. First, it develops a comprehensive measure of green finance by combining three indicators: green credit, green investment, and government support. Green credit is measured by (1) the growth of credit to the agricultural sector (CFA: Credit for Agriculture) and (2) the growth of credit to the renewable energy sector (CFE: Credit for Renewable Energy Generation). Together, these indicators reflect the role of financial intermediaries—such as banks and other credit institutions—in channeling funds toward environmentally sustainable activities.

Including agricultural credit is especially important, as agriculture consumes significant natural resources while also offering substantial potential for carbon sequestration. By expanding credit to support sustainable practices (e.g., organic farming, water-saving technologies, improved land management), financial institutions contribute to emissions reduction and ecosystem restoration [3, 10].

Green investment is proxied by the public R&D budget for the renewable energy sector (BRE), expressed as a share of the total public R&D energy budget. This indicator reflects the extent to which public funding flows into the green financial market through investments in sustainable energy technologies. Finally, government support is measured by the public R&D budget allocated to environmental protection (BE), as a share of total public R&D spending. This captures the government's commitment to long-term environmental research and development.

The second contribution of this study is a comparative analysis between developed and developing countries. Given that pathways to green growth vary significantly by level of economic development, natural resource endowments, and institutional capacity, this cross-country perspective offers valuable insights into the diverse dynamics linking green finance and green growth. In doing so, we highlight critical differences between the two country groups and propose tailored policy recommendations for each context. This approach addresses a notable gap in the existing literature and contributes to a more nuanced understanding of global sustainable development trajectories.

The remainder of this paper is structured as follows. Section 2 reviews the key concepts of green finance and green growth, summarizing relevant findings and identifying research gaps. Section 3 outlines the methodology, including the construction of the green finance index and the data sources used. Section 4 presents the empirical results and discussion, comparing the relationship between green finance and green growth across developed and developing countries. Finally, Section 5 concludes the paper with policy implications and suggestions for future research.

2. Literature Review

Simon Kuznets first introduced the concept of Gross Domestic Product (GDP) in 1934 [11], and it has since become the standard metric used by governments, international organizations, and the private sector to monitor economic growth and guide policy and resource allocation decisions. However, relying solely on GDP to measure a country's economic activity—and to compare economic performance across countries—has attracted considerable criticism [12]. Nations differ significantly in fundamental prerequisites such as population size, educational attainment, infrastructure quality, natural resource availability, and currency stability [13], rendering direct GDP comparisons problematic. In response, alternative indicators have been proposed, including the United Nations Development Programme's Human Development Index (HDI), introduced in 1990, and the World Happiness Report (WHR), introduced by Helliwell et al. in 2012. Despite such critiques, GDP remains dominant, although measures like GDP per capita have been introduced to better capture the productive contributions of residents. The emergence of green GGDP represents a further effort to correct for GDP's environmental shortcomings by accounting for pollution and resource depletion.

In 1993, the United Nations Statistical Institute introduced the concept of GGDP, which incorporates environmental degradation and resource depletion into national economic accounting to address the limitations of traditional GDP. This approach provides a more accurate and comprehensive assessment of a country's development by taking into account ecological impacts, thereby aligning GGDP growth more closely with environmental quality [1, 14, 15]. At the same time, green finance has emerged as a critical enabler of environmental sustainability, facilitating reductions in greenhouse gas emissions and pollution while supporting the conservation of natural resources [16].

Green finance sits at the intersection of financial systems and environmental responsibility, emphasizing how the financial sector can support the global transition to a low-carbon, sustainable economy [17]. In practice, green finance mobilizes capital for environmentally friendly initiatives, including energy efficiency, renewable energy projects, sustainable agriculture, and R&D in environmental technologies, thereby promoting economic growth while mitigating the ecological harm caused by conventional practices [2, 17]. It also provides investment opportunities for businesses and individuals seeking to make a positive environmental impact. By directing capital flows toward green sectors, green finance facilitates a more harmonious balance between economic growth and environmental protection.

Specifically, green finance influences GGDP through several mechanisms. First, it supports the expansion of the renewable energy sector by providing targeted credit for projects in solar, wind, and tidal energy. Financial institutions offer specialized tools—such as green bonds and concessional loans—that reduce both the cost and risk of investing in clean energy [18, 19]. These instruments attract capital to sustainable energy while helping countries meet domestic and international emissions-reduction commitments.

Second, public green finance—especially government R&D support—drives innovation in energy-efficient technologies across various sectors, including construction, transportation, and heavy industry. Investments in low-energy solutions (e.g., smart buildings, clean mobility) reduce both energy intensity and carbon emissions. Environmental R&D funding enhances technological readiness and market diffusion, catalyzing structural transformation toward a low-carbon economy.

Third, green finance fosters sustainable agriculture by funding nature-positive models—such as regenerative agriculture, agroecology, and agroforestry—that restore soil health, sequester carbon, enhance biodiversity, and improve climate resilience. Financial institutions have developed tailored mechanisms (e.g., concessional credit lines, risk-sharing schemes, outcome-based lending) to empower farmers in adopting sustainable practices. Such financial support is especially vital in rural and developing areas, where limited access to capital often hinders innovation in agriculture.

