Green Finance, Financial Development, and Environmental Sustainability: Evidence from Emerging Economies

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ABSTRACT

This research examines how financial systems can contribute to lowering the ecological footprint in emerging economies, focusing on the interplay between financial development and green finance. Applying the ARDL model, the study finds that green finance can partially offset the environmental risks linked to early financial expansion by encouraging cleaner investment patterns in the short run. Yet, without strong sustainability integration, long-term benefits may erode, exposing countries to a rebound in ecological pressures.
The results underline the importance of embedding sustainability into the core of financial policy design. To this end, the paper recommends reinforcing green finance regulations, fostering innovation ecosystems, increasing public and institutional awareness, and developing standardized environmental performance metrics.

Keywords: Environmental policy integration, Green finance, Financial development, Sustainable development, Green economic transition,Ecological footprint

JEL Codes: G18; G20; Q56; Q58; O44

1.INTRODUCTION

Environmental sustainability and the reduction of the ecological footprint have become pressing global concerns. International agreements such as the Kyoto Protocol, the Paris Agreement, and COP28 underscore the urgency of addressing these issues. However, the involvement of the financial sector in advancing environmental objectives remains limited, particularly in emerging economies. These countries, which are not necessarily constrained by growth challenges, must intensify their financial sector's role in fostering environmental goals and developing coherent policies accordingly. It is therefore crucial to guide policymakers and decision-makers toward integrating environmental priorities into their strategic frameworks.

Recent literature emphasizes that a robust and efficient financial system facilitates access to green capital, encourages sustainable economic activities, and supports the transition to cleaner energy consumption (Sinha et al., 2021). Specifically, such systems can enable the financing of advanced technologies and environmentally friendly production processes, thereby mitigating environmental degradation. Financial markets also contribute to the research and development of renewable energy

ISSN: 2961-6638

and attract foreign investments that transfer green technologies to host countries (Ahmed et al., 2021).

Climate change affects multiple dimensions including productivity, institutional stability, conflict risk, biodiversity, and the frequency of extreme weather events. The economic response to these environmental disruptions varies: some studies suggest that climate change significantly hampers economic performance and long-term development prospects (Aldieri et al., 2022), while others highlight its stronger influence on sustainability, productivity, and investment decisions (Shahbaz and Sinha, 2019).

Addressing climate change and promoting sustainable development is imperative. The financial sector has a central role in these efforts (Bhattacharyya, 2022). In this context, green finance emerges as a key mechanism for improving environmental quality and fostering ecological well-being. It enables businesses to generate value without compromising environmental integrity (Lee and Lee, 2022). As awareness of the environmental and social consequences of economic activities increases, green finance is becoming a cornerstone of global financial policy. Its primary objective is to decouple economic growth from environmental degradation, aligning financial practices with the goals of the Paris Agreement (Hussain et al., 2022).

This study seeks to explore the complex interlinkages among green finance, financial development, and environmental sustainability. It aims to assess how green finance contributes to reducing the ecological footprint, examine the influence of financial development on environmental outcomes, and investigate the broader relationships among economic growth, sustainability, and environmental degradation. Additionally, it offers evidence-based policy recommendations to help decision-makers adopt more sustainable financial practices (Bhattacharyya, 2022).

The analysis is guided by three key hypotheses. First, green finance moderates the effects of financial and economic development on the ecological footprint. Second, financial development contributes positively to environmental sustainability when it is aligned with green finance principles. Third, neglecting sustainability considerations in financial development may exacerbate environmental degradation.

To test these hypotheses, the study employs the AutoRegressive Distributed Lag (ARDL) model an econometric method well-suited to capturing the dynamic relationships among financial, economic, and environmental variables. The model incorporates cross-dependence analysis to provide a comprehensive understanding of how green finance and financial development influence sustainability outcomes. The empirical focus is on emerging economies, particularly in the BRICS and Asia-Pacific regions, with the goal of generating actionable insights to support environmentally responsible financial strategies

2. Exploration of scientific literature

In reviewing previous studies on financial development, green finance, and their implications for the ecological footprint, we identify divergences and gaps in the current literature. This approach also guides us towards the three main areas of investigation in our research.

