







“Assessing the impact of tech-driven financial development and IT governance on environmental funds in emerging economies”

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ASSESSING THE IMPACT OF TECH-DRIVEN FINANCIAL DEVELOPMENT AND IT GOVERNANCE ON ENVIRONMENTAL FUNDS IN EMERGING ECONOMIES

Abstract

The transition toward low-carbon economies has become a central environmental priority worldwide, requiring nations to allocate adequate resources for conservation efforts. However, emerging economies often face chronic shortages of environmental conservation funds, constraining their progress toward sustainability. Addressing this challenge, the present empirical study examines the dynamic influence of tech-driven financial development on national environmental conservation funds, with IT governance introduced as a moderating factor. Using a panel dataset of 55 emerging economies from 2004 to 2023, the analysis employs the two-step system generalized method of moments (sys-GMM) and dynamic panel data estimation (DPDE). The results reveal that both tech-driven financial development and IT governance significantly increase environmental conservation funds, with coefficients of 1.633 ($p < 0.05$) and 1.272 ($p < 0.01$), respectively. Moreover, their interaction produces a further positive moderating effect, with a coefficient of 1.294 ($p < 0.01$), indicating that strong IT governance enhances the effectiveness of tech-driven financial systems in scaling and optimizing environmental conservation funds. These findings underscore the need to integrate technological innovations in finance with robust IT governance frameworks to strengthen environmental financing in emerging economies. Policy recommendations are offered based on the empirical outcomes. The empirical investigation conclusively demonstrates that both tech-driven financial development and robust IT governance serve as pivotal catalysts for the mobilization of environmental funds within emerging economies. Crucially, the observed synergistic interplay between these two elements indicates that well-structured digital governance frameworks significantly amplify the efficacy of financial technology in channeling resources toward environmental conservation.

Keywords

environmental conservation funds, tech-driven financial development, IT governance, two-step sys-GMM

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Q56, Q54, O33, H23

INTRODUCTION

Environmental conservation has become a critical policy priority worldwide, especially in the pursuit of low-carbon development to mitigate escalating ecological challenges. A persistent obstacle to achieving sustainability goals is the ineffective mobilization and utilization of environmental conservation funds (Zhang, 2023). Governments allocate these funds to support activities such as pollution control, climate change mitigation, and sustainable resource management (Stojičić et al., 2024). Yet emerging economies often face structural and institutional constraints – including weak financial systems, limited access to capital, and inadequate governance frameworks – that limit their ability to mobilize and deploy such funds effectively (Haiyang & Xiaohui, 2022).

The core scientific problem underpinning these challenges concerns how emerging economies can enhance the mobilization, allocation, and management of environmental conservation funds despite limited financial resources and institutional weaknesses. In particular, it remains unclear how tech-driven financial development – including digital finance platforms, blockchain technologies, mobile banking, and crowdfunding mechanisms – can be leveraged to increase accessibility, transparency, and efficiency in environmental financing (Ahmad et al., 2024; Bobbo et al., 2024). Likewise, although IT governance has the potential to strengthen oversight, accountability, and transparency, its role in supporting environmental conservation funds has received limited empirical attention (Troitiño et al., 2024). Significant research gaps persist in understanding how technological financial innovations, when combined with strong governance structures, can address environmental financing constraints in emerging economies.

1. LITERATURE REVIEW

Financial systems serve a crucial function in supporting environmental sustainability initiatives. Tech-driven financial development – encompassing blockchain, digital payment systems, and online banking – can increase the availability of environmental funding by improving financial inclusion and reducing transaction costs. These technologies support the creation of innovative financing instruments such as green bonds and digital environmental funds, enabling broader participation from public and private stakeholders (Udeagha & Muchapondwa, 2023).

A growing body of research demonstrates that such technological solutions enhance transparency and accountability in fund management. Blockchain, for instance, provides immutable transaction records that can reduce fraud, mitigate corruption risks, and encourage trust in environmental projects (Bertalan & Kocsis, 2024; Qin et al., 2024). Moreover, digital platforms expand the potential pool of contributors by enabling crowdfunding and facilitating micro-investments into green projects (Muganyi et al., 2021).

Much of the existing literature examines environmental outcomes – such as carbon emissions (Ali et al., 2024; Udeagha & Muchapondwa, 2023), greenhouse gases (Tao et al., 2022), and sulfur dioxide emissions (Nenavath, 2022) – in relation to technological financial innovations. Other studies employ alternative proxies, including ecological load capacity (Okere et al., 2024) and environmental efficiency (Uddin et al., 2024). However, despite the recognized benefits, the specific role of tech-driven financial development in supporting environmental conservation funds remains insufficiently explored, especially within emerging economies.