From this analysis, it is clear that green finance plays a pivotal role in fostering GGDP growth by reallocating funds from traditional projects to environmentally sustainable initiatives. Such examples span both private-sector tools, such as green credit for agriculture and renewable energy, and public-sector investments aimed at pollution reduction. These instruments support initiatives that conserve natural resources, reduce greenhouse gas emissions, and promote eco-friendly economic development.

However, the impact of green finance is constrained by the lack of standardized definitions of what qualifies as a "green" project. Additionally, as the green finance market is still in its early stages and lacks comprehensive legal frameworks and robust regulatory oversight, persistent information asymmetries hinder the efficient operation of investors and regulators.

Although the concept of green growth gained prominence in the early 2000s and quickly became a fixture in policy discourse, exploring its relationship with green finance requires substantial resources—such as funding, technical expertise, and time—that are often scarce in many contexts. Furthermore, the topic did not receive sustained scholarly or policy attention until March 2016, when the United Nations Department of Economic and Social Affairs launched the Sustainable Development Goals (SDGs). Following this announcement, numerous countries adopted green growth-oriented development strategies [20]. Nevertheless, empirical studies investigating the nexus between green growth and green finance remain limited.

Due to limited data availability, there is no universally accepted method for measuring green finance and green growth, posing challenges for cross-country comparisons and impact assessments. For example, Liu et al.[2] examined 30 Chinese regions from 2007 to 2016 using four proxies for green finance (green insurance, green investment, green credit, and green securities) and five proxies for green growth (economic development dynamics, social development dynamics, environmental pressures, environmental status, and technological responsiveness)—all based on domestic Chinese data. Similarly, Lv et al.[8] employed four indicators (green credit, green investment, green insurance, and government support) to construct a green finance index for China, while Jiang et al.[6] relied on three indicators covering economic, financial, and environmental dimensions.

In Bangladesh, Rahman et al.[21] used content analysis to develop nine criteria for green finance, including energy conservation, alternative energy, waste management, renewable energy, eco-friendly brick and facility production, green financial policy, environmental dimensions, and sustainable performance. Because most existing studies rely on country-specific data—particularly from China—there is a lack of consistency in measurement frameworks across different contexts.

Building upon the methodologies of Lv et al.[8], Feng et al.[22], and Mo et al.[23], this study proposes a more generalizable green finance index. We integrate three key components: government support, green credit, and green investment. Green credit is measured by the combined credit growth directed to the agricultural sector and renewable energy generation. Green investment and government support are proxied by public R&D budgets—one allocated to renewable energy and the other to environmental protection. By utilizing these three indicators, each derived from internationally accessible data sources, we aim to construct a more transparent and comparable cross-country measure of green finance.

Secondly, the relationship between green finance and green growth is inherently multifaceted, involving intermediary factors such as economic expansion, investment, innovation, and environmental protection, which interact in complex and dynamic ways. Existing studies tend to focus on specific linkages: Mo et al.[23] investigate the impact of green finance on agriculture; Feng et al.[22] explore how government investment affects green growth; Yue et al.[24] analyze the role of foreign direct investment (FDI) in promoting green growth; Jiang et al.[6] assess the poverty-reduction effects of green finance; Li et al.[7] examine the connection between renewable energy consumption and green finance; Lv et al.[8] evaluate how green finance and development influence energy density; Wang[16] studies the nexus between green energy use, economic growth, and carbon emissions in Henan, China; Wu et al.[17] examine China's investments in air quality and environmental governance; and Zeng et al.[18] assess the impact of green finance policies on regional green innovation.

While these studies offer valuable insights, they tend to analyze isolated dimensions. A comprehensive and interdisciplinary approach is therefore needed to fully understand the bilateral dynamics between green finance and green growth. This paper addresses that gap by investigating the integrated relationship, rather than focusing on discrete thematic channels.

Thirdly, most empirical studies remain limited to subnational analyses. For instance, Jiang et al.[6] apply the entropy method across 25 Chinese provinces; Wang[16] employs a Vector Autoregression (VAR) model in Henan province; and Lv et al.[8], as well as Wu et al.[17], utilize spatial econometric models in other Chinese regions. By contrast, this study adopts a Panel Vector Autoregression (PVAR) approach, which treats all variables as jointly endogenous rather than arbitrarily designating some as exogenous. In the PVAR framework, each variable is modeled as a function of its own lagged values and those of all other variables, capturing their dynamic and interdependent relationships. This methodology is particularly well-suited for uncovering the interconnected dynamics of green finance and green growth at the cross-country level.

Finally, most existing studies on this topic have focused on provincial or national levels. In this paper, we extend the analysis to compare developed and developing countries, acknowledging their divergent institutional and economic conditions. According to Rasoulinezhad and Taghizadeh-Hesary[19] and Dmuchowski and Dmuchowski[20], the key differences between these country groups concerning green growth and green finance include:

(1) **Access to Capital:** Developed countries generally enjoy better access to financial resources, enabling them to more easily fund green projects. In contrast, developing nations often face significant constraints in securing adequate capital, which hampers their capacity to implement sustainable initiatives.

(2) **Investment Capital:** Financial markets in developed economies tend to be more mature, offering broader investment pools and a wider variety of green financial instruments. Conversely, developing countries—with more limited capital markets—often struggle to establish and scale similar financial mechanisms.

(3) **Green Financial Instruments:** Developed countries typically have access to a broader range of financial tools—such as green bonds, green equities, and sustainability-linked loans—that can be mobilized to support environmentally beneficial initiatives. In developing countries, the lack of such instruments poses a significant barrier to the effective deployment of green finance.