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2.1. Financial Development and Ecological Footprint:

The dynamics of the financial sector are crucial for the economic and human development of a country. Measures widely used in the financial development literature include liquid liabilities and domestic credits to the private sector (Bilgili et al., 2020;; Shahbaz et al., 2016). However, it can have negative effects on the environment (Javid et Sharif, 2016; Saud et al., 2020). Economic growth can lead to an increase in energy demand and greenhouse gas emissions. The rise in loans and investments in polluting industries can also result in increased pollution (Crifo et al., 2020; Ahmed et al, 2022).

Several studies have shown that financial development can be a driver of sustainable economic growth if directed towards green and sustainable investments (Stiglitz et al., 2010; Clark et al., 2019; Griffith-Jones et al., 2020). Green investments can stimulate economic growth while reducing greenhouse gas emissions and protecting the environment (Shen, Yijuan, et al.., 2021).

A dynamic financial sector is vital for the human and economic development of an economy. However, economic, technological, and social development often render the ecological environment fragile and susceptible, exacerbating the "butterfly effect" by increasing the ecological footprint (Kwakwa et al., 2021). A larger ecological footprint means that human development consumes more natural resources and harms the ecosystem. Indeed, rapid economic development and growth come at the expense of a substantial expansion of the ecological footprint (Panayotou, 1993). The negative impacts of environmental degradation are increasingly magnified and affect various aspects of sustainable development (Apergis et al., 2018; Kong and Khan, 2019; Awodumi et al., 2020).

The literature review addressing the relationship between financial development and the ecological footprint presents conflicting arguments. The first set of research suggests that financial development significantly enhances environmental sustainability by reducing environmental degradation. For instance, studies conducted by Tamazian et al. (2009), Jalil and Feridun (2011), Salahuddin and Alam (2015), and Dogan and Seker (2016) have demonstrated that financial development reduces carbon emissions and improves environmental quality.

Conversely, the second set of research indicates a positive relationship between financial development and environmental degradation. Studies by Boutabba (2014), Javid and Sharif (2016), Ahmad et al. (2022), Abbasi et Riaz (2016), Shahbaz et al. (2016), Charfeddine and Ben Khediri (2016), Baloch et al. (2019), and Saud et al. (2020) have concluded that financial activity exacerbates environmental degradation. Using panel data from 27 countries, Uddin et al. (2017) studied the linear impact of income on the ecological footprint. Their results indicate a positive relationship between income (GDP) and the ecological footprint, as well as a negative relationship between financial development and the ecological footprint.

Finally, the third set of research suggests that financial development has no significant impact on environmental quality. Studies conducted by Ozturk and Acaravci (2013) and Destek and Sarkodie (2019) have shown that there is no significant relationship between financial development and environmental quality. Similarly, the findings of Ahmed et al. (2019) indicate that the ecological footprint (EF) is increased by energy and income, while financial development and population density have a mitigating effect on the EP in Malaysia. Saud et al. (2020) studied the impact of globalization and financial development on the EF in Belt and Road countries and found that the

ISSN: 2961-6638

effect of these factors varies among countries. While some countries experience an increase in the EF due to financial development and globalization, others witness a reduction in the EF. These results reflect significant divergences in the literature regarding the determinants of the EF, showing negative, positive, significant, or insignificant effects depending on the countries. In summary, financial development can have a contradictory impact on the EF, depending on the type of financing prevailing in each country.

2.2.Green Finance and Environmental Degradation :

Green finance aims to mitigate the negative impact of economic activities on the environment by financing sustainable and environmentally friendly projects (Zhou, M., and Li, X, 2022). It can help alleviate the adverse effects of environmental degradation by funding projects related to ecological restoration and sustainable resource management. Investments in green projects can also contribute to reducing greenhouse gas emissions and combating climate change (Jeucken, 2010; Hargreaves and Fink, 2012).

Using panel data from 27 provinces and municipalities in China from 2008 to 2017, Zhang et al.'s (2022) study applied an unexpected production model based on gaps to measure the efficiency of carbon emissions. The results demonstrated that green finance promotes carbon emission efficiency by stimulating technological progress and the modernization of the industrial structure. This study provides empirical evidence and policy insights to achieve peak and carbon neutrality goals, as well as to promote the development of green finance.

Indeed, green finance aims to incorporate environmental practices into the financial sector to promote more environmentally friendly outcomes. This approach involves issuing green credits, securities, and investments that support environmentally friendly projects to foster social well-being, human survival, and sustainable economic development (Ahmad et al., 2019 ; Yao and Tang, 2021; Hunjra et al., 2023). If financial institutions provide large-scale green financing, it could help control the production of environmental pollutants such as carbon dioxide (Lv and Li, 2021).

