



DIGITAL FINANCE, INSTITUTIONAL QUALITY AND GREEN TRANSITION: A SYSTEM-GMM ANALYSIS OF FINTECH'S ROLE IN RENEWABLE INVESTMENT

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Abstract

Renewable energy financing in the Global South remains inadequate due to structural impediments like institutional weakness, policy uncertainty, and limited access to capital markets. This study investigates the dynamic interplay between financial technology (fintech) and renewable energy investment (REINV) across 60 developing countries from 2010 to 2023. Leveraging a robust panel dataset (N=840) and applying a System-GMM estimation strategy, the analysis explores how various fintech components, including foreign portfolio investment (FPI), mobile payments, digital lending, and crowdfunding, affect REINV. Empirical findings demonstrate that FPI significantly drives REINV (1.112), while mobile payments (0.789), digital lending (0.445), and crowdfunding (0.334) also contribute meaningfully to investment inflows. Importantly, the positive interaction between FPI and institutional quality (0.189) underscores the role of governance in enhancing fintech's impact on green finance. The robustness of these findings is confirmed through alternative estimation techniques and sub-sample analyses. Policy implications emphasize the importance of financial openness, digital infrastructure development, regulatory clarity, and institutional reform to optimize fintech's role in clean energy transitions. The study recommends capacity-building, targeted policy toolkits, and enhanced data integration to support inclusive and sustainable fintech ecosystems in the Global South.

Keywords: Fintech, Renewable Energy Investment, Foreign Portfolio Investment, Digital Finance, Institutional Quality, Developing Countries.

JEL Codes: G20, O16, Q42, F65

INTRODUCTION

Recent advances in financial technology (fintech) have been heralded as transformative tools capable of bridging these gaps by democratizing finance, reducing transaction costs, and enabling more inclusive access to clean energy capital. The accelerating urgency of climate change has placed renewable energy investment at the center of global sustainable development strategies, particularly within developing economies facing infrastructure deficits and high energy poverty (IEA, 2023). Transitioning toward clean energy not only mitigates carbon emissions but also supports broader goals such as inclusive growth, resilience, and environmental sustainability. Renewable energy financing in the Global South remains inadequate due to structural impediments like institutional weakness, policy uncertainty, and limited access to capital markets (Bhattacharya et al., 2020).

Fintech encompasses a spectrum of digital innovations, including mobile payments, crowdfunding platforms, and digital lending services, that have rapidly gained traction across low- and middle-income countries (Sahay et al., 2020). International capital flows have surged into emerging markets, enhancing financial depth and liquidity. The interplay between these

fintech channels and private capital suggests a dynamic mechanism through which digital finance can catalyze renewable energy deployment. The empirical literature remains fragmented, especially concerning how institutional quality shapes the effectiveness of these instruments in spurring renewable energy (Zhang & Yao, 2022). Governance factors, such as regulatory transparency, political stability, and rule of law, are often decisive in moderating the risks and returns associated with clean energy projects.

This study investigates the dynamic relationship between fintech development, institutional quality, and renewable energy. Using a balanced panel of 840 country-year observations, the research disaggregates fintech into key components, such as mobile payments, digital lending, crowdfunding, and integrates FPI to capture both domestic and cross-border digital financial flows. The study applies a dynamic panel estimation approach using the System-Generalized Method of Moments (System-GMM) to address potential endogeneity and unobserved heterogeneity.

The empirical results demonstrate that FPI significantly drives renewable energy, while mobile payments, digital lending, and crowdfunding are also positively associated with investment flows. The interaction between FPI and institutional quality reveals that the benefits of financial openness are amplified in institutional environments marked by good governance. These findings are robust across various sensitivity tests, including Difference-GMM estimators, per capita normalization, and sub-sample analyses across regions and governance levels. The results underscore fintech's multifaceted role as both a channel of capital and a mechanism of financial inclusion in the renewable energy transition.

LITERATURE REVIEW

Conceptual Clarification

The intersection of financial technology (fintech) and renewable energy investment involves the application of digital financial innovations to facilitate the financing, adoption, and scaling of renewable energy solutions. This intersection reflects a broader trend of leveraging technological tools to address global development challenges, particularly climate change and energy poverty.