(4) **Green Growth Objectives:** In developed economies, policy efforts frequently focus on "greening" existing industries and infrastructure while promoting innovation in green technologies such as renewable energy. By contrast, green growth often receives less sustained attention in developing countries, where governments may prioritize immediate environmental responses to crises (e.g., natural disasters or public health emergencies). Furthermore, traditional GDP growth remains a dominant objective, often overshadowing long-term GGDP development strategies.

3. Method

3.1. Research Variables and Models

Data were collected for 41 developing countries (Angola, Albania, Armenia, Azerbaijan, Benin, Bangladesh, Bosnia and Herzegovina, Belarus, Bolivia, Brazil, China, Arab Republic of Egypt, Ethiopia, Georgia, Honduras, Indonesia, India, Islamic Republic of Iran, Jordan, Kazakhstan, Kenya, Cambodia, Lao PDR, Moldova, Myanmar, Mauritius, Namibia, Pakistan, Paraguay, Romania, Rwanda, Sudan, El Salvador, Serbia, Thailand, Tanzania, Uganda, Ukraine, Vietnam, South Africa, and Zambia) and 11 developed countries (United Arab Emirates, Austria, Bulgaria, Chile, Finland, France, Croatia, Netherlands, Norway, Poland, and Portugal) for the period 2005–2022.

3.1.1. Green Finance

Prior studies have measured green finance using indicators such as green credit and green investment, which aim to increase financing for the agricultural and renewable energy sectors, thereby contributing to pollution reduction [3]. In this paper, we construct a composite Green Finance Index using Principal Component Analysis (**Appendix A**: Green Growth Index (GGDP) formula and variable definitions).

3.1.2. Green Growth (GGDP)

To proxy green growth, we follow Rahman et al. [21] and use Adjusted Net Savings (ANS). ANS is defined as net national savings plus public expenditure on education, minus the costs associated with energy depletion, mineral depletion, net forest depletion, and carbon dioxide emissions.

We select ANS for several reasons. First, ANS captures both positive and negative contributions to sustainable development by including education expenditure as an investment in human capital and accounting for the depletion of natural resources and environmental degradation. Second, compared with traditional GDP measures, ANS offers a more comprehensive perspective on a country's genuine wealth by reflecting the long-term sustainability of economic activities. Third, ANS is a standardized indicator published by the World Bank, ensuring cross-country comparability and consistent data availability—an essential feature for our comparative analysis of developed and developing economies. By using ANS as a proxy for green growth, this study seeks to more accurately assess the balance between economic expansion and environmental preservation.

In addition to ANS, we include the following control variables: urban population rate (UR), trade openness (OPE), inflation growth rate (INF), and foreign direct investment as a share of GDP (FDI_GDP). Full definitions and data sources are detailed in **Appendix B**.

The linkage between green growth (GGDP) and green finance (GF) is estimated using a dynamic panel framework (Equation 1).

$$Y_{i,i} = A_1 Y_{i,t-1} + A_2 Y_{i,t-2} + \ldots + A_k Y_{i,t-k} + \beta_X X_{i,t} + u_i + \varepsilon_{i,t} \quad (1)$$

In which i is country and t is time

$Y_{i,t}$ = $(GGDP_{i,t}, GF_{i,t})$ is a random-level (1 × 2) vector of endogenous;

$Y_{i,t-p}$ are the level vectors (1 × 2) lagged endogenous variables;

$A_1, A_2, \ldots, A_k$ is the order vector ($k \times k$) of the estimated coefficients;

k is the optimal delay;

β_X are the matrices (l × k) estimated coefficients;

u_i is the dependent variable fixed effect vector;

$\varepsilon_{i,t}$ is the eigenvector error.

$X_{i,t}$: are exogenous vectors, UR, OPE, Inflation rate INF, and FDI_GDP.

The variables of the research model in this study are summarized in **Appendix B**.

3.2. Methodology

Principal Component Analysis (PCA) begins by standardizing each indicator (e.g., green credit, green investment, and public R&D spending) so that they all have a mean of zero and a standard deviation equal to one. Next, it computes the covariance (or correlation) matrix of these standardized variables and performs an eigen decomposition on the matrix to obtain a set of eigenvalues and their corresponding eigenvectors. Each eigenvector defines a principal component (PC)—a linear combination of the original indicators, ranked by the proportion of total variance it explains (i.e., based on its eigenvalue).

In our study, we retain the first principal component, as it accounts for the largest proportion of variance among the three indicators. The associated weights (loadings) reflect the relative contribution of each green finance metric. We then construct the Green Finance (GF) Index by projecting the standardized data onto this first eigenvector, producing a single composite score for each country and year.

By transforming correlated variables into an orthogonal (uncorrelated) component, PCA eliminates multicollinearity and ensures that the GF index preserves as much statistical information as possible without redundancy [22–25]. This procedure reduces dimensionality—distilling multiple indicators into a single, robust proxy—and mitigates overfitting, making the index suitable for both cross-sectional and time-series analyses. Recent studies have validated PCA as an effective technique for developing composite indices in the fields of finance, green growth, and sustainable development [26–28].

Panel Vector Autoregression (PVAR) is employed to examine the dynamic interactions between green finance and green growth across our two country groups. Unlike traditional panel models, PVAR treats all variables as jointly endogenous, allowing each to depend not only on its past values but also on the lagged values of all other variables [28]. This structure ensures that feedback effects—such as how changes in green finance influence green growth and vice versa—are fully captured.