IT governance refers to the strategic use of information technologies to enhance organizational efficiency, regulatory oversight, and decision-making processes. In emerging economies – where governance institutions are often comparatively weak – IT governance can strengthen environmental fund management by improving monitoring mechanisms, minimizing regulatory inefficiencies, and promoting transparency (Troitiño et al., 2024). Studies indicate that robust IT governance frameworks significantly improve the credibility and effectiveness of environmental initiatives, helping governments better allocate resources and respond to ecological challenges (Medina Alves et al., 2025).

Furthermore, IT governance facilitates the successful implementation of tech-driven financial systems by ensuring secure digital infrastructure, enabling public-private collaboration, and mitigating risks such as cybercrime, corruption, and financial mismanagement (Hossain et al., 2025). While the link between IT governance and technological financial development is acknowledged, their combined influence on environmental conservation funds remains largely unexplored. High-quality governance fosters more efficient fund allocation and implementation, contributing to improved sustainability outcomes (Niu, 2024; Wang et al., 2024).

Governments – being the central custodians of environmental policy and public resources – play a pivotal role in ensuring that environmental conservation funds are allocated effectively. Yet many emerging economies continue to underfund environmental initiatives due to competing priorities and structural limitations (Muganyi et al., 2021). The lack of empirical research on the direct and

moderating effects of IT governance in strengthening environmental conservation funds underscores a significant research gap.

Overall, there is growing evidence supporting the potential benefits of tech-driven financial solutions for environmental conservation. However, empirical analysis in the context of emerging economies remains limited. Key research gaps include the absence of in-depth examinations of how financial technologies can optimize the mobilization, allocation, and management of environmental funds. Moreover, little is known about how strong governance frameworks interact with tech-driven financial development to facilitate more efficient environmental conservation financing in emerging economies.

Several structural and institutional factors significantly influence the effectiveness of environmental conservation funds. Technology-oriented financial systems and governance reforms offer modern and sustainable approaches for increasing fund availability and improving fund management practices. Furthermore, tech-driven financial development and IT governance are interlinked – each influencing the effectiveness, transparency, and accountability of environmental conservation mechanisms.

Contemporary academic discourse increasingly highlights the intricate FinTech–environment nexus, underscoring how digital advancements are fundamentally reshaping ecological governance paradigms. For instance, Rahman and Hossain (2025) emphasize that a cohesive synergy among governance structures, financial mechanisms, and technological innovations is indispensable for achieving sustainable natural resource management, particularly within institutional contexts marked by considerable uncertainty. Concurrently, Zhang (2024) points out a notable lacuna in previous research, which frequently overlooked the environmental advantages inherent in digital governance within BRICS nations, thereby suggesting that FinTech synergies are instrumental in progressing towards the Sustainable Development Goals (SDGs).

Moreover, the concept of green FinTech has emerged as a potent dual-pronged approach, en-

compassing both technological empowerment and strategic financial resource allocation. This dual functionality significantly enhances the efficiency of environmental governance by mitigating informational asymmetries and reducing transactional overheads. In nascent markets, where conventional financial infrastructures may be fragmented, technology-driven solutions, including blockchain-based green bonds and AI-powered impact tracking systems, provide the requisite transparency to attract vital international conservation capital (World Bank, 2025). Despite these significant strides, the precise interaction between IT governance frameworks and their role in scaling national environmental funds remains an area requiring deeper theoretical and empirical exploration, which forms the core impetus for the present study's focus on this moderating relationship.

Founded on the existing gaps, this study aims to contribute to the environment, finance, and governance literature by empirically evaluating whether tech-driven financial development can help overcome funding shortages for environmental conservation in emerging economies. It further seeks to determine whether IT governance acts as an institutional amplifier that strengthens the capacity of digital financial systems to mobilize conservation funds. The study ultimately seeks to provide policy insights for strengthening environmental financing through the integration of financial technology and robust IT governance frameworks.

2. METHOD

To achieve the study's objective, we follow the methodological approaches of Fareed et al. (2022) and Yin et al. (2023) to construct the econometric models presented below. In addition, the logarithmic transformation of environmental conservation funds, gross government debt, inflation, final consumption expenditure, and socioeconomic conditions is applied to normalize the data distribution and reduce skewness.