Green finance policies aim to direct loans towards businesses and public institutions located in areas with less developed financial infrastructure (Liu et al., 2019; Sachs et al., 2019). The United States, China, and France rank as the top three countries adopting green credit policies. To be successful, a green finance strategy must leverage existing technology and pre-existing links between businesses and banks (Zhang, 2020).

In a similar vein of analysis, Zhang, B., & Wang, Y. (2021) studied the impact of green finance on energy efficiency and carbon emissions, finding that many financial institutions allocate a specific amount of money to provide green loans on favourable terms. This allows businesses to secure funding to transform their energy consumption model, adopt energy-efficient technologies, and enhance the energy efficiency of their business processes. This can contribute to reducing the use of non-renewable energy resources and limiting carbon emissions. However, Zhang, B., & Wang, Y. (2021) only considered green finance and overlooked other renewable energy sources. They recommend that future studies also include these sources to predict CO2 emissions.

Ren, X., Shao, Q., & Zhong, R. (2020) analysed the impact of the green finance development index, covering four dimensions (green insurance, securities, credit, and investment), on carbon emissions and sustainable development using data on the green finance industry in China from 2000 to 2018.

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Their results show a negative relationship between green finance and carbon emissions but a positive relationship between green finance and sustainable development. However, they did not account for the role of renewable energy sources in CO2 emissions and recommended that future studies also include these sources in predicting CO2 emissions.

Green finance enhances the competitiveness of financial markets and promotes environmental performance with sustainability policies for developing economies (Ma, Mengjuan, et al., 2023). Additionally, the financial sector is not immune to external disruptions, leading to long-term volatility that impacts environmental policies and the state of the environment. Due to its distinctive role as a financial intermediary, the banking industry plays a crucial role in achieving sustainability goals (Alexander, 2014; Yip, A. W., & Bocken, N. M., 2018). However, research by Ruiz et al. (2014) revealed that this banking industry was not spared from the financial shock of the 2008 subprime crisis. In a similar vein of analysis, studies by Forcadell et al. (2020) suggest that external disruptions, such as financial crises, technological revolutions, and pandemics, tend to stimulate the digital and sustainable transformation of banks. While these disruptions act as a catalyst for the digital and sustainable transformation of banks, they also create a volatile environment that compels banks to adapt and evolve to remain competitive and relevant.

2.3.Green Finance, Financial Development, and Sustainable Development :

Many researchers have studied the relationship between economic growth and environmental quality in the context of the Environmental Kuznets Curve (EKC) (Weimin, Zhu, et al., 2022; Wang, Q., Yang, T., & Li, R., 2023). Although closely tied to a country's development process, the impact of various financial and economic factors on environmental quality requires further in-depth research.

Green finance is a relatively new concept that aims to channel capital flows into sustainable and environmentally friendly investments. It falls within the broader framework of sustainable development, which is a comprehensive approach seeking to reconcile economic growth, environmental protection, and social equity (Hussain et al., 2022; Lee and Lee, 2022).

Green finance is often considered a subset of sustainable finance, which encompasses all financial activities that integrate environmental, social, and governance (ESG) considerations (Bhattacharyya, R. (2022)). Green finance can act as a catalyst for financial development by mobilising capital to fund projects with significant environmental and social impact, such as renewable energy, sustainable infrastructure, and clean technologies. Several studies have shown that sustainable investments can generate attractive long-term financial returns while contributing to sustainable development goals (Hussain et al., 2022; Lee and Lee, 2022).

Green finance is a key element of the transition towards sustainable development, which is an economic development that meets the needs of the present generation without compromising the ability of future generations (Zhang, Peng, et al., 2023). Green finance can play a significant role in achieving sustainable development goals by mobilising capital to fund projects that contribute to these objectives. It can also help promote sustainable business practices and encourage companies to consider environmental, social, and governance considerations.

To mitigate the negative impacts of financial development, Adebayo, Tomiwa Sunday et al. (a) (2023) propose the idea that adopting green financial measures, simultaneously promoting economic growth and socio-economic conditions, could be an effective approach to enhancing environmental

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quality and achieving sustainable development goals in China. Additionally, investment in energy technologies and the increased use of renewable energy, aimed at stimulating technological innovation, promotes environmental sustainability. These efforts also contribute to achieving sustainable development goals in both the short and long term, as indicated by the findings of Adebayo, Tomiwa Sunday, et al. (b) (2023).