Given our relatively small sample size and limited period, we apply a standard temporal disaggregation technique to convert annual data into quarterly observations. By interpolating the annual series into quarterly frequencies, we increase the number of time-period observations, thus enhancing the robustness and reliability of our PVAR estimates.

4. Results

4.1. The Principal Components Analysis (PCA) Result

Table 1 reports the loadings of each standardized indicator on the first principal component used to construct GF.

Each loading reflects the relative contribution of that indicator to the GF index (Equation 2). Specifically, the GF score for country i and year t is calculated as a weighted sum of the four normalized variables:

$$GF = 0.4044^{*}CFA + 0.0155^{*}CFE + 0.5849^{*}BRE + 0.7049^{*}BE \quad (2)$$

Table 1. PCA result.

Green Finance (GF)				
Variable	**CFA**	**CFE**	**BRE**	**BE**
	0.7049	0.0155	0.5849	0.4044

The PCA loadings reveal that credit directed toward agriculture (CFA, 0.7049) contributes most significantly to the composite Green Finance (GF) index, followed by public R&D for renewable energy (BRE, 0.5849) and public R&D for the environment (BE, 0.4044). In contrast, credit for renewable energy (CFE, 0.0155) carries a negligible loading, indicating that the other components largely explain its variation. Practically speaking, these loadings suggest that agricultural lending plays the most influential role in defining a country's green finance profile, while government R&D—particularly in renewable energy—also contributes substantially. The minimal loading on CFE implies that, once agriculture credit and public R&D budgets are accounted for, additional credit to the renewable energy sector adds little unique explanatory power to the GF index.

CFA (Credit for Agriculture) exhibits the highest loading (0.7049), underscoring its pivotal role in the green finance framework. Agriculture often imposes significant environmental pressures, such as land degradation, water scarcity, and vulnerability to climate change. Directing credit into sustainable farming practices can therefore yield substantial environmental benefits. For instance, financing organic agriculture, water-efficient irrigation systems, and climate-resilient crop varieties helps reduce soil erosion, conserve water, and preserve biodiversity. Such investments not only mitigate agriculture's carbon footprint but also enhance carbon sequestration in soils. By prioritizing sustainable agriculture, green finance can transform a high-impact sector into a central driver of environmental resilience and long-term green growth.

CFE (Credit for Renewable Energy) and BRE (Public R&D Budget for Renewable Energy) play a more indirect role in the agricultural sector. For example, financing solar-powered irrigation or biogas systems generated from farm waste can enhance the sustainability of farming operations. Although the PCA assigns a low loading to CFE (0.0155), this result suggests that, within our dataset, the direct financial link between renewable energy and agriculture remains limited. Nonetheless, as renewable energy infrastructure expands, especially in rural areas, its contribution to agricultural sustainability is likely to grow by delivering affordable, clean energy that supports both productivity and environmental objectives.

BRE's loading of 0.5849 underscores the significance of government investment in renewable energy R&D. In the agricultural context, such funding stimulates the development of technologies—such as bioenergy from crop residues and solar-powered farming equipment—that reduce the environmental footprint of agriculture. By supporting research on renewable energy applications in farming, public R&D investment fosters resource-efficient innovations, lowers greenhouse gas emissions, and promotes carbon-neutral agricultural practices.

BE's loading of 0.4044 highlights the importance of government spending on environmental R&D in advancing sustainable agriculture. Although its weight is lower than that of CFA, BE-driven investments contribute to improved land management practices, including soil conservation and precision farming, which help prevent erosion and minimize pollutant runoff. Research funded through BE can also generate innovative, eco-friendly agricultural technologies—such as biodegradable pest control solutions and water-treatment systems for agricultural runoff—that address the challenges of soil degradation and water scarcity. By financing studies focused on ecological restoration and sustainable resource use, BE enables agricultural practices to evolve in ways that safeguard ecosystem services, enhance biodiversity, and ensure long-term productivity.

Overall, the PCA findings indicate that channeling credit into sustainable agriculture (CFA) constitutes the most influential component of the Green Finance Index, emphasizing the sector's critical role in fostering green growth. Government R&D support—both for renewable energy (BRE) and broader environmental research (BE)—also makes substantial contributions by enabling innovations that mitigate agriculture's ecological impact. Integrating agriculture more fully into green finance strategies offers policymakers a powerful tool to combat environmental degradation, improve resource efficiency, and enhance resilience and food security.

In practical terms, this means designing targeted financial instruments—such as concessional loans for climate-smart agriculture—and strategically allocating public R&D funding toward technologies that improve soil health, conserve water, and promote the use of renewable energy in farming. Such measures are essential to steering agriculture toward a truly sustainable trajectory.

4.2. PVAR Regression Results

4.2.1. Descriptive Statistics

The summary statistics reveal notable contrasts between developed and developing countries in both green growth (GGDP) and green finance (GF) over the 2005–2022 period. On average, developing economies exhibited a higher mean GGDP (18.76) than their developed counterparts (14.46), suggesting stronger adjusted net savings once environmental factors are incorporated. However, this was accompanied by greater volatility, with a standard deviation of 4.06 compared to 2.85 for developed countries, indicating more pronounced year-to-year fluctuations (**Table 2**). GGDP in developing countries ranged from a low of 12.21 to a high of 33.34, whereas developed nations experienced a narrower span, from 8.31 to 25.02. These figures suggest that although developing economies often achieved higher levels of green growth, their progress was less stable, likely due to episodic policy interventions and a heavier reliance on external funding sources. In contrast, developed countries demonstrated more consistent—albeit moderate—advancements in aligning economic growth with environmental sustainability.