Direct-effect baseline model:

$$ECF_{it} = \alpha_0 + \alpha_1 TFD_{it} + \alpha_2 ITGOV_{it} + \beta(Controls)_{it} + \mu_{it} \quad (1)$$

Indirect-effect baseline model:

$$\begin{aligned}
 ECF_{it} = & \alpha_0 + \alpha_1 TFD_{it} + \alpha_2 ITGOV_{it} \\
 & + \alpha_3 (TFD \cdot ITGOV)_{it} \quad (2) \\
 & + \beta(Controls)_{it} + \mu_{it}.
 \end{aligned}$$

In these models, environmental conservation funds, tech-driven financial development, and IT governance are represented by ECF, TFD, and ITGOV, respectively. The subscripts i and t denote country and time, while μ_{it} represents the error term. The parameters α_0 , α_1 , α_2 , α_3 , and β are unknown coefficients to be estimated. The interaction term $(ITGOV)_{it}$ captures the moderating effect of IT governance on the relationship between tech-driven financial development and environmental conservation funds in country i during year t .

The technical framework guiding this empirical analysis is illustrated in Figure 1.

After completing the variable construction and model specification, the study applies advanced panel-data econometric techniques and analyzes the dataset using Stata 17. Selecting an appropriate estimation method is essential for generating reliable results; therefore, several pre-analy-

sis diagnostic tests are performed to detect potential data issues and to guide methodological decisions.

The analysis proceeds in several stages. First, descriptive statistics are examined to understand the nature and distribution of the variables. Next, we conduct the Pesaran et al. (2004) cross-sectional dependence (CSD) test, given that CSD is common in macro-panel datasets due to interlinkages among countries. Such dependence may arise from unobserved common shocks, macroeconomic or spatial effects, trade and geographical ties, measurement errors, and other omitted factors. Assuming cross-sectional independence when dependence is present may lead to biased parameter estimates and misleading statistical inference (Musah et al., 2024).

Cross-sectional dependence is a critical consideration in panel-data econometrics because it influences both the choice of stationarity tests and the selection of the most suitable estimation method. First-generation unit-root tests assume cross-sectional independence, whereas second-generation tests accommodate cross-sectional dependence. Similarly, specific panel-data estimators are designed to address CSD issues effectively (Awad & Warsame, 2022). In the third stage, we employ

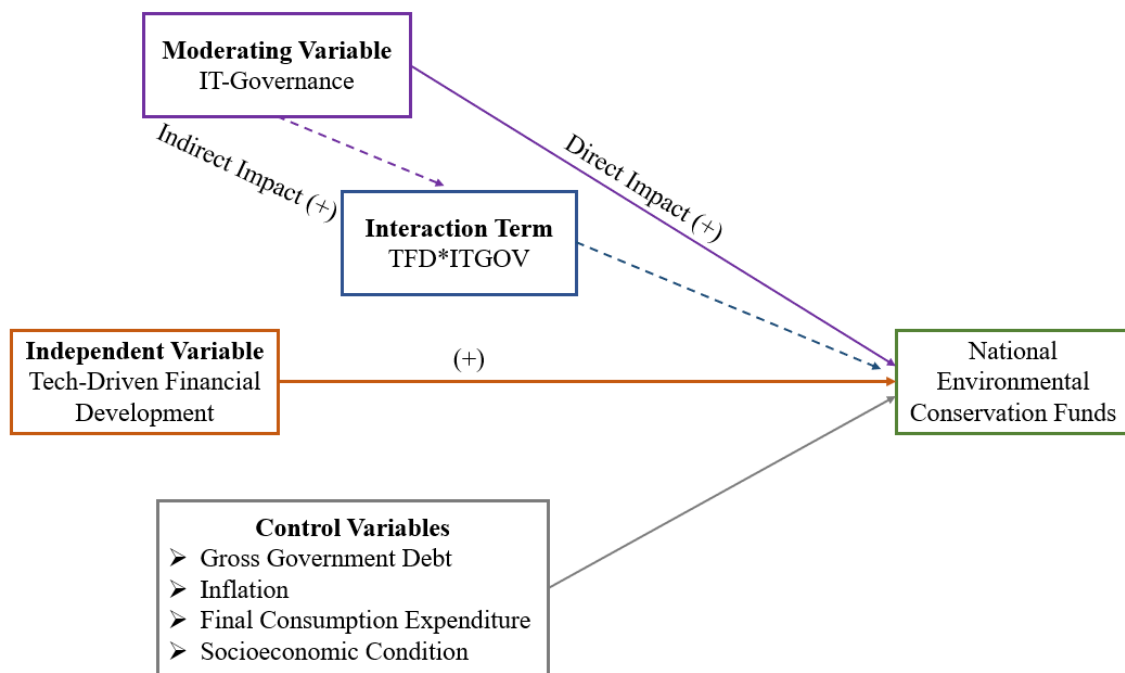


Figure 1. Technical route of the current empirical investigation

the second-generation CIPS unit-root test developed by Pesaran (2007), which accounts for both heterogeneity and CSD and is therefore suitable for cross-sectionally dependent panels (Işık et al., 2024).

