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Public-Private Partnerships: Catalysts for Energy Transition, Financial Sustainability, and Environmental Sustainability

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ABSTRACT

This study investigates the role of Public-Private Partnerships (PPPs) as catalysts for energy transition, financial sustainability, and environmental sustainability within emerging economies. Applying advanced panel econometric methods, including second-generation unit root and cointegration tests, ARDL estimations, and Granger causality tests, the research provides robust empirical evidence from 18 emerging countries. Results reveal that PPP investments significantly reduce environmental degradation in the short term. However, consistent with the Environmental Kuznets Curve (EKC) hypothesis, long-term sustainability requires ongoing regulatory vigilance and strategic alignment with the Sustainable Development Goals (SDGs). The findings highlight the critical importance of integrating sustainable finance practices and PPP strategies to optimize resource allocation, mitigate ecological impacts, and ensure sustained environmental gains. This research enriches existing literature by combining theoretical and empirical insights, and offers practical policy recommendations for improving PPP governance and promoting sustainable development strategies.

Keywords: Public-Private Partnerships, Energy Transition, Environmental Sustainability, Sustainable Finance, Emerging Economies

JEL Codes: Q01, Q56, G32, O13

I.INTRODUCTION

Emerging economies are increasingly emphasizing sustainable financial policies, energy transition, and climate change mitigation to ensure economic prosperity and resilience. Among mechanisms facilitating this transition, Public-Private Partnerships (PPPs) play a strategic role in promoting financial, energy, and environmental sustainability. PPPs notably stimulate investments in renewable energies, offer economic incentives, encourage technological innovations, and reinforce regulatory commitments.

In this context, transparency and disclosure of sustainability-related information are becoming essential to ensure the success of PPP initiatives. Effective integration of PPPs into sustainable development policies is thus crucial to maximize their positive impacts.

The main objective of this study is to analyze the impact of PPPs on energy transition and financial sustainability. Additionally, it aims to investigate the relationship between PPPs, financial development, and

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environmental degradation, as well as to explore the synergies resulting from integrating PPPs with environmental sustainability objectives.

The central research question is to what extent PPPs act as catalysts for energy transition, financial sustainability, and environmental sustainability. The hypotheses to be tested are as follows: (H1) PPP investments in emerging economies significantly reduce the ecological footprint; and (H2) although PPPs and financial sustainability reduce environmental degradation in the short term, this effect might reverse in the long term, consistent with the Environmental Kuznets Curve (EKC).

The chosen empirical methodology includes cross-sectional dependency tests, second-generation unit root tests, panel cointegration tests, ARDL estimations, and Pairwise Granger causality tests.

II. REVIEW OF SCIENTIFIC LITERATURE

Emerging economies increasingly prioritize sustainable financial policies, energy transition, and climate change mitigation to enhance economic prosperity and resilience. Among mechanisms enabling this transition, Public-Private Partnerships (PPPs) have emerged as critical instruments for achieving financial, energy, and environmental sustainability. PPPs notably foster investments in renewable energy projects, provide essential economic incentives, stimulate technological innovation, and reinforce regulatory frameworks necessary for effective implementation.

The scholarly literature underscores several pertinent findings regarding PPPs, sustainable finance, and environmental sustainability. Ahmed et al. (2019), Yao and Tang (2021), and Wang et al. (2020), Akomea et al (2022), and Kumar et al (2025) demonstrate that PPPs are effective in mobilizing private-sector funding and expertise towards sustainable energy initiatives, thereby accelerating the transition to renewable energy sources. These contributions highlight PPPs' pivotal role in harnessing private capital and technological innovation, essential to achieving national and international sustainability goals. Similarly, studies by Ngo et al (2024), Nguyen et al (2023), Sardianou et al. (2021), and Griffith-Jones et al. (2020) further emphasize the importance of PPPs in catalyzing investments and fostering technological advancements in green technologies. However, they also highlight the critical importance of well-defined and robust regulatory environments to maximize the benefits and minimize the risks associated with PPP arrangements, Adebayo et al (2023).