Table 2. Descriptive statistics for the period variables from 2005–2022.

	Developed Countries				**Developing Countries**			
	Mean	**Std. Dev.**	**Maximum**	**Minimum**	**Mean**	**Std. Dev.**	**Maximum**	**Minimum**
GGDP	14.4644	2.8464	8.3144	25.0161	18.7644	4.0644	12.214	33.3444
GF	11.4747	11.0462	55.4875	−5.9438	19.8829	29.3554	200.4737	−8.2607
UR	73.8190	12.0826	91.8760	54.3150	49.9764	17.8209	91.2030	17.0040
OPE	94.5908	31.7043	176.7476	50.4625	70.8084	36.2394	210.4002	1.2188
INF	2.1819	2.1198	12.3487	−1.9311	6.2252	8.4208	63.2925	−1.5841
FDI_GDP	−0.0084	0.0509	0.2019	−0.2906	−0.0440	0.1438	0.1269	−1.8934

A similar pattern emerges in the domain of green finance. Developing countries recorded a higher average GF index (19.88) compared to developed countries (11.47), implying greater mobilization of capital toward environmentally beneficial projects. Nonetheless, the variability in GF was substantially higher in developing economies, with a standard deviation of 29.36, compared to 11.05 in developed ones. This reflects sharp spikes—most notably a peak value of 200.47—followed by occasional contractions, with values dropping as low as −8.26. In contrast, developed countries maintained smaller but more stable green finance flows, ranging from −5.94 to 55.49. These disparities are likely attributable to differences in institutional capacity and access to capital: developing nations often experience intermittent surges due to international financing or time-bound subsidy programs, while developed economies benefit from mature financial markets and consistent regulatory frameworks.

Taken together, these results indicate that developing countries, while making significant strides in green growth and green finance, face greater challenges in sustaining such efforts. Developed countries, by contrast, demonstrate more incremental yet reliable progress in integrating environmental objectives into their economic frameworks.

4.2.2. Unit Root Test

To estimate the PVAR model, we first conducted panel unit root tests to assess the stationarity of each time series, employing the Augmented Dickey-Fuller (ADF) test tailored for panel data. In the group of developed countries, the variables green growth (GGDP), green finance (GF), and foreign direct investment as a share of GDP (FDI_GDP) were found to be stationary at levels (i.e., integrated of order zero, I(0)). By contrast, inflation (INF) and trade openness (OPE) became stationary only after first differencing, indicating that they are integrated of order 1 [I(1)]. For developing countries, the results revealed that urbanization rate (UR) and FDI_GDP are I(0), while INF and OPE remain non-stationary at levels but become stationary after first differencing (I(1)). Given the mixed orders of integration across variables and country groups, we specified the PVAR model in levels for I(0) series and in first differences for I(1) series. This approach ensures that each variable satisfies the necessary stationarity condition before proceeding with model identification and estimation (**Table 3**).

Table 3. Unit root test results.

Variable	Developed Countries		Developing Countries	
	Coefficient	**Probability**	**Coefficient**	**Probability**
GGDP	57.6026	0.0001***	93.1116	0.1887
GF	34.546	0.0432**	65.8557	0.9034
OPE	19.2080	0.6325	66.3192	0.8961
UR	6.4858	0.9994	511.021	0.0000***
INF	18.5677	0.6718	68.1709	0.8631
FDI_GDP	63.1651	0.0000***	219.362	0.0000***

Note: ** and *** denote statistical significance at the 5% and 1% levels, respectively.

4.2.3. Optimal Lag Selection

Before estimating the PVAR, we determined the optimal lag length using several information criteria. As shown in **Tables 4** and **5**, the sequential modified LR test (LR), Akaike information criterion (AIC), final prediction error (FPE), Schwarz information criterion (SC), and Hannan-Quinn criterion (HQ) all indicate that a lag length of three is optimal for the developed-country sample, while a lag length of five is optimal for the developing-country sample.

4.2.4. The Analysis of Autocorrelation

Table 6 presents the results of the autocorrelation tests conducted for the PVAR model specifications. In the developed-country sample, neither the third-order lag nor any of the first through third lags exhibit statistically significant autocorrelation. This suggests that the residuals up to lag 3 behave as white noise, indicating the absence of serial correlation. Similarly, in the developing-country model, no evidence of autocorrelation is found at lag 5 or across lags 1 through 5. These findings validate the appropriateness of the selected lag lengths—three lags for developed countries and five lags for developing countries—in capturing the underlying dynamics of the data. By effectively eliminating serial correlation in the error terms, the lag specifications satisfy a key assumption for consistent and unbiased PVAR estimation.

Table 4. Results of optimal lag testing of model variables for developed countries.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−421.2000	NA	4.6337	12.8849	13.0176	12.9373
1	−258.3541	301.0182	0.0542	8.4350	9.0985	8.6972
2	−220.7948	64.8750	0.0284	7.7817	8.9760*	8.2536
3	−195.9027	39.9782*	0.0219*	7.5122*	9.2374	8.1939*
4	−182.4075	20.0384	0.0243	7.5881	9.8441	8.4796

Note: * marks the optimal lag order under this criterion. More indicators point to the third order, so lag 3 is selected as the optimal lag length.