In the subsequent stage, the choice of the primary empirical method is guided by the diagnostic results and the characteristics of the dataset. The two-step system GMM (sys-GMM) estimator is selected as the main technique for several reasons. First, sys-GMM is particularly well-suited for panels with many cross-sections and relatively short time spans ($T < N$). Given that the dataset includes 55 emerging countries over a 20-year period, this technique is appropriate for the study (Sumba et al., 2024). Second, sys-GMM is advantageous when the distribution of the dependent variable is unspecified, as it addresses such issues by incorporating lagged values of the dependent variable. Third, it effectively handles heterogeneity, cross-sectional dependence, over-identification concerns, heteroskedasticity, autocorrelation, and other estimation challenges (Assfaw & Sharma, 2024). Fourth, endogeneity – stemming from reverse causality, omitted variables, or lagged dynamics – can be significant in panel-data settings. Sys-GMM is particularly robust in addressing endogeneity by employing internal instruments (Hussain et al., 2024). Fifth, compared to the difference GMM estimator, sys-GMM provides superior performance in managing instrument proliferation (Yitayaw et al., 2023).

To ensure instrument validity and model specification accuracy, the study employs the Sargan and Hansen tests for over-identification diagnostics. The direct and moderating sys-GMM models used in the analysis are specified as follows:

Direct effect sys-GMM model:

$$ECF_{it} = \alpha_0 + \alpha_1 ECF_{it-1} + \alpha_2 TFD_{it} + \alpha_3 ITGOV_{it} + \beta (Controls)_{it} + \Psi_t + \mu_{it}. \quad (3)$$

Indirect effect sys-GMM model:

$$ECF_{it} = \alpha_0 + \alpha_1 ECF_{it-1} + \alpha_2 TFD_{it} + \alpha_3 ITGOV_{it} + \alpha_4 (TFD \cdot ITGOV)_{it} + \beta (Controls)_{it} + \Psi_t + \mu_{it}. \quad (4)$$

In the above expressions, the lagged value of the dependent variable is represented by $ECF_{(t)}$, while Ψ_t captures the time-specific effects. According to Kiviet (2020), a model incorporating lagged dependent variables is considered dynamic because it allows for long-term effect estimation and helps address autocorrelation.

Finally, dynamic panel data estimation (DPDE) is employed as a secondary robustness technique. This method is suitable for large, cross-sectionally dependent panels and effectively addresses endogeneity, heterogeneity, and dynamic temporal relationships (Adewumi, 2024; Ahmad et al., 2021). The `xtdpd` command in Stata is used for this validation analysis.

The choice of variables is governed by their conceptual and empirical relevance to the study's core relationships. Following Niu (2024), government environmental protection expenditure (as a percentage of GDP) serves as the proxy for environmental conservation funds (dependent variable), with data obtained from the International Monetary Fund (IMF). Tech-driven financial development, the key independent variable, is measured using the financial development index (0-1 scale), as applied by Ali et al. (2024); the IMF database is used as the data source.

IT governance is included as the moderating variable and is composed of four components: online services, telecommunications infrastructure, human capital, and e-participation. Its values range from 0 (the lowest level of IT governance) to 1 (the highest level), following the approach of Roxas (2025). The data are sourced from the United Nations E-Government Knowledgebase (UNEGK). Control variables include gross government debt, inflation, final consumption expenditure, and socioeconomic conditions, selected on the basis of their relevance to environmental financing dynamics. Details of variables, their measurement, and data sources are presented in Table 1.

The final dataset consists of a strongly balanced panel of 55 emerging economies covering the period 2004–2023. Country selection is based solely on data availability, and countries with incomplete data are excluded. The study employs the `winsor2` command to reduce the influence of extreme val-

Table 1. Details of data

Variable	Symbol	Measurement	Source and Base
Dependent Variable			
Environmental Conservation Funds	ECF	Environmental protection expenditure (percentage of GDP)	IMF (Niu, 2024)
Independent Variable			
Tech-Driven Financial Development	TFD	Financial development index (ranging from 0 to 1)	IMF (Ali et al., 2024)
Moderating Variable			
IT Governance	IT-GOV	E-government development index comprising e-participation, online services, human capital, and telecommunication infrastructure as basic components (ranging between 0 and 1)	UNEGK (Roxas, 2025)
Control Variables			
Gross Government Debt	GGD	General gross government debt as a percentage of GDP	IMF (Carvelli & Trecroci, 2024)
Inflation	INF	Inflation, consumer prices (annual percentage)	World Bank (Uddin & Rahman, 2023)
Final Consumption Expenditure	FCE	Final consumption expenditure as a percentage of GDP	World Bank (Patra & Sethi, 2024)
Socioeconomic Condition	SEC	Risk lies between 0 to 12, where 0 indicates a higher risk and 12 symbolizes a lower risk	ICRG (Adebayo & Özkan, 2024)

ues, and missing data are addressed using regional averages. A complete list of countries included in the sample is provided in Appendix A.