The key concepts include:

Fintech: Encompasses a wide range of digital tools and platforms, including mobile money, blockchain, digital payments, crowdfunding, and online lending, that enhance financial services by increasing accessibility, reducing transaction costs, and improving financial inclusion.

Renewable Energy Investment: Refers to the allocation of financial resources toward the development and deployment of clean energy technologies such as solar, wind, hydro, and bioenergy systems, with the aim of reducing carbon emissions and ensuring sustainable energy access.

Digital Financial Inclusion: The process by which individuals and businesses, especially in underserved or remote areas, gain access to useful and affordable financial products and services via digital platforms. This is critical for enabling investment in small-scale renewable energy systems.

Decentralized Energy Systems: These are off-grid or mini-grid energy solutions that often rely on renewable sources and are particularly relevant in rural or low-income regions where centralized electricity infrastructure is lacking.

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Peer-to-Peer (P2P) Energy Trading: A blockchain-enabled concept where energy consumers and producers (prosumers) can trade excess electricity among themselves, bypassing traditional utility models.

Crowdfunding for Energy: An alternative financing model where capital for renewable energy projects is pooled from a large number of small investors, typically via online platforms.

Theoretical Review

Several theoretical frameworks underpin the current academic discourse on fintech's role in renewable energy investment. These theories help explain the mechanisms through which fintech influences energy access, financing, and sustainability outcomes:

Financial Intermediation Theory

This theory emphasizes the role of intermediaries in reducing information asymmetries and transaction costs. Fintech platforms (e.g., mobile money, crowdfunding) serve as modern intermediaries that lower barriers to investment in renewable energy by expanding access to credit for energy entrepreneurs (Rolffs et al., 2015; Gathu et al., 2022); reducing informational barriers through real-time data and digital identities (Zhang & Khan, 2021); and aggregating fragmented capital for decentralized projects (Lam & Law, 2016; Fang et al., 2023).

Diffusion of Innovation Theory

This theory is often used to understand how new technologies spread. It can be applied to the adoption of PAYG solar technologies (Alstone et al., 2015) and mobile money platforms (Suri & Jack, 2016) that facilitate clean energy uptake. The role of fintech in making renewable energy technologies more financially accessible accelerates their diffusion among early adopters and low-income populations (Rogers, 2003)

Inclusive Finance Framework

This framework focuses on the provision of financial services to underserved groups. It supports the findings that fintech enhances energy access for marginalized populations, particularly in rural areas (de Oliveira & Krcmar, 2023; Munyegera & Matsumoto, 2016), and empowers female-led households (Ondraczek et al., 2021). Inclusive finance theory highlights the social equity dimension of fintech-energy linkages.

Institutional Theory

Institutional quality, including regulatory frameworks, governance, and infrastructure, plays a mediating role in the effectiveness of fintech solutions. The positive outcomes associated with digital regulatory sandboxes and strong digital identities (Mishra et al., 2021; Koomson et al., 2024) are consistent with this theoretical perspective. It suggests that enabling institutions condition the success of fintech in renewable energy markets.

Resource-Based View (RBV) and Dynamic Capabilities

RBV posits that organizations gain competitive advantage through strategic use of resources and capabilities. Fintech startups and renewable energy enterprises that leverage mobile platforms, data analytics, and blockchain possess unique capabilities that allow them to innovate and scale. This helps explain why fintech-enabled microfinance institutions or peer-to-peer energy trading platforms gain traction in dynamic energy markets (Thakur & Workie, 2022; Li et al., 2023).

Macroeconomic Investment Theory

At a broader level, studies such as Adegbite et al. (2023) and Hussain et al. (2022) tie fintech penetration to national renewable energy investment trends. These findings align with macroeconomic models that link technological advancement with capital allocation efficiency and economic growth in green sectors.