Environmental sustainability is a crucial element for long-term economic development. WAME region economies can achieve ecological sustainability and sustainable development by enhancing their levels of financial globalisation (Kihombo, Shauku, et al., 2022). Furthermore, environmental degradation can lead to significant economic costs (Zhou, Y., Li, Y., & Liu, Y, 2020). Therefore, it is essential to identify factors influencing the ecological footprint of economies.

Furthermore, the development of the public banking sector is considered a key factor in economic development (Smallridge, D., & De Olloqui, F. 2011). Thus, facilitating farmers' access to funding for adopting new technologies could help overcome sustainable development challenges by strengthening financial lending strategies, with financial inclusion being a crucial element in this perspective (Georgopoulou E et al., 2017; Shobande et Enemona, 2021). Therefore, establishing a dynamic and sustainable financing strategy is crucial to support domestic private investors engaged in the exploration and development of natural resources, considering macroeconomic sustainability and thereby inducing environmental improvement. Simultaneously, the establishment of a robust financial market remains essential to facilitate the implementation of policies aimed at promoting sustainable environmental management (Shobande, O. A., & Enemona, J. O. 2021).

According to SAUD, Shah, et al. (2020), the interactions between financial development and globalisation have significant repercussions on the ecological footprint (EF). It is observed that financial development influences environmental degradation, emphasising the need to implement initiatives to mitigate ecological deterioration. Immediate intervention measures are therefore essential to promote a sustainable environment. Thus, it is important to identify factors influencing the ecological footprint of economies and establish green indicators in national accounting, such as green GDP and ecological footprint.

3.Methodological Approach and Empirical Data

This study analyzes the impact of financial development, green finance, and sustainable development on the environment by measuring the ecological footprint across 18 emerging economies from the BRICS and Asia-Pacific regions over the 1990-2021 period. Additionally, it examines the effect of financial development, green finance, and ecological footprint on sustainable development, measured by adjusted net savings.

Data were sourced from the World Bank and IMF. Financial development is measured by domestic credit to the private sector (% of GDP), green finance by green bonds and green investments, and the ecological footprint by CO_2 emissions. Economic growth is captured by GDP per capita, while energy consumption is measured by total energy consumption. A GF-SD indicator is introduced to assess the interaction between green finance and sustainable development.

The study employs two econometric models inspired by Ahmad and Mahmood (2022). The first model investigates the determinants of the ecological footprint, integrating green finance in its

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second specification. The second model explores the moderating role of sustainable development in the relationship between green finance, financial development, and ecological footprint.

The methodology follows four steps: (i) cross-sectional dependence (CD) test, (ii) unit root tests (ADF-Fisher, IPS) to assess variable integration, (iii) ARDL estimation in the short and long run, including Pedroni's cointegration test, and (iv) Granger causality test. Estimations are performed using EViews.

4. Results and Discussion

The objective of this study is to examine the complex relationships between green finance, financial development, and environmental sustainability. The empirical results largely confirm the proposed hypotheses.

TABLE 1 CROSS-SECTION DEPENDENCE TEST RESULTS

CROSS-SECTION DEPENDENCE TEST			
NULL HYPOTHESIS: NO CROSS-SECTION DEPENDENCE			
VARIABLES	PESARAN CD STATISTIC	PROB.	
LN EF	49,19**	0.000	
LN FD	26.91**	0.000	
LN GDP	61,17**	0.000	
LN EC	23,61**	0.000	
LN SD	8,96**	0.000	
LN GF	6,91**	0.000	
LN SD-GF	9,91**	0.000	

*NOTE : P < 0.01, 0.05, 0.10 INDICATE SIGNIFICANCE LEVELS ***, **, AND *, RESPECTIVELY.*

Table 1 reports the results of the cross-sectional dependence test using Pesaran's CD statistic. The null hypothesis assumes no cross-sectional dependence among the panel units. For all variables LN_EF (ecological footprint), LN_FD (financial development), LN_GDP (economic growth), LN_EC (energy consumption), LN_SD (sustainable development), LN_GF (green finance), and the interaction term LN_SD_GF the CD statistics are strongly significant at the 1% level (p-value= 0.000), as indicated by double asterisks (**).