3. RESULTS AND DISCUSSION

Descriptive statistics offer an initial overview of the dataset by summarizing its central tendency, dispersion, and distributional properties. Measures such as the mean and median provide information on the typical values of each variable, while the standard deviation indicates the degree of variability within the data. Additionally, skewness and kurtosis help assess the shape of the distribution, revealing potential asymmetry or the presence of outliers (Sindermann et al., 2021). Accordingly, in the first stage of the empirical analysis, we computed descriptive statistics for

all study variables, and the results are presented in Table 2, which reports the mean, standard deviation, minimum and maximum values, and total number of observations. The outcomes show that each variable contains 1,100 observations, corresponding to 55 emerging economies over 20 years. Overall, the descriptive statistics suggest a generally normal dispersion of values, indicating that the variables are reasonably distributed around their respective means and are suitable for further econometric analysis.

Checking for cross-sectional dependence (CSD) is a crucial step in panel-data analysis because many econometric models assume that error terms across cross-sectional units – such as countries, firms, or regions – are independent. In reality, these units are often interconnected, and their economic, political, or environmental conditions

Table 2. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Environmental Conservation Funds	1100	-2.462	1.461	-7.093	0.19
Tech-Driven Financial Development	1100	0.252	0.137	0.03	0.66
IT Governance	1100	0.559	0.124	0.07	0.78
FD*IT-GOV	1100	0.107	0.139	0	0.542
Gross Government Debt	1100	3.720	0.698	-0.186	6.397
Inflation	1100	1.552	0.956	-3.912	6.323
Final Consumption Expenditure	1100	4.339	0.242	2.399	4.8
Socioeconomic Condition	1100	1.374	0.541	-2.526	2.184

can influence one another. If CSD is ignored, parameter estimates may become inefficient and biased, and standard errors may be incorrectly computed, leading to unreliable significance levels and misleading inferences. CSD frequently arises due to spillover effects, shared shocks, regional integration, or unobserved common factors, and when not accounted for, it can result in model misspecification and unreliable empirical outcomes (Musah et al., 2024; Valizadeh et al., 2024).

To address this concern, the present study employs the Pesaran et al. (2004) test to detect the presence of CSD. The results, reported in Table 3, show that all variables – including the interaction term – are statistically significant at the 1% level. This indicates that all series in the dataset exhibit cross-sectional dependence and are jointly influenced by common shocks, validating the need for methodological approaches capable of handling CSD.

The results of the CSD analysis also play an important role in determining the appropriate stationarity tests. First-generation unit-root tests assume cross-sectional independence, whereas second-generation tests are specifically designed to ac-

commodate cross-sectional dependence in panel datasets (Kostakis et al., 2023). Given that our panel exhibits significant CSD, this study employs the second-generation CIPS unit-root test developed by Pesaran (2007) to examine the stationarity properties of the variables. The outcomes of the CIPS stationarity test are presented in Table 4. The findings indicate that all variables in the study are stationary at level, with the exception of the interaction term between tech-driven financial development and gross government debt, which becomes stationary after first differencing. These results confirm that the chosen variables meet the necessary conditions for subsequent dynamic panel estimations.

The two-step system GMM estimator is particularly well-suited for large-scale panel data analyses because it effectively addresses several econometric challenges inherent in such datasets, including unobserved heterogeneity, cross-sectional dependence, endogeneity, and dynamic panel bias. Compared with alternative estimators, system GMM provides a more robust analytical framework by simultaneously combining equations in levels and first differences. The two-step procedure enhances estimator efficiency by using an

Table 3. Outcomes of CSD test

Variables	CSD	P-Value
Environmental Conservation Funds	17.644***	0.000
Tech-Driven Financial Development	72.16***	0.000
IT Governance	13.335***	0.000
FD*IT-GOV	18.672***	0.000
Gross Government Debt	61.535***	0.000
Inflation	27.134***	0.000
Final Consumption Expenditure	5.081***	0.000
Socioeconomic Condition	4.357***	0.000

Note: *** p < 0.01 (1%), ** p < 0.05 (5%), * p < 0.1 (10%).