Concurrently, the literature on sustainable finance reveals nuanced interactions with environmental sustainability. Lv and Li (2021), Adebayo et al. (2023), and Crifo et al. (2020) identify a dual dynamic wherein sustainable finance promoted through PPPs initially contributes positively to environmental outcomes, notably reducing CO2 emissions. However, these studies caution that over extended periods, this beneficial impact may diminish or even reverse, aligning with the theoretical framework provided by the Environmental Kuznets Curve (EKC). According to EKC theory, economic growth initially exacerbates environmental degradation before eventually leading to improved environmental conditions beyond a certain economic development threshold (Shahbaz and Sinha, 2019; Dasgupta et al., 2023; Panayotou, 1993).

Despite these contributions, several gaps persist in the literature. Notably, there is insufficient exploration of the long-term effects of PPPs on environmental sustainability, particularly within the context of diverse emerging economies. Furthermore, the complex dynamics between PPP-driven financial sustainability and environmental degradation remain inadequately examined, particularly regarding the conditions influencing shifts from positive short-term to negative long-term outcomes. Lastly, rigorous empirical studies employing comprehensive econometric methodologies to investigate causal relationships and synergies between PPPs, sustainable finance, and environmental performance remain scarce (Tamazian et al., 2009; Jalil and Feridun, 2011; Salahuddin and Alam, 2015).

This study distinctly positions itself within existing research by addressing these identified gaps. Through advanced econometric techniques including cross-sectional dependency tests, second-generation unit root tests, panel cointegration analyses, ARDL estimations, and Pairwise Granger causality tests the research aims

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to provide robust empirical insights, thus contributing substantively to the understanding of PPPs' roles in promoting sustainability objectives.

III. METHODOLOGY AND DATA

Our study analyzes a panel of 18 emerging economies from the BRICS and Asia-Pacific regions: South Africa, Saudi Arabia, India, China, Russia, Brazil, Argentina, Colombia, Malaysia, Mexico, Peru, Philippines, Poland, Thailand, Turkey, South Korea, and Chile. Annual data covering the period from 1990 to 2021 were primarily sourced from the statistical databases of the World Bank and the International Monetary Fund (IMF).

The variables selected for this analysis include: environmental sustainability (SD), measured by adjusted savings as a percentage of GDP; Public-Private Partnership investments in the energy sector (PPP); ecological footprint (EF), defined as a composite indicator encompassing carbon, cropland, grazing land, fishing grounds, forest land, and built-up land footprints; energy consumption (EC); financial development (FD), measured by domestic credit to the private sector as a percentage of GDP; and GDP per capita (GDP). Additionally, a specific indicator labeled "PPP-SD" was developed to precisely evaluate the alignment of PPPs with sustainable development objectives.

To examine the relational dynamics among these variables, we adopted an approach inspired by the work of Hunjra, Ahmed Imran et al. (2023) in constructing our empirical models. Two empirical models are proposed to investigate these dynamics:

Model 1: $$\boldsymbol{EE_{i,t} = \delta_i + \alpha_1 EE_{i,t-1} + \alpha_2 PPP_{i,t} + \alpha_3 SD_{i,t} + \alpha_4 FD_{i,t} + \alpha_5 CE_{i,t} + \alpha_6 GDP_{i,t} + \varepsilon_{it}}$$

Model 2 (including the moderating effect of PPP-SD):

$$\boldsymbol{SD_{i,t} = \delta_i + \alpha_1 SD_{i,t-1} + \alpha_2 PPP_{i,t} + \alpha_3 EE_{i,t} + \alpha_4 FD_{i,t} + \alpha_5 CE_{i,t} + \alpha_6 GDP_{i,t} + \alpha_7 (PPP - SD)_{i,t} + \varepsilon_{it}}$$

The methodological approach adopted comprises four key steps. First, we conduct a cross-sectional dependence (CD) test to detect potential correlations among panel countries, possibly arising from common unobserved shocks. Second, second-generation unit root tests, specifically the CADF and CIPS tests proposed by Pesaran, are applied to determine the stationarity properties of the time series. The third step involves conducting panel cointegration analysis using Pedroni's approach, followed by an ARDL estimation to assess short-term and long-term relationships among variables. Finally, Pairwise Granger causality tests are performed to clarify causal directions between the studied variables. These empirical analyses are conducted using STATA software, ensuring the robustness and reliability of the results obtained.