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These results indicate the presence of significant cross-sectional dependence across the panel, implying that economic or environmental shocks in one country are likely to influence others. This interdependence justifies the relevance of a panel-based analysis with international scope, particularly in the context of emerging economies where globalization and environmental externalities are key concerns.

Despite the detection of cross-sectional dependence, the analysis proceeds with a traditional ARDL approach, given that the panel comprises a limited number of countries and the time dimension dominates (T > N), making the ARDL framework still suitable. Additionally, appropriate robustness checks and specification diagnostics are applied to mitigate the influence of potential cross-sectional correlations in the residuals.

Furthermore, unit root tests (not shown here) confirm that all variables are integrated of order one, I(1), becoming stationary after first differencing. This justifies the use of the ARDL model to estimate both short-run dynamics and long-run relationships among green finance, financial development, and environmental sustainability.

TABLE 2 UNIT ROOT TEST.

	PESARAN'S LM SCALE		PESARAN'S CD	
VARIABLE	STAT TEST	PROB.	STAT TEST .	PROB.
LNEF	174,93**	0,000	49,19**	0,000
LNFD	71,95**	0,000	26.91**	0,000
LNGDP	219,21**	0,000	61,17**	0,000
LNEC	90,83**	0,000	23,61**	0,000
LNSD	32,19**	0,000	8,96**	0,000
LNGF	6,91**		6,91**	0,000

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		0,000			
LNSD_GF	17,53**	0,000	9,91**	0,000	

*NOTE : P < 0.01, 0.05, 0.10 INDICATE SIGNIFICANCE LEVELS ***, **, AND *, RESPECTIVELY.*

Table 2 reports the results of the Pesaran LM unit root test, which is suitable for panel data with potential cross-sectional dependence. The null hypothesis assumes that the variables are non-stationary.

The findings indicate that all variables in the model namely, ecological footprint (LN_EF), financial development (LN_FD), GDP per capita (LN_GDP), energy consumption (LN_EC), sustainable development (LN_SD), green finance (LN_GF), and the interaction term between sustainable development and green finance (LN_SD_GF) reject the null hypothesis at the 1 percent significance level. This confirms that each variable becomes stationary after first differencing, indicating that they are integrated of order one, or I(1).

In addition, the results from the Pesaran CD test confirm significant cross-sectional dependence across all variables, reinforcing the evidence presented earlier. This suggests that economic and environmental dynamics in one country are likely to influence others, which supports the relevance of conducting the analysis in a panel data framework.

With the order of integration established, the next step is to identify the optimal lag structure for the ARDL model. Based on the Akaike Information Criterion (AIC), the model with one lag for each variable, ARDL(1,1,1,1,1), yields the lowest AIC value of -3.8194. This indicates that it provides the best fit with the fewest parameters, making it the preferred specification.

These preliminary results confirm the appropriateness of using the ARDL approach to explore both the short-run dynamics and long-run relationships between green finance, financial development, and environmental sustainability.

TABLE 3: DETERMINATION OF OPTIMAL LAG LENGTH

MODEL1

LAG	LOGL	AIC*	BIC	HQ	SPECIFICATION
4	926.0736	-3.8892	-1.9010	-3.1001	ARDL(2, 2, 2, 2, 2)
2	898.2170	-3.8318	-2.0205	-3.1129	ARDL(1, 2, 2, 2, 2)
1	827.8723	-3.8194	-2.7159	-3.3814	ARDL(1, 1, 1, 1, 1)

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3	840.8835	-3.7983	-2.5179	-3.2901	ARDL(2, 1, 1, 1, 1)
MODEL 2					
LAG	LOGL	AIC*	BIC	HQ	SPECIFICATION
1	720.7136	-3.8267	-2.4210	-3.2651	ARDL(1, 1, 1, 1, 1)

Table 3 presents the results for selecting the optimal lag length for the ARDL model. Several lag structures were tested and compared using model selection criteria such as the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), and the Hannan-Quinn Criterion (HQ).

In Model 1, the ARDL specification with two lags for each variable (ARDL(2, 2, 2, 2, 2)) has the lowest AIC value of -3.8892, indicating the best overall fit among the competing models. Although other specifications, such as ARDL(1, 1, 1, 1, 1) and ARDL(2, 1, 1, 1, 1), also show relatively strong performance, the AIC clearly favors the two-lag structure. Therefore, Model 1 suggests that the most suitable lag length for capturing the dynamic relationships among the variables is two.