Table 4. Outcomes of the CIPS stationarity test

Variables	CIPS I (0)	CIPS I (1)	Conclusion
Environmental Conservation Funds	-2.475***	–	I (0)
Tech-Driven Financial Development	-2.695***	–	I (0)
IT Governance	-2.764***	–	I (0)
FD-IT-GOV	-1.240	-3.033***	I (1)
Gross Government Debt	-1.894	-3.558***	I (1)
Inflation	-2.729***	–	I (0)
Final Consumption Expenditure	-2.271***	–	I (0)
Socioeconomic Condition	-2.421***	–	I (0)

Note: *** p < 0.01 (1%), ** p < 0.05 (5%), * p < 0.1 (10%).

updated, optimal weighting matrix in the second stage. Additionally, this approach is capable of correcting heteroskedasticity and serial correlation – issues that commonly arise in macro-panel datasets (Assfaw & Sharma, 2024; Hussain et al., 2024).

After completing all necessary diagnostic tests and applying appropriate data treatments, the study employs the two-step system GMM as the primary estimation technique to analyze the dynamic impact of tech-driven financial development and IT governance on national environmental conservation funds. Table 5 reports the results of the system GMM estimation for both the direct and moderating effect models.

The results of the direct-effect model are presented in the first column of Table 5. The findings show that the dependent variable – national environmental conservation funds – is dynamic, as indicated by the statistically significant coefficient of its lagged value at the 1% level. This confirms the appropriateness of using a dynamic estimator such as system GMM.

The coefficient of tech-driven financial development is positive and statistically significant (1.633, $p < 0.05$), indicating that a one-unit increase in tech-driven financial development leads to a 163.3% rise in national environmental conservation funds. Similarly, IT governance exerts a significant positive influence on environmental conser-

Table 5. Outcomes of the main approach (Two-step IV system GMM)

Variables	(Model 1)	(Model 2)
	Two-step IV Sys-GMM (Direct Impact)	Two-step IV Sys-GMM (Indirect Impact)
	Log ECF	Log ECF
Log Environ. Conservation Funds (t-1)	0.621*** (0.034)	0.618*** (0.029)
Tech-Driven Financial Development	1.633** (0.746)	1.390** (0.572)
IT Governance	1.272*** (0.339)	1.139*** (0.329)
FD*IT-GOV		1.294*** (0.494)
Log Gross Government Debt	-0.117** (0.053)	-0.103*** (0.040)
Log Inflation	-0.076* (0.043)	-0.056 (0.037)
Log Final Consumption Expenditure	0.469*** (0.166)	0.429** (0.168)
Log Socioeconomic Condition	-0.084 (0.086)	-0.076 (0.073)
Year Impact	Yes	Yes
Constant	-3.347*** (0.746)	-3.349*** (0.807)
Observations	1,045	1,045
Number of Countries	55	55
AR (1)	-3.518	-3.501
AR (1) P-value	0.000434	0.000463
AR (2)	1.084	1.066
AR (2) P-value	0.278	0.287
Sargan	55.80	58.62
Sargan P-value	3.12e-05	0.000257
Hansen	24.35	32.35
Hansen P-value	0.227	0.182
J-Stat/ No. of Instruments	46	53
Chi2	9429	119432
Chi2 P-value	0	0

Note: Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

vation funds, with a coefficient of 1.272 ($p < 0.01$), implying that a one-unit improvement in IT governance enhances conservation funds by 127.2%.

Regarding control variables, gross government debt and inflation exhibit negative and significant coefficients (-0.117 , $p < 0.05$; and -0.076 , $p < 0.10$, respectively). These results suggest that a one-percent increase in gross government debt and inflation decreases conservation funds by 0.117% and 0.076%, respectively. In contrast, final consumption expenditure shows a positive and highly significant coefficient (0.469, $p < 0.01$), indicating that a one-percent increase in consumption expenditure raises conservation funds by 0.469%. Socioeconomic condition displays a negative but statistically insignificant relationship with environmental conservation funds.

The second column of Table 5 reports the findings for the indirect-effect (moderation) model. Similar to the direct model, the lagged dependent variable remains significant at the 1% level, confirming the dynamic nature of the model. Tech-driven financial development continues to exhibit a strongly positive and significant impact, with a coefficient of 1.390 ($p < 0.05$), meaning that a one-unit increase in tech-driven financial development increases conservation funds by 139%. IT governance also maintains a positive and significant coefficient (1.139, $p < 0.01$), indicating that a one-unit improvement in IT governance enhances conservation funds by 113.9%.

The moderating effect captured through the interaction term (TFD \times IT-GOV) is positive and highly significant (1.294, $p < 0.01$). This demonstrates that strong IT governance amplifies the positive influence of tech-driven financial development on national environmental conservation funds. Specifically, a one-unit increase in the interaction term elevates conservation funds by 129.4%, underscoring the synergistic relationship between technological financial systems and robust governance structures.