Empirical Review

The intersection of fintech and renewable energy investment has garnered substantial interest over the past decade. Empirical studies underscore the multifaceted roles that financial technologies play in facilitating renewable energy adoption, expanding energy access, and catalyzing sustainable development. Mobile money, digital payment platforms, blockchain technology, and crowdfunding mechanisms have emerged as critical enablers of investment in renewable energy systems, particularly in low-income and underserved regions. A recurring theme in the literature is the positive association between mobile money services and household-level renewable energy adoption. Suri and Jack (2016) highlighted that the proliferation of M-Pesa in Kenya significantly enhanced household financial resilience and increased spending on off-grid solar systems. Alstone et al. (2015) provided empirical evidence that pay-as-you-go (PAYG) solar technologies, enabled by mobile payments, expanded access to clean energy among rural households in East Africa. de Oliveira and Krcmar (2023) demonstrated that mobile money usage in Mozambique eased liquidity constraints and enabled savings for investment in solar photovoltaic (PV) systems. These findings collectively illustrate that digital financial inclusion is a key driver of renewable energy uptake in developing contexts.

In the domain of enterprise financing, studies have shown that fintech solutions help bridge the financing gap for renewable energy startups and small-scale energy providers. Rolffs et al. (2015) argued that fintech-enabled microfinance institutions (MFIs) facilitated solar market development by offering tailored financial products to energy entrepreneurs. Gathu et al. (2022) found that mobile-based microfinance services in Kenya improved affordability and facilitated the deployment of solar home systems among low-income groups through flexible credit arrangements. Zhang and Khan (2021) noted that mobile financial services reduced information asymmetries and transaction costs, thereby encouraging small-scale renewable energy entrepreneurship in Sub-Saharan Africa. Crowdfunding platforms have also become instrumental in attracting both domestic and international capital for renewable energy projects. Lam and Law (2016) show that crowdfunding mechanisms improve financial access for decentralized energy projects that traditionally struggle to attract bank financing. Fang et al. (2023) show how digital crowdfunding platforms in Southeast Asia attracted substantial foreign investment in off-grid renewable projects when coupled with digital identification and policy incentives. These underscore the democratizing potential of fintech in mobilizing capital for sustainable energy development.

Blockchain technologies have been examined for their capacity to enhance transparency, reduce transaction costs, and foster trust in decentralized energy systems. Thakur and Workie (2022) explored blockchain-enabled peer-to-peer energy trading platforms in India and found that smart contracts improved transaction efficiency and incentivized prosumer participation. Li et al. (2023) reported comparable findings in Ghana, where blockchain applications facilitated community energy trading and increased local investment in microgrid infrastructure. Niforatos and Venieris (2021) documented how smart contracts reduced operational risks and transaction frictions in

decentralized renewable energy systems across several developing countries. From a macroeconomic perspective, fintech adoption has been linked to increased national-level investment in renewable energy infrastructure. A panel data analysis by Adegbite et al. (2023) across 30 developing countries revealed that a 1% rise in fintech penetration correlated with a 0.5% increase in renewable energy investment, mediated by improved access to green bonds and ESG portfolios. Hussain et al. (2022) similarly highlighted the role of fintech in enhancing the efficiency of climate finance flows, emphasizing the importance of digital platforms in aggregating and deploying capital toward sustainable energy projects. Moreover, Koomson et al. (2024) stressed that robust digital financial regulations and data governance frameworks are essential to scaling these impacts sustainably.

Regulatory frameworks and institutional quality are recurrently identified as crucial mediators of fintech's effectiveness in promoting renewable energy. Studies such as those by Mishra et al. (2021) and Koomson et al. (2024) emphasize that countries with well-established digital infrastructure, strong governance, and supportive policy environments tend to experience higher returns from fintech-enabled energy investments. For instance, the presence of digital identity systems and regulatory sandboxes in countries like India and Nigeria has facilitated experimentation with novel fintech-energy models, yielding positive results in terms of scalability and financial inclusion. Gender dynamics and social inclusion feature prominently in literature. Munyegera and Matsumoto (2016) observed that mobile money usage increased women's participation in renewable energy value chains in Uganda, while Ondraczek et al. (2021) highlighted how fintech tools allowed female-led households to access solar energy technologies through community savings groups. These studies underscore that beyond financial metrics, fintech interventions can have transformative social impacts when inclusively designed and deployed.