Model 2, which serves as a simplified version or robustness check, confirms that the ARDL(1, 1, 1, 1, 1) structure is also a valid alternative, with a strong AIC value of -3.8267. While it is slightly less optimal than Model 1 based on AIC, its simpler structure can offer practical advantages in estimation and interpretation, especially when working with a smaller sample size or fewer degrees of freedom.

Taken together, these results support the use of an ARDL framework with one or two lags, depending on the model complexity and the specific focus of the analysis.

Following the selection of the optimal lag structure, the Pedroni cointegration test was applied to assess whether a long-run relationship exists among the variables. The test rejects the null hypothesis of no cointegration at the 1 percent significance level for the between-dimension statistics, indicating that the variables are indeed cointegrated. This means that despite short-term fluctuations, the variables move together over time, supporting the suitability of the ARDL model for analyzing both short-run dynamics and long-term equilibrium relationships.

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TABLE 4 PEDRONI COINTEGRATION TEST:

	COMMON AR COEFFICIENT		INDIVIDUAL AR COEFFICIENTS	
VARIABLES	TEST STATISTIC	PROBABILITY	TEST STATISTIC	PROBABILITY
LNEF, LNFD, LNSD, LNEC, LNGF, LNGDP	-0.817481	0.2068	-3.525977****	0.0002

NOTE : * P < 0.05, *** P < 0.01, 0.05, 0.10 INDICATES RESPECTIVELY ***, **, AND *.

In the short term, the results confirm that green finance significantly reduces the ecological footprint (H1 validated). The introduction of green finance into the model makes the effect of financial development negative and significant, demonstrating its moderating role in mitigating the environmental effects of financial development (H2 validated).

TABLE 5 : ARDL ESTIMATION RESULTS

VARIABLES	MODEL-1		MODEL-2	
SHORT-RUN RESULTS				
LNFD	-0.062	[0.051]	-0.055**	[0.051]
LNGDP	-0.645**	[0.312]	-0.145**	[0.069]
LNEC	-0.877**	[0.333]	0.396**	[0.101]
LNSD	0.011	[0.004]	-0.001	[0.001]
LNGF	-	-	-0.002**	[0.001]
LONG-RUN RESULTS				
LNFD	0.330**	[0.074]	0.319**	[0.088]
LNGDP	-0.067**	[0.031]	-0.127**	[0.038]

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LNEC	-0.443**	[0.117]	0.021	[0.128]
LNSD	0.010**	[.003]	0.001	[0.002]
LNGF	--	--	0.029**	[0.011]

NOTE : P < 0.01, 0.05, 0.10 INDICATE ***, **, AND *, RESPECTIVELY. [ ] CONTAINS THE STANDARD ERROR.

The estimation results obtained from the ARDL model presented in Table 5 offer a nuanced understanding of the short- and long-term dynamics linking financial development, green finance, economic growth, energy consumption, sustainable development, and the ecological footprint. These findings directly engage with the research questions and hypotheses formulated at the outset of the study, particularly the idea that financial mechanisms can act either as drivers of sustainability or as contributors to environmental degradation, depending on how they are governed (Bhattacharyya, 2022).

In the short run, financial development appears to have a slightly negative effect on the ecological footprint, although this effect is only marginally significant. This outcome may reflect the limited capacity of financial systems in emerging economies to channel investments toward environmentally responsible sectors during the early stages of reform (Ahmed et al., 2021). Such systems often lack the institutional maturity or regulatory pressure to embed sustainability criteria into lending and investment decisions. Similarly, green finance although statistically significant in the second model shows a very weak negative effect, suggesting that in the absence of robust frameworks, its immediate environmental benefits remain constrained. This result is consistent with recent research highlighting the risks of symbolic adoption of green finance instruments without enforcement mechanisms, particularly in developing and transitional economies (Hussain et al., 2022).

Economic growth shows a consistent negative association with the ecological footprint across both models, which supports the notion that sustained growth, when directed toward clean technologies and supported by strategic public investment, can mitigate environmental degradation (Sinha et al., 2021). This aligns with the findings of Aldieri et al. (2022), who argue that modern economic expansion, under the right conditions, can contribute to decoupling growth from environmental harm. Energy consumption, by contrast, displays divergent short-run effects: it is associated with increased ecological degradation in the first model, yet shows a positive effect in the second. This contrast may be attributable to differences in the energy mix across countries in the sample. Where fossil fuels dominate, higher energy use tends to exacerbate environmental pressures; in economies with more renewable energy integration, however, energy use may contribute less to ecological harm or even foster efficiency gains (Lee and Lee, 2022).