Among the control variables in the indirect model, gross government debt remains negative and significant (-0.103 , $p < 0.01$), whereas final consumption expenditure retains its positive and significant effect (0.429, $p < 0.05$). Inflation and socioeconomic condition remain statistically insignificant.

To ensure the robustness of these findings, several post-estimation diagnostic tests are reported in the lower panel of Table 5. The AR(1) test yields p -values below 0.05, while the AR(2) test produces p -values above 0.05 for both models. This indicates the presence of first-order serial correlation but the absence of second-order correlation – consistent with the assumptions of valid system GMM estimation. The significant chi-square statistics further confirm the overall validity of the models.

Instrument validity is supported by the Sargan and Hansen tests. For both models, Sargan test p -values exceed 10%, indicating no over-identification problems. Hansen test p -values fall within Roodman's (2009) recommended range of 0.10 to 0.30 (0.227 for the direct model and 0.182 for the indirect model), demonstrating reliable and non-overfitted instruments. Additionally, the number of cross-sections (55) exceeds the number of instruments (46 and 53 in the direct and indirect models, respectively), confirming the instrument count is appropriate.

Overall, the diagnostic tests collectively affirm that all key assumptions of the two-step system GMM approach are satisfied. Therefore, the empirical estimates are consistent, efficient, and suitable for drawing reliable conclusions regarding the determinants of environmental conservation funds in emerging economies.

The final stage of the empirical analysis focuses on assessing the robustness of the primary estimation technique (sys-GMM) by employing an alternative methodological approach. For this purpose, the study utilizes linear dynamic panel data estimation (DPDE) as a robustness check. This approach provides consistent estimates by addressing key econometric challenges common in panel data – such as endogeneity, heteroskedasticity, and cross-sectional dependence. Moreover, DPDE enhances estimator efficiency and reduces dynamic bias, making it particularly suitable for datasets characterized by many cross-sectional units and relatively short time spans (Adewumi, 2024; Ahmad et al., 2021).

Consistent with the results obtained from the main sys-GMM model, the robustness estimations reveal that both the direct and indirect models re-

Table 6. Outcomes of robust approach (Dynamic panel data estimation)

Variables	(Model 1)	(Model 2)
	Dynamic Panel Data Estimation (Direct Impact)	Dynamic Panel Data Estimation (Indirect Impact)
	Log ECF	Log ECF
Log Environ. Conservation Funds (t-1)	0.455*** (0.015)	0.443*** (0.024)
Tech-Driven Financial Development	0.86*** (0.228)	0.742*** (0.254)
IT Governance	0.415*** (0.149)	0.729*** (0.235)
FD*IT-GOV		0.689*** (0.223)
Log Gross Government Debt	-0.099*** (0.014)	-0.134*** (0.024)
Log Inflation	-0.002 (0.007)	-0.002 (0.008)
Log Final Consumption Expenditure	0.13** (0.051)	0.208* (0.111)
Log Socioeconomic Condition	-0.09 (0.059)	-0.048 (0.078)
Constant	-1.801*** (0.266)	-2.243*** (0.462)
Observations	1045	1045
Number of Countries	55	55
Wald/Chi-Square	4321.595	1826.10
Prob. > Chi-Square	0.0000	0.0000

Note: Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

main dynamic, as indicated by the significance of the lagged dependent variable. Additionally, tech-driven financial development and IT governance retain their statistically significant and positive associations with environmental conservation funds across both model specifications. The interaction term between tech-driven financial development and IT governance is also positive and significant, suggesting that the moderating effect remains robust. These results, presented in Table 6, confirm the reliability and stability of the primary findings and reinforce the validity of the empirical strategy employed in this study.

The robustness findings reaffirm that tech-driven financial development substantially enhances national environmental conservation funds in both the direct and moderating models. Similar results were documented by Mertzanis (2023) and Qin et al. (2024), who identified a positive link between technology-driven financial development and environmental outcomes across different country panels using various environmental indicators. These findings also align with green finance theo-

ry, which emphasizes the importance of financial systems in supporting environmental sustainability. Tech-driven financial development promotes green finance by enabling innovative platforms that facilitate investments in clean technologies, green bonds, and sustainable financial products (Belgibayeva et al., 2025; Sharma et al., 2022; Udeagha & Muchapondwa, 2023). In emerging economies, technological financial innovations can improve access to finance, enhance transparency, stimulate green investments, and encourage public participation – such as through micro-donation platforms and green crowdfunding. They can also support clean-energy startups by offering alternative financing avenues that ultimately strengthen national environmental conservation funding.