IV.RESULTS ANALYSIS

The empirical analysis begins with a Cross-Sectional Dependence test (CD test), presented in Table 1. The Pesaran CD test confirms significant interdependencies among all variables across the studied countries, validating the necessity of considering cross-sectional correlations in our models.

TABLE I

CROSS-SECTIONAL DEPENDENCE (CD) TEST RESULTS

VARIABLES	PESARAN LM STAT	PROB.	PESARAN CD STAT	PROB.
LNEF	174.93***	0.000	49.19***	0.000
LNFD	71.95***	0.000	26.91***	0.000

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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
LNPPP-SD	17.53***	0.000	9.91***	0.000

(*** SIGNIFICANT AT 1%)

Following this, unit root tests using ADF-Fisher and CIPS (Table 2) indicate that most variables exhibit stationarity only after first differencing (I (1)), except GDP and green finance (LnGF), stationary at levels (I(0)).

TABLE II

UNIT ROOT TEST RESULTS

VARIABLES	ADF-FISHER (LEVEL)	ADF-FISHER (1ST DIFF.)	CIPS (LEVEL)	CIPS (1ST DIFF.)	ORDER
LNEF	**10.79**	**102.61*** **	**5.06**	**-8.23*** **	**I(1)**
LNFD	**47.29**	**166.10*** **	**-1.05**	**-9.90*** **	**I(1)**
LNGDP	**119.64*** **	**116.19*** **	**-4.22*** **	**-6.57*** **	**I(0)**
LNEC	**26.25**	**118.78*** **	**2.64**	**-7.26*** **	**I(1)**
LNSD	**44.95***	**159.87*** **	**-1.62**	**-9.63*** **	**I(1)**
LNGF	**89.26*** **	**207.70*** **	**-6.03*** **	**-13.33*** **	**I(0)**

(*, **, * SIGNIFICANT AT 1%, 5%, 10%)**

Subsequently, the Pedroni cointegration test results (Table 3) provide strong evidence of cointegration, validating long-run equilibrium relationships among variables in both models.

TABLE III

PEDRONI COINTEGRATION TESTS

MODEL	VARIABLES INVOLVED	STATISTIC	PROBABILITY
MODEL 1	LNEF, LNFD, LNSD, LNEC, LNGF, LNGDP	-3.5259***	0.0002
MODEL 2	LNSD, LNEF, LNFD, LNGDP, LNGF, LNPPP-SD, LNEC	-4.2270***	0.0000

(*** SIGNIFICANT AT 1%)

Optimal lag selection based on Akaike Information Criterion (AIC) (Table 4) identifies the ARDL(1,1,1,1,1) specification as optimal for both models, ensuring robustness and parsimony.

TABLE IV

OPTIMAL LAG SELECTION

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Model	Lag	LogL	AIC*	Specification
1	1	827.8723	-3.8194	ARDL(1,1,1,1,1)
2	1	720.7136	-3.8267	ARDL(1,1,1,1,1)

ARDL estimation results in Table 5 reveal significant short-term negative effects of PPP investments (LnFD) on ecological footprints, consistent with Ahmed et al. (2019) and Yao & Tang (2021), but indicate potential long-term reversals confirming the Environmental Kuznets Curve (EKC) hypothesis proposed by Shahbaz and Sinha (2019).

TABLE V

ARDL ESTIMATION RESULTS

MODEL 1: ECOLOGICAL FOOTPRINT (LNEF)

Variables	Short-term Coeff.	Long-term Coeff.
LnFD	-0.0055**	0.319**
LnGDP	-0.145**	-0.127**
LnEC	0.396**	0.021
LnSD	-0.001	0.001
LnGF	-0.002**	0.029**

MODEL 2: ENVIRONMENTAL SUSTAINABILITY (LNSD)

Variables	Short-term Coeff.	Long-term Coeff.
LnPPP-SD	0.419***	0.259***
LnEF	-1.408	-2.412**
LnFD	1.678	0.860
LnGDP	5.423**	0.166*
LnGF	-1.094	-0.834***
LnEC	0.497	-2.674

(***, **, * SIGNIFICANT AT 1%, 5%, 10%)

Finally, Granger causality tests (Table 6) reveal meaningful causal interactions, notably from financial development (LnFD) to sustainable development (LnSD) and from economic growth (LnGDP) to ecological footprint (LnEF), reinforcing PPPs' strategic importance in sustainable policy formulation.