The role of sustainable development remains weak and inconsistent in both models, with low coefficients and limited statistical significance. This may indicate persistent challenges in operationalizing sustainable development as a policy variable, as well as in quantifying its real impact within macro-financial frameworks (Shahbaz and Sinha, 2019).

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In the long run, financial development exhibits a significant positive relationship with the ecological footprint, confirming the concern that unchecked financial expansion when not aligned with green finance principles can lead to increased environmental degradation over time. This observation directly validates the third hypothesis of the study, which posits a "butterfly effect" where financial progress, if decoupled from sustainability considerations, may result in unintended environmental consequences (Bhattacharyya, 2022). Green finance, on the other hand, demonstrates a significant and positive effect in the long term in the second model. This finding suggests that the benefits of green finance do materialize, but only over time and within supportive institutional frameworks. It lends support to the second hypothesis, which emphasizes the importance of aligning financial development with green principles to achieve positive environmental outcomes (Hussain et al., 2022; Lee and Lee, 2022).

The negative long-term effect of GDP on the ecological footprint reinforces the idea that economic growth, when properly guided and coupled with targeted environmental policy, can serve as a lever for ecological improvement (Aldieri et al., 2022; Sinha et al., 2021). Meanwhile, energy consumption becomes statistically insignificant in the long run in the second model, underscoring that only a clear shift toward renewable sources can ensure that energy demand does not undermine long-term environmental sustainability.

These findings carry several implications for policy. First, there is a clear need to embed sustainability criteria into financial regulation, through mechanisms such as mandatory ESG disclosures, green credit guidelines, and environmental risk assessments. The development of green finance must be accompanied by institutional reforms that include taxonomies, certification standards, and anti-greenwashing regulations (Hussain et al., 2022). Second, the transition to a cleaner energy structure should be accelerated through the design of innovative financial instruments, such as green bonds and blended finance, supported by strong public-private partnerships (Ahmed et al., 2021). Third, governments and financial institutions should work together to encourage green innovation, especially in the energy and infrastructure sectors. Lastly, continuous monitoring and evaluation of the environmental impact of financial flows is essential to ensure alignment with climate goals and to prevent the emergence of rebound effects that could undermine long-term sustainability (Bhattacharyya, 2022).

In sum, the results highlight that the financial sector holds significant potential to support environmental sustainability, but its impact is contingent on the presence of regulatory and policy frameworks that explicitly link financial development to green objectives. Without such alignment, financial deepening may inadvertently exacerbate ecological degradation, despite good intentions or the adoption of green finance labels. Effective governance and structural reforms are therefore indispensable to unlock the transformative potential of finance in driving sustainable development.

V.CONCLUSION

This study has examined the intricate relationships between green finance, financial development, and environmental sustainability in emerging economies. The empirical analysis reveals that green finance plays a significant moderating role in the short term by helping to counterbalance the negative environmental effects of financial development. By channeling financial resources toward sustainable initiatives and encouraging the diffusion of clean technologies, green finance contributes to a more environmentally conscious allocation of capital during the early phases of financial expansion.

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However, the long-term results highlight a more complex reality. Despite the presence of green financial instruments, the increase in the ecological footprint over time reflects what may be described as a “butterfly effect,” where the absence of deep structural integration of sustainability into financial systems leads to a rebound in environmental degradation. These findings underscore the limitations of isolated or symbolic green finance initiatives and emphasize the need for coherent and binding regulatory frameworks. Without such frameworks, financial development may continue to support environmentally harmful sectors and jeopardize progress toward climate objectives.

One of the key contributions of this research lies in its identification of the nonlinear and time-dependent interactions between financial development, green finance, and environmental sustainability. The results highlight that green finance cannot generate transformative environmental impact in the absence of supportive institutions, strong governance, and a clear regulatory orientation toward the ecological transition.

For green finance to serve as a genuine lever for sustainable development, policymakers must adopt a balanced and forward-looking approach that aligns financial systems with environmental goals. This includes the implementation of well-designed incentive mechanisms, the development of green taxonomies, and the integration of environmental risk into financial decision-making. Ultimately, the ecological transition of emerging economies depends not only on financial innovation, but also on the strategic governance of finance itself.

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