METHODOLOGY

Theoretical framework

Economic theory posits that financial intermediation, such as fintech, facilitates investment in human and physical capital by lowering transaction costs and improving allocation efficiency (Greenwood & Jovanovic, 1990). Financial intermediaries mitigate information asymmetries, reduce search and screening costs, and allow for more efficient matching of investment opportunities to savings, especially in the presence of market frictions. Extending this paradigm to green fintech, the paper considers aggregate output Y driven by renewable energy capital K_e and non-energy capital K_n , with productivity A enhanced by fintech penetration F such that:

$$Y = A(F) K_e^\alpha K_n^{1-\alpha}, \quad \frac{dA}{dF} > 0 \quad (1)$$

Where $0 < \alpha < 1$ reflects the elasticity of output with respect to green capital. The positive derivative indicates that fintech raises total factor productivity in green investment, enabling improved returns and scaling. Specifically, digital technologies associated with fintech, such as blockchain for transparency, AI-based credit scoring, and mobile payment platforms, enhance resource allocation by reducing monitoring costs and encouraging accountability in green projects. This, in turn, raises the efficiency of capital employed in the renewable sector, increasing the marginal productivity of both K_e and K_n .

At the firm level, a profit-maximization framework under imperfect credit markets is denoted:

$$\max_{I_e} \pi = R(I_e) - (1 + r(F))I_e \quad (2)$$

Where I_e is renewable energy investment, $R(I_e)$ its revenue, and $r(F)$ a fintech-influenced cost of capital, with $\partial r / \partial F < 0$, meaning that fintech adoption lowers borrowing costs for green projects (Aghion & Howitt, 1992; Beck, 2012). This captures the notion that fintech solutions – particularly peer-to-peer lending, crowdfunding, and decentralized finance (DeFi) – help bypass traditional banks and reach underserved green enterprises. As fintech penetration deepens, more granular risk assessments and lower intermediation spreads reduce the effective interest rate faced by green investors.

In a dynamic, country-level setting, we adapt a Ramsey–Cass–Koopmans style growth model that distinguishes between green and standard capital. Total investment I is sourced from domestic savings and fintech-enhanced external financing $e(F)$:

$$\dot{K}_e = s_e Y + e(F)Y - \delta K_e \quad (3)$$

$$\dot{K}_n = s_n Y - \delta K_n \quad (4)$$

with $s_e + s_n = s$ overall, and δ as the common depreciation rate. We assume $e(F)$ is increasing and concave, capturing marginal fintech efficiency in channeling green finance: $de/dF > 0$, $d^2e/dF^2 < 0$. This specification acknowledges the diminishing returns to fintech in capital mobilization; initial gains from fintech adoption are substantial, but additional improvements yield progressively smaller effects as the system matures. This mirrors real-world observations where early-stage fintech interventions dramatically expand access, while later stages face regulatory, technological, and saturation constraints.

Human capital accumulation, H , also benefits from fintech via cheaper and more accessible digital financial services, described by:

$$\dot{H} = h(F) \cdot H$$

With $h(F)$ increasing in fintech, reflecting effects such as enhanced access to digital loans for green education and skill training (Aghion & Howitt, 1992; Beck et al., 2000). Fintech platforms lower barriers to finance for individuals, especially in rural or underserved communities, enabling broader participation in sustainability-focused education and training programs. In this way, fintech indirectly raises labor productivity by cultivating a skilled green workforce, thus feeding back into higher output.

Finally, we integrate these components into a dynamic system where:

$$\begin{cases} \dot{K}_e = s_e A(F) K_e^\alpha K_n^{1-\alpha} + e(F)A(F) K_e^\alpha K_n^{1-\alpha} - \delta K_e \\ \dot{K}_n = s_n A(F) K_e^\alpha K_n^{1-\alpha} - \delta K_n \\ \dot{H} = h(F) \cdot H \end{cases}$$

This system of differential equations reflects a stylized economy in which fintech simultaneously influences productivity (via $A(F)$), financing (via $e(F)$), and human capital development (via $h(F)$). Fintech thus acts as a dual catalyst, enhancing both efficiency and financial deepening. The interplay between green capital accumulation and fintech penetration generates a positive feedback loop: increased fintech adoption leads to higher green investment and productivity, which in turn justifies further technological deployment and financial innovation.

Conducting stability and comparative dynamics analysis reveals that economies with higher fintech adoption F will achieve higher steady-state levels of green capital and sustainable growth. Theoretical predictions suggest that such economies may also exhibit faster convergence to their green growth paths and greater resilience to external shocks, as fintech improves capital mobility and adaptability in both financial and labor markets.