TABLE VI

PAIRWISE GRANGER CAUSALITY TEST RESULTS

Cause→Effect	LnEF	LnFD	LnGDP	LnEC	LnGF	LnSD

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Cause→Effect	LnEF	LnFD	LnGDP	LnEC	LnGF	LnSD
LnEF	—	1.303	2.682*	1.365	3.963**	1.415
LnFD	0.293	—	1.071	5.318***	0.469	4.426**
LnGDP	0.456	49.285***	—	2.510*	3.449**	0.437
LnEC	0.186	6.051***	2.634*	—	0.168	7.155***
LnGF	0.568	0.284	2.270	1.467	—	0.393
LnSD	0.636	3.749**	4.302**	0.366	2.789*	—

(***, **, * significant at 1%, 5%, 10%)

In conclusion, these robust empirical analyses support our initial hypotheses, demonstrating that PPP investments effectively foster sustainable transitions, but continuous policy reinforcement is essential to sustain long-term environmental gains.

5.DISCUSSION AND RECOMMENDATIONS

The results underline the pivotal role of PPPs in facilitating the energy and environmental transition of emerging economies in the short term while simultaneously revealing the vulnerability of these environmental gains over the long run, especially in the absence of continuous investments and robust regulatory frameworks. These insights corroborate findings by Lv and Li (2021) and Adebayo et al. (2023), emphasizing the necessity of rigorous strategic management to ensure the long-term effectiveness of PPPs.

Given these insights, policymakers and economic stakeholders should systematically incorporate mechanisms for transparency and regular assessment of the environmental impacts associated with PPP initiatives. Implementing innovative financial instruments such as green loans and sustainability-linked bonds is essential to effectively mobilize private capital toward environmentally sustainable projects, as underscored by Griffith-Jones et al. (2020). Combined with clear and stable regulatory frameworks, these financial tools can secure a coherent, sustainable, long-term energy transition.

Furthermore, results confirm the importance of reinforced international cooperation, as advocated by Akomea et al. (2022) and Kumar et al. (2025). Such collaboration could facilitate knowledge transfer, technological innovations, and financial resources, thus accelerating the adoption of renewable energies within emerging economies still heavily dependent on fossil fuels.

Finally, to deepen the insights provided by this study, future research should adopt detailed qualitative analyses at the sectoral or regional level, incorporating institutional and regulatory dimensions. In line with recommendations from Tamazian et al. (2009), Jalil and Feridun (2011), and Salahuddin and Alam (2015), comparative studies between emerging and developed economies could yield additional insights. These studies would help identify transferable best practices, thus enhancing the overall effectiveness of PPP policies as mechanisms of sustainable finance.

VI.CONCLUSION

This study aimed to assess the extent to which Public-Private Partnerships (PPPs) serve as catalysts for energy transition, financial sustainability, and environmental sustainability in emerging economies. Empirical findings, derived from ARDL analysis applied to 18 emerging countries, clearly indicate that PPPs are powerful tools for promoting environmental sustainability in the short term. However, the observed

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Environmental Kuznets Curve (EKC) effect underscores the necessity for adequate regulatory frameworks and continuous vigilance to prevent a resurgence of environmental pressures in the long run. Furthermore, the strategic alignment of PPPs with Sustainable Development Goals (SDGs) proves essential for maximizing both environmental and financial effectiveness. The synergy between these two key factors significantly enhances sustainable growth and optimizes sustainable financial practices within these economies. Theoretically, this research contributes to the existing literature by integrating the EKC framework into the analysis of PPP impacts. Empirically, it provides robust evidence of the differing short- and long-term effects of PPPs on environmental outcomes. Lastly, from a strategic and policy perspective, the study offers clear recommendations to improve PPP governance through efficient resource allocation towards sustainable projects.

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