Table 5. Results of optimal lag testing of model variables for developing countries.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−4731.9460	NA	264055.2000	20.9975	21.0249	21.0083

Table 5. *Cont.*

Lag	LogL	LR	FPE	AIC	SC	HQ
1	−3849.2900	1749.6560	5484.0960	17.1232	17.23263	17.1664
2	−3847.2360	4.0444	5655.6820	17.1540	17.3455	17.2295
3	−3844.6750	5.0084	5819.5880	17.1826	17.4561	17.2904
4	−3825.3220	37.5894	5558.6000	17.1367	17.4922	17.2768
5	−3757.5260	130.7822	4282.986*	16.8759*	17.3135	17.04840

Note: * marks the optimal lag order under this criterion. More indicators point to the fifth order, so lag 5 is chosen as the optimal lag length.

Table 6. Autocorrelation analysis results.

Developed Countries			Developing Countries		
Lag	**LM. Statistics**	**Probability**	**Lag**	**LM. Statistics**	**Probability**
1	21.8122	0.1495	1	9.4072	0.3600
2	37.8287	0.1333	2	1.0406	0.9993
3	21.9922	0.1436	3	4.7112	0.8586
			4	7.0610	0.6308
			5	9.7339	0.3725

4.2.5. IRF Results

In developed countries, a positive shock to green finance (GF) leads to a 0.5966% increase in green growth (GGDP) in the second quarter, with the effect persisting into the third quarter at 0.4367%. This outcome suggests that robust regulatory environments and mature green-finance frameworks effectively channel capital into environmentally sustainable projects, such as technological innovation and green infrastructure investments. These initiatives help mitigate climate change, lower CO_2 emissions, and reduce pollution-related costs, thereby promoting improvements in GGDP (**Figure 1**).

Conversely, a positive shock to GGDP induces a 0.9201% rise in GF during the first quarter, implying that stronger green-growth performance incentivizes both policymakers and financial institutions to reinforce green-finance mechanisms. Put differently, as green growth enhances returns on sustainable investments and raises environmental awareness among firms and households, it attracts additional capital into green-finance instruments.

Taken together, these findings indicate a mutually reinforcing, bidirectional relationship between green finance and green growth in developed economies. This dynamic aligns with prior empirical evidence reported by Van et al [3], which also document the presence of positive feedback loops between financial mobilization and environmental sustainability outcomes in high-income contexts.

In developing countries, a one-standard-deviation increase in green finance (GF) results in a 2.387% decline in GGDP in the second quarter, with no further significant effects thereafter. Conversely, a positive shock to GGDP induces a 0.4236% rise in GF during the first quarter, with the effect dissipating shortly after.

These findings indicate a negative and asymmetric dynamic between green finance and green growth in developing economies—a result that diverges notably from previous research, and from our own findings in developed countries. This contrast represents a novel contribution of the present study.

The negative relationship between GF and GGDP in developing contexts can be attributed to several structural and institutional shortcomings. First, weak transmission mechanisms prevent green-finance resources from reaching genuinely sustainable or environmentally beneficial projects. Unstable regulatory environments, limited oversight of credit allocation, and ambiguous or poorly enforced green classification criteria often lead to the misallocation or ineffective use of green funds. As a result, the environmental returns expected from these investments are not realized, undermining GGDP.

Second, many developing countries continue to prioritize conventional economic growth (TGDP) over sustainability considerations. Consequently, their green finance ecosystems remain nascent, fragmented, and underregulated. This structural imbalance is evident in **Figure 2**, which shows that while both GF and TGDP trended upward from 2005 to 2022, GGDP growth sharply deteriorated, from 19.01% in 2005 to just 2.10% in 2019. Notably, when environmental costs were fully internalized, GGDP fell into negative territory, reaching a value of −4.41% in 2015.