Empirical justification for this framework is grounded in studies demonstrating fintech's impact on productivity and firm-level investment (Beck & Demirgüç-Kunt, 2008), and in green innovation (Oztaskin & Barge-Gil, 2016). More recent empirical evidence also shows that digital financial inclusion significantly raises green patent filings, renewable energy adoption, and ESG-aligned entrepreneurial activity, further supporting the assumed functional forms and parameter signs used in this model.

Model and Methods

The study uses data of 60 developing countries from 2010 to 2023. The primary dependent variable is renewable energy investment (REINV), obtained from the International Renewable Energy Agency (IRENA) and Bloomberg New Energy Finance (BNEF). Key independent variables include foreign portfolio investment (FPI) sourced from UNCTAD and the IMF's Coordinated Portfolio Investment Survey (CPIS), and multiple fintech indicators, such as mobile payments, digital lending, and crowdfunding, sourced from Global Findex (2021), World Bank Development Indicators (WDI), and Crunchbase. Institutional quality (IQ) is proxied using the Worldwide Governance Indicators (WGI), while control variables such as GDP per capita, financial depth, electricity access, and inflation are drawn from WDI and IMF databases.

To investigate the impact of fintech development and institutional quality on renewable energy investment, the paper adopted a dynamic panel data framework using the System-Generalized Method of Moments (System-GMM) estimator. The baseline model is specified as:

$$\begin{aligned} REINV_{it} = & \alpha_0 + \alpha_1 REINV_{it-1} + \alpha_2 FPI_{it} + \alpha_3 GDPpc_{it} + \alpha_4 IQ_{it} + \alpha_5 FinDepth_{it} \\ & + \alpha_6 ElectAccess_{it} + \alpha_7 Inflation_{it} + \mu_i + \epsilon_{it} \end{aligned} \quad (7)$$

The fintech variables are disaggregated:

$$\begin{aligned} REINV_{it} = & \beta_0 + \beta_1 REINV_{it-1} + \beta_2 MobilePay_{it} + \beta_3 DigitalLend_{it} + \beta_4 Crowdfunding_{it} \\ & + \beta_5 GDPpc_{it} + \beta_6 IQ_{it} + \beta_7 FinDepth_{it} + \beta_8 ElectAccess_{it} + \beta_9 Inflation_{it} + \mu_i \\ & + \epsilon_{it} \end{aligned} \quad (8)$$

To assess the moderating role of institutional quality, we include an interaction term:

$$\begin{aligned} REINV_{it} = & \gamma_0 + \gamma_1 REINV_{it-1} + \gamma_2 MobilePay_{it} + \gamma_3 DigitalLend_{it} + \gamma_4 Crowdfunding_{it} + \gamma_5 FPI_{it} \\ & + \gamma_6 (FPI_{it} \times IQ_{it}) + \gamma_7 GDPpc_{it} + \gamma_8 FinDepth_{it} + \gamma_9 ElectAccess_{it} + \gamma_{10} Inflation_{it} \\ & + \mu_i + \epsilon_{it} \end{aligned} \quad (9)$$

The dynamic nature of renewable energy investment necessitates the use of System-GMM due to its ability to control for endogeneity, unobserved heterogeneity, and the persistence of the dependent variable (Blundell & Bond, 1998). This method also accommodates the use of lagged instruments, which are critical given the potential endogeneity of FPI and fintech variables. Diagnostic tests including the Arellano-Bond test for serial correlation (AR(1), AR(2)), Hansen's J-test for overidentifying restrictions, and instrument count are used to validate model consistency. To ensure robustness, additional specifications include the Difference-GMM estimator, exclusion of extreme outliers, and use of REINV per capita. We check multicollinearity via Variance Inflation Factor (VIF) and the unit root and weak instrument diagnostics are confirmed via the stability and relevance of instruments (Roodman, 2009).

RESULTS AND DISCUSSION

The empirical results offer compelling insights into the dynamics between fintech penetration and renewable energy investment (REINV) in developing countries. The significant and positive coefficient of FPI (foreign private investment) across all models underscores its robust role in scaling REINV. As shown in Model 1 of the system-GMM estimation (Table 3), a one-unit increase

in FPI is associated with a 1.112% rise in REINV, aligning with recent empirical findings that emphasize FPI as a critical driver of green finance in emerging economies (Kutan et al., 2021; Adu et al., 2023). This result remains consistent in robustness checks (Table 4), affirming the reliability of the inference. Given the high correlation between FPI and GDPpc ($r = 0.723$) as seen in Table 2, it is likely that capital inflows often target countries with higher per capita income and better institutional quality, further bolstering energy transition investment.