Similarly, the results indicate that IT governance significantly contributes to environmental conservation funds in emerging economies under both the direct and indirect models. These findings are supported by Khan et al. (2024) and Lyulyov et al. (2024), who observed that strong IT gover-

nance enhances a country's ability to achieve sustainability objectives by improving environmental management systems. Effective IT governance frameworks are particularly crucial in emerging economies where environmental funding is often limited and must be deployed efficiently. By strengthening transparency, accountability, and oversight, IT governance ensures that conservation funds are managed effectively and directed toward impactful initiatives. Through improved coordination, efficient resource allocation, and integration of digital tools, IT governance enhances the long-term performance of environmental programs and supports the achievement of national sustainability goals.

The observed positive synergy between tech-driven financial development (TFD) and IT governance strongly implies that technological solutions, in isolation, are insufficient; their effectiveness is profoundly contingent upon a robust 'governance anchor.' This finding resonates with the Institutional Quality Hypothesis, which posits that the benefits derived from financial innovation are intrinsically linked to the strength and reliability of the underlying regulatory and institutional environment. In the context of emerging economies, IT governance functions as this essential anchor, providing the necessary oversight to counteract practices such as 'greenwashing' and ensuring that technology-enabled funds are judiciously channeled towards verifiable environmental projects. This insight significantly expands upon the work of Hossain et al. (2025) by empirically elucidating the specific scaling effect that this synergy imparts on national conservation budgets.

Furthermore, the interaction between tech-driven financial development and IT governance significantly enhances environmental conservation funds, underscoring the complementary relationship between these two factors. As emphasized by Hossain et al. (2025), tech-driven financial de-

velopment, IT governance, and sustainable performance are deeply interconnected; collectively, they strengthen the long-run resilience and sustainability of both the financial system and environmental management. Tech-driven financial development facilitates efficient resource allocation and transparent fund tracking, ensuring that financial resources reach high-impact environmental projects. At the same time, strong IT governance frameworks uphold the integrity of these systems by minimizing corruption, reducing mismanagement, and ensuring compliance. Together, these mechanisms substantially improve the effectiveness and scale of environmental conservation funds across emerging economies.

This empirical investigation is limited to a sample of 55 emerging economies over the period 2004–2023 and focuses specifically on national environmental conservation funds, tech-driven financial development, and IT governance as the primary variables. Future research can extend this paper in several ways. First, scholars may incorporate additional variables that are conceptually and empirically linked to environmental conservation funds such as environmental regulations, institutional quality, environmental taxation, renewable energy deployment, or climate-related financial disclosures. Second, while this study centers on emerging economies, future investigations may expand the dataset to include developed, low-income, or geographically diverse nations, enabling comparative analysis across different economic structures. Third, researchers may employ more recent or higher-frequency datasets to improve temporal coverage and capture contemporary technological advancements more accurately. Finally, future studies can apply alternative and advanced econometric techniques such as dynamic threshold models, spatial econometrics, panel quantile regression, or machine-learning-based causal inference to further validate or extend the relationships examined here.

CONCLUSION

This study was designed to empirically investigate the influence of tech-driven financial development on national environmental conservation funds across 55 emerging economies, with a particular focus on the moderating role played by IT governance.

The comprehensive empirical analysis unequivocally demonstrates that both advancements in tech-driven financial development and the implementation of effective IT governance frameworks substantially enhance the mobilization of environmental funds. Furthermore, the results underscore a potent synergistic effect, wherein robust IT governance structures significantly augment the capacity of financial technologies to scale and optimize conservation financing initiatives.

Based on these compelling findings, it is imperative that emerging economies prioritize the integrated development of financial innovation and stringent digital oversight to effectively address the existing environmental funding disparities. Consequently, strengthening IT governance emerges not merely as a technical prerequisite but as a strategic imperative for ensuring the transparency, accountability, and overall effectiveness of tech-driven environmental finance mechanisms.

AUTHOR CONTRIBUTIONS

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APPENDIX A

Table A1. List of emerging countries incorporated in the dataset

Albania	Botswana	Dominican Rep.	Haiti	Kenya	Nicaragua	South Africa
Algeria	Brazil	Ecuador	Honduras	Lebanon	Nigeria	Sri Lanka
Angola	Bulgaria	Egypt	India	Libya	Pakistan	Tanzania
Armenia	Cameroon	El Salvador	Indonesia	Mexico	Papua New Guinea	Tunisia
Azerbaijan	China	Gabon	Iran	Mongolia	Paraguay	Ukraine
Bangladesh	Colombia	Ghana	Iraq	Morocco	Peru	Vietnam
Belarus	Congo Rep.	Guatemala	Jamaica	Myanmar	Philippines	Zimbabwe
Bolivia	Cote d'Ivoire	Guyana	Jordan	Namibia	Senegal	