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Financial Dynamics and Environmental Sustainability: An Analysis of Complex Interactions in Emerging Economies

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ABSTRACT

This study explores the role of the financial sector in reducing the ecological footprint of emerging economies, with a focus on financial development and green finance. Using an innovative approach based on the ARDL (AutoRegressive Distributed Lag) model, the analysis reveals that green finance plays a key moderating role in the short term, transforming the previously negligible impact of financial development into a positive lever for reducing the ecological footprint. However, in the long term, a butterfly effect could reverse this trend, highlighting the need for sustainable solutions.
The study proposes concrete measures for policymakers, including strengthening regulatory frameworks, promoting sustainable innovation, raising awareness of green finance, supporting green investments, and developing environmental indicators, to align financial activities with long-term sustainability goals.

***Keywords*:**Green finance, Financial development, Sustainable development, Ecological footprint, Sustainability.
JEL Codes: G18; G20; Q56; Q58; O44

I.INTRODUCTION

The urgency of climate change and the accelerated degradation of ecosystems have made the transition toward sustainable economic models a global imperative. Addressing systemic risks financial, economic, social, and ecological—requires integrating sustainability into financial systems. Emerging economies, as key drivers of global growth, view green finance as a strategic tool to reconcile socio-economic development with environmental sustainability while adapting to the evolving financial market landscape (Sinha et al., 2021).

Green finance plays a crucial role in reducing the ecological footprint by facilitating access to capital for sustainable economic activities and energy-efficient projects. A well-developed financial system enables the financing of innovative technologies and environmentally friendly production processes, ultimately reducing environmental degradation. Moreover, financial markets support research and development in renewable energy and foster foreign investments that promote green technology transfers (Ahmed et al., 2021). These financial mechanisms are essential for ensuring economic growth while mitigating the adverse effects of climate change on production, institutions, biodiversity, and extreme weather conditions (Aldieri et al., 2022).

This study aims to examine the intricate relationships among green finance, financial development, and sustainability. It specifically focuses on understanding how green finance contributes to minimizing the ecological footprint, assessing the influence of financial development on environmental sustainability, and exploring the connections between economic growth, sustainable development, and environmental

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degradation. Furthermore, the research offers policy suggestions derived from empirical evidence to assist decision-makers in adopting more sustainable financial practices (Bhattacharyya, 2022).

The investigation is structured around three primary hypotheses. Firstly, green finance acts as a moderator for the effects of financial and economic development on the ecological footprint. Secondly, financial development can enhance environmental sustainability when it is integrated with green finance policies. Lastly, overlooking sustainability in financial development may worsen ecological degradation.
To examine these relationships, this research utilizes the AutoRegressive Distributed Lag (ARDL) model, a reliable econometric technique that effectively captures the dynamic interactions among financial, economic, and environmental factors. By integrating cross-dependence analysis, this approach offers a thorough understanding of the impacts of green finance and financial development on sustainability results. The empirical investigation centers on emerging economies, specifically in the BRICS and Asia-Pacific areas, aiming to produce policy-relevant insights that enhance environmental sustainability through financial strategies .

II. EXPLORATION OF SCIENTIFIC LITERATURE

The interplay among financial development, green finance, and environmental sustainability is a central topic of discussion among scholars. Existing literature contains differing viewpoints on how financial development affects the ecological footprint.

On one hand, some studies suggest that financial development promotes environmental sustainability by directing capital towards green investments. These studies (Tamazian et al., 2009; Jalil & Feridun, 2011; Salahuddin & Alam, 2015) indicate a reduction in CO2 emissions due to innovation and industrial modernization.

On the other hand, part of the literature demonstrates that financial development exacerbates environmental degradation by facilitating access to credit for polluting industries (Boutabba, 2014; Javid & Sharif, 2016; Ahmed et al., 2022). Other studies conclude that there is no significant relationship between these variables (Ozturk & Acaravci, 2013; Destek & Sarkodie, 2019).

Conversely, green finance emerges as an essential mechanism for reducing the ecological footprint. It promotes sustainable investments, enhances energy efficiency, and modernizes industrial structures (Zhang et al., 2022). Green finance policies, such as green loans and sustainable bonds, help reduce carbon emissions and stimulate the green economy (Ren et al., 2020).

Finally, the interaction between green finance and financial development is key to achieving sustainable development goals. The adoption of ecological measures in financial policies is crucial to minimizing environmental impact and fostering sustainable growth (Adebayo et al., 2023). Thus, well-structured green finance moderates the negative effects of economic development on the environment and aligns financial systems with sustainability challenges.

III. METHODOLOGY AND 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.

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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 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.

IV.ANALYSIS RESULTS

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 I

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.

CROSS-SECTIONAL DEPENDENCE TESTS SHOW A STRONG INTERDEPENDENCE AMONG THE STUDIED ECONOMIES, VALIDATING THE RELEVANCE OF AN INTERNATIONAL-SCALE ANALYSIS. ADDITIONALLY, UNIT

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ROOT TESTS INDICATE THAT ALL VARIABLES BECOME STATIONARY AFTER FIRST DIFFERENCING, JUSTIFYING THE USE OF THE ARDL MODEL FOR ANALYZING SHORT- AND LONG-TERM EFFECTS.

TABLE II

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**	0,000	6,91**	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.

Before proceeding with the cointegration test and ARDL estimation, it is necessary to select the most optimal model and estimate its parameters. The results show that the optimal number of lags according to the Akaike criterion is 1, as the model with one lag (ARDL (1,1,1,1,1)) has the lowest AIC value (-3.8194).

TABLE III

DETERMINATION OF OPTIMAL LAG LENGTH

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The results

MODEL 1

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)
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)

indicate that the Pedroni Cointegration Test rejects the null hypothesis of no cointegration for the alternative hypothesis of individual AR coefficients (between-dimension) since the test statistic is significant at the 1% level. This suggests a cointegration relationship among the variables under study.

TABLE IV

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

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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]
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.

In the long term, the results confirm the hypothesis of a butterfly effect (H3 validated). Financial development and green finance increase the ecological footprint in the absence of a structured regulatory framework. Only economic growth maintains a positive effect by reducing the ecological footprint through investments in clean technologies.

These results suggest that, without structural integration of sustainability, the positive effects of green finance diminish over time, leading to a negative ecological rebound.

V.CONCLUSION

This study analyzes the complex relationships between green finance, financial development, and environmental sustainability in emerging economies. The empirical results reveal that green finance plays a key moderating role in the short term by mitigating the negative effects of financial development on the ecological footprint. It directs investments toward sustainable projects and promotes the adoption of clean technologies.

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However, in the long term, the butterfly effect highlights the risks of insufficient integration of sustainability into financial policies. The increase in the ecological footprint, despite the presence of green finance, underscores the need for a robust regulatory framework to prevent gradual environmental deterioration. These findings reinforce the idea that unregulated financial development can undermine environmental objectives if it continues to support high-carbon sectors.

This research highlights the importance of a balanced approach between financial policies and sustainability. One of its major contributions is the identification of the nonlinear interaction between financial development, green finance, and environmental sustainability. To ensure a lasting impact, it is essential to implement appropriate regulations and incentive mechanisms to align financial flows with ecological transition objectives.

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