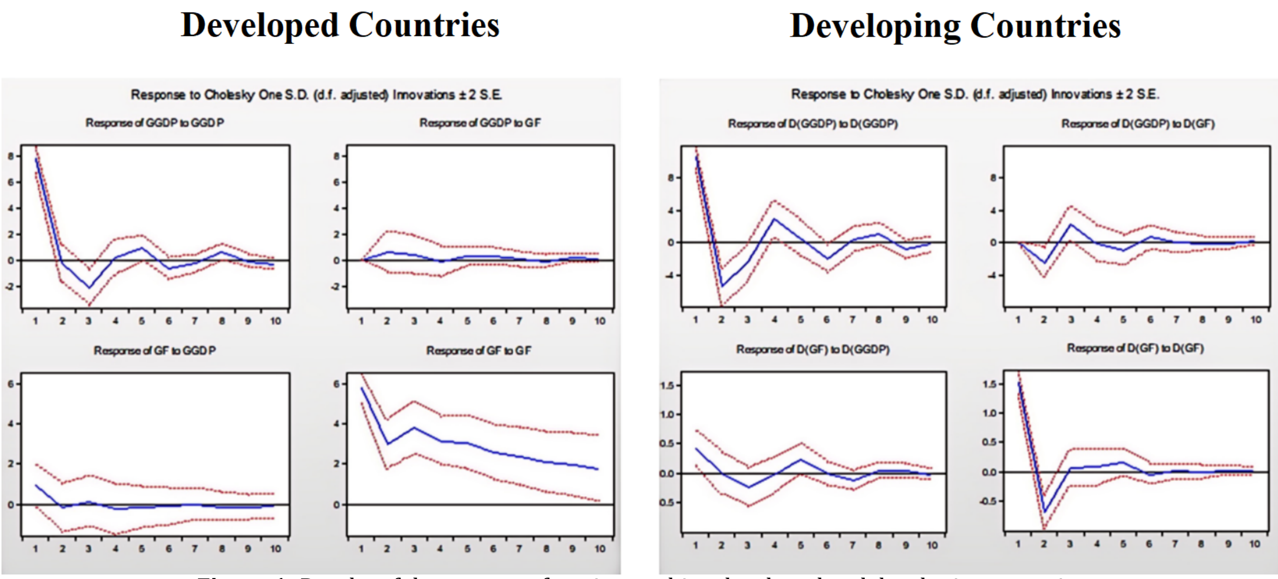

Figure 1. Results of the response function pushing developed and developing countries.

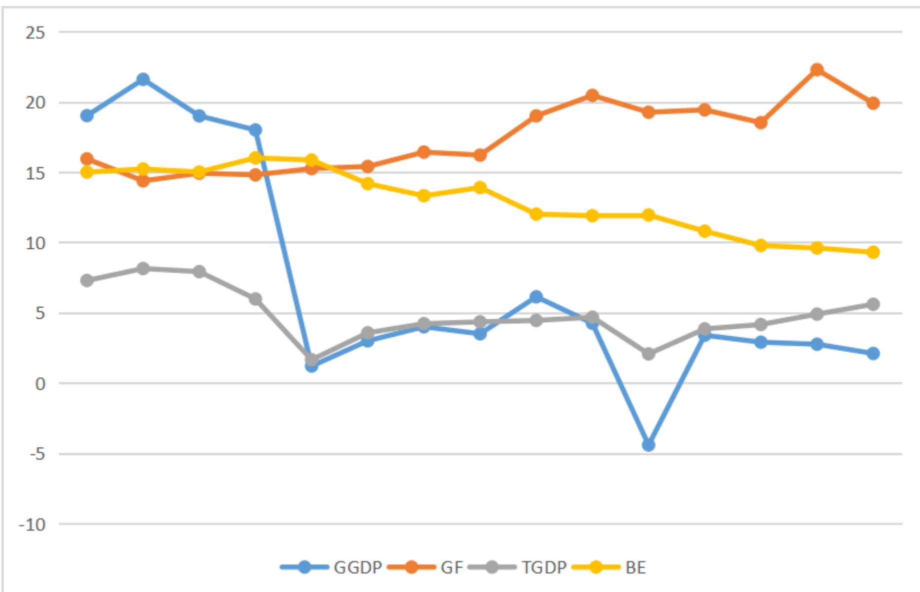

Figure 2. Growth chart of GGDP, traditional GDP and green finance of developing countries 2005–2022.

These patterns suggest that, in the absence of robust institutions, effective governance, and a genuine commitment to sustainable development, green finance in developing countries may inadvertently exacerbate environmental degradation, rather than mitigate it. Without substantial reforms, expanding green finance alone will be insufficient—and could even be counterproductive—in promoting green growth in these contexts.

Figure 2 also reveals a steady decline in public R&D spending on environmental protection (BE) in developing countries, underscoring deeper political-economy constraints. Environmental initiatives typically require long-term investment horizons and sustained political commitment, both of which are frequently sacrificed in favor of more immediate economic or political objectives.

Given limited fiscal resources, governments in developing economies face difficult budgetary trade-offs, and environmental R&D often ranks low on the priority list compared to sectors such as healthcare, education, and infrastructure. Moreover, public awareness of environmental issues remains limited in many of these countries, weakening grassroots support for sustainability initiatives. In some cases, resistance from industries concerned about compliance costs and profit margins further impedes policy momentum.

Persistent underfunding of environmental R&D hinders green finance from delivering tangible green growth outcomes. Without adequate investment in research and innovation, green-finance mechanisms struggle to generate the technological breakthroughs and institutional capacity needed to support a meaningful and sustained transition toward environmental sustainability.

Table 7 presents the variance decomposition results, revealing significant contrasts between developed and developing countries in terms of how green finance (GF) and other factors contribute to fluctuations in green growth (GGDP). In developed economies, 89.73% of the variation in GGDP is explained by its past values, while GF accounts for only 5.46%, and the remaining 4.81% is attributed to trade openness, inflation, urbanization, and international integration. By contrast, in developing countries, GF contributes a larger share—6.57%—to GGDP variation, while GGDP's lags explain 87.72%, and other variables account for 5.71%.

Table 7. Variance decomposition results.