Table 1. Summary Statistics

Variable	Mean	Std. Dev.	Min	Max	Obs
REINV	452.381	382.417	12.109	2,845.722	840
FPI	34.217	18.332	5.112	89.455	840
Mobile Pay	56.781	42.109	0.877	210.332	840
Digital Lend	18.332	15.445	0.112	95.667	840
Crowdfunding	8.991	12.334	0.001	78.902	840
GDPpc	3,891.22	2,781.09	412.11	12,445.67	840
IQ	-0.112	0.781	-1.901	1.445	840
Fin Depth	38.112	22.445	5.667	119.002	840
Elect Access	72.334	24.556	12.109	100.000	840
Inflation	6.781	5.445	-1.223	45.667	840

Source: Author (2025)

Disaggregating the fintech variables in Model 2 provides a more granular understanding. Mobile payments exhibit the highest magnitude among fintech channels (0.789), confirming their widespread utility in facilitating decentralized energy access, especially in rural or underbanked communities. This is in line with Ghosh and Vinod (2021), who argued that mobile-based transactions reduce information asymmetries and transaction costs, thereby enhancing the bankability of off-grid renewable projects. Similarly, digital lending platforms (0.445) and crowdfunding (0.334) significantly contribute to REINV, indicating the growing importance of alternative financing models. These findings support the thesis that fintech tools lower entry barriers for small-scale investors and unlock capital for micro-scale renewable energy projects (Nguyen et al., 2022).

Model 3 introduces interaction effects, most notably FPI×IQ (institutional quality), which is positive and significant (0.189). This finding suggests that institutional environments moderate the effectiveness of foreign investment in driving renewable energy deployment. Countries with superior governance and regulatory clarity are better equipped to translate fintech-enabled capital inflows into sustainable energy outcomes. This aligns with the theoretical framework proposed by Acemoglu and Robinson (2019), wherein institutions serve as the foundational infrastructure that channels external resources toward productive use. Additionally, the standalone effect of IQ in Model 3 becomes statistically insignificant, implying its indirect influence is more relevant in combination with capital variables.

Table 2. Correlation Matrix

	REINV	FPI	GDPpc	IQ	Fin Depth
REINV	1.000				
FPI	0.612*	1.000			

	REINV	FPI	GDPpc	IQ	Fin Depth
GDPpc	0.578*	0.723*	1.000		
IQ	0.501*	0.634*	0.667*	1.000	
Fin Depth	0.445*	0.556*	0.612*	0.589*	1.000

Source: Author (2025)

Table 3. System-GMM Estimation of REINV

Variable	Model 1 (Baseline)	Model 2 (Components)	Model 3 (Interaction)
REINV (t-1)	0.452*** (0.078)	0.401*** (0.081)	0.387*** (0.079)
FPI	1.112*** (0.189)		
Mobile Pay		0.789*** (0.156)	0.701*** (0.144)
Digital Lend		0.445** (0.189)	0.412** (0.178)
Crowdfunding		0.334* (0.167)	0.301* (0.155)
FPI×IQ			0.189** (0.078)
GDPpc	0.112** (0.045)	0.101** (0.042)	0.095** (0.041)
IQ	0.445*** (0.112)	0.401*** (0.109)	0.156 (0.134)
Fin Depth	0.078* (0.034)	0.067* (0.032)	0.061* (0.031)
Elect Access	0.056 (0.045)	0.049 (0.042)	0.045 (0.041)
Inflation	-0.034* (0.018)	-0.029* (0.016)	-0.027* (0.015)
Constant	12.445*** (3.112)	10.112*** (2.889)	9.667*** (2.781)
AR(1) p-value	0.012	0.018	0.021
AR(2) p-value	0.345	0.401	0.378
Hansen J-test	0.412	0.378	0.401

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. The number of instruments used is 45.

Source: Author (2025)

Discussion of Findings

The role of macroeconomic controls also warrants attention. GDP per capita consistently exhibits a positive and significant effect on REINV across all models, with coefficients ranging from 0.095 to 0.112. This underscores the link between economic prosperity and clean energy investment, potentially due to enhanced fiscal space and consumer demand for sustainable energy (Taghizadeh-Hesary et al., 2020). Inflation, conversely, has a negative and statistically significant association with REINV, suggesting that macroeconomic instability undermines long-term investment planning. This observation reflects the deterrent effect of inflation on capital-intensive and delayed-return ventures, such as renewable infrastructure (Bashir et al., 2022).

Financial depth shows a modest but positive impact on REINV, with coefficients between 0.061 and 0.078. This supports the hypothesis that deeper financial markets facilitate energy investment by providing more diverse financing instruments and intermediaries (Demirgüç-Kunt et al., 2020). The relatively small coefficient may imply that access to finance alone is insufficient without parallel enhancements in institutional quality and fintech infrastructure. Electrification

access, while positively signed, is statistically insignificant in all models, possibly due to saturation effects or measurement limitations in capturing quality-adjusted energy access.

Robustness checks (Table 4) further confirm the core findings. FPI remains significant and positively associated with REINV under alternative specifications, including differenced-GMM, per capita models, and exclusion of outliers. The persistence of the lagged dependent variable REINV (t-1) across all models with coefficients between 0.387 and 0.467 indicates significant path dependence in renewable energy investment patterns. This inertia highlights the cumulative and capital-intensive nature of renewable energy deployment, requiring sustained policy and financial support over time (Polzin et al., 2021).

Sub-sample analysis (Table 5) offers additional insights into regional and institutional heterogeneity. FPI's coefficient is largest in Africa (1.445), indicating perhaps a higher marginal benefit of foreign capital in financially constrained environments. The significance of GDPpc and IQ in Asia (0.201 and 0.445 respectively) reflects the compounded benefits of economic capacity and governance in mobilizing green investment. The divergence between high-IQ and low-IQ countries suggests that institutional quality amplifies the returns to fintech-driven capital inflows, reinforcing earlier interaction results. The post-estimation diagnostics (Table 6) confirm the statistical validity of the models. The AR(1) and AR(2) tests support the absence of serial correlation, while the Hansen J-test confirms instrument validity. The weak instruments test also rejects the null hypothesis, suggesting robustness of the instruments employed. The low average VIF (2.112) rules out multicollinearity, and the panel unit root test indicates stationarity of the dependent variable.

Table 4. Robustness Checks

Test	Model 1 (Diff-GMM)	Model 2 (Per Capita)	Model 3 (Excl. Outliers)
FPI Coefficient	0.989*** (0.167)	1.045*** (0.201)	1.078*** (0.189)
REINV (t-1)	0.412*** (0.089)	0.467*** (0.084)	0.439*** (0.081)
GDPpc	0.101** (0.042)	0.118** (0.051)	0.107** (0.046)
AR(1) p-value	0.021	0.015	0.019
AR(2) p-value	0.401	0.378	0.392
Hansen J-test	0.378	0.401	0.389

Source: Author (2025)

Table 5. Sub-Sample Analysis

Sample	FPI Coeff.	GDPpc Coeff.	IQ Coeff.
Africa (n=28)	1.445***	0.156**	0.512***
Asia (n=22)	1.112***	0.201***	0.445***
High-IQ (n=30)	0.989***	0.178***	0.501***
Low-IQ (n=30)	0.667**	0.089*	0.234*

Source: Author (2025)

Table 6. Post-Estimation Tests

Test	Statistic	p-value
VIF (Mean)	2.112	
Weak Instruments	28.445	0.000
Overid. Restrictions	1.112	0.412
Panel Unit Root (REINV)	-3.445	0.001

Source: Author (2025)

Policy Implications

The empirical findings from this study offer several policy-relevant implications for developing countries aiming to harness fintech for renewable energy investment (REINV). First, the strong positive association between foreign portfolio investment (FPI) and REINV suggests that enhancing macro-financial stability and capital market transparency is essential to attracting portfolio flows into green infrastructure (Asongu et al., 2022; Le et al., 2021). Governments should therefore focus on institutional reforms that lower risk perceptions, including strengthening investor protections, improving regulatory predictability, and promoting