Variance Decomposition of GGDP						
	Developed Countries			Developing Countries		
Period	**GDP**	**GF**	**Other Variables**	**GDP**	**GF**	**Other Variables**
1	100.0000	0.0000	0.0000	100.0000	0.0000	0.0000
2	87.8652	6.9763	5.1585	90.2571	6.3826	3.3602
3	85.9731	7.1427	6.8842	80.3133	10.3251	9.3616
4	85.0291	7.7148	7.2561	80.3110	9.5647	10.1244
Variance Decomposition of GF						
	Developed Countries			Developing Countries		
Period	**GDP**	**GF**	**Other Variables**	**GDP**	**GF**	**Other Variables**
1	1.2732	98.7268	0	4.3343	95.6657	0.0000
2	1.1072	98.6957	0.1971	4.6698	94.4856	0.8446
3	0.8616	97.7499	1.3886	4.9560	92.4774	2.5666
4	0.7779	97.9365	1.2856	4.9155	91.6274	3.4572

The pattern reverses when decomposing the variance of green finance (GF). In developed countries, GF is largely self-determined (98.28%), with only 1.01% explained by GGDP and 0.72% by the remaining variables. In developing economies, however, GF is more responsive, with 4.72% of its variation driven by GGDP and 1.72% by other factors. This result suggests a stronger feedback loop in developing contexts, where improvements in green growth stimulate additional green-finance allocations, possibly reflecting adaptive responses by policymakers or financial institutions to sustainability signals.

Although the 6.57% contribution of GF to GGDP variation may appear modest, it nevertheless underscores the growing importance of green finance in shaping environmental and economic trajectories in developing nations. Comparative findings from the literature support this interpretation. For instance, Zhang et al.[25] report that green finance explained approximately 25% of high-quality economic development in China's Yangtze River Delta at an early stage, rising to 56% as institutional and policy environments matured. Similarly, Rasoulinezhad and Taghizadeh-Hesary [19] observed strong impacts of green finance on environmental quality in countries with established green credit frameworks. The lower proportion observed in our study likely reflects the nascent stage of green finance development in many developing countries, where institutional support, public awareness, and data infrastructure are still in the process of evolving. Additionally, the exclusion of informal or unreported green-finance activities from official metrics may lead to an underestimation of their true impact. In sum, although smaller than in some prior studies, the 6.57% share highlights an important policy implication: there is substantial potential to enhance the role of green finance in fostering green growth, particularly through institutional strengthening, financial innovation, and policy integration in the developing world.

5. Conclusions and Policy Implications

This report examines the relationship between green growth and green finance in both developed and developing countries from 2005 to 2022. Using a PVAR model, the IRF results reveal opposing effects between the two groups. In developed economies, green finance has a positive and reinforcing relationship with green growth. This suggests that well-established regulatory frameworks and mature green financial systems effectively channel capital into environmentally sustainable projects—particularly in technology and infrastructure—that help mitigate climate change, reduce CO_2 emissions, lower pollution costs, and stimulate GGDP growth.

By contrast, in developing countries, the relationship between green finance and green growth is negative. This implies that green financial systems in these countries have not yet translated into meaningful support for eco-friendly initiatives or pollution mitigation. Additionally, public R&D spending on environmental protection has not yielded the intended environmental or economic outcomes.

The variance decomposition analysis further reveals that the interaction between green finance and green growth is more pronounced and responsive in developing countries compared to developed ones. This indicates a greater potential—but also higher volatility—in the effectiveness of green finance mechanisms in these emerging contexts.

Policy implications are twofold. For developing countries, it is essential to strengthen their legal and institutional frameworks for green finance and promote commercial investment in environmentally beneficial projects. This includes clearer definitions of what constitutes "green" projects, improved oversight, and targeted incentives.

For developed countries, policies should focus on accelerating the transition to sustainable business models by:

- Phasing out or divesting from projects and firms with high environmental risks (e.g., fossil fuel dependency);
- Encouraging investments in renewable energy, sustainable materials, and low-carbon technologies;
- Supporting firms and funds that lead in renewable energy production and distribution.

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Not applicable.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The author declares no conflict of interest.

Appendix A

Table A1. Description of variables and indicators of green finance and green growth.

Green Finance (GF)				
Variable Name	**Indicators and Symbols**	**Measure**	**Ref.**	**Data Sources**
Green Credit	Credit for Agriculture (CFA)	Credit growth provided to the agricultural sector (%)	Van et al. [3]	OECD
	Credit for renewable energy generation (CFE)	Credit growth provided for renewable energy (%)	Van et al. [3]	
Green Investment	Public R&D budget for renewable energy sector (BRE)	Public R&D budget for renewable energy to total public R&D energy (%)	Li et al. [7]	
Government Support	Public R&D budget for the environment (BE)	Environmentally related public R&D budget to total public R&D (%)	Li et al. [7]	

Source: Compiled by the authors.

Appendix B

Table A2. Description of variables in the model.

Dependent Variable	Sign	Measure	Source	Data
Green Growth	GGDP	GGDP is proxied with adjusted net savings which is the sum of net national savings and education expenditure minus energy depletion, mineral depletion, net forest depletion, and carbon dioxide. (%)	Dmuchowski et al. [20]	WDI
Green Finance	GF	Calculation by PCA method with the criteria in **Appendix A** (%)	Author	
Urban Population	UR	Urban population/Total population (%)	Khoi and Dinh [26]	WDI
Trade Openness	OPE	Total exports and imports as a percentage of GDP	Ozili [5], Huy et al. [29]	
Inflation Rate	INF	Annual CPI growth rate (%)	Khoi and Dinh [26], Nguyen The et al. [30]	
International Integration	FDI-GDP	Foreign direct investment as a percentage of GDP	Nguyen The et al. [30], Huy and Tam [31], Saydaliev and Chin [32]	

Source: Compiled by the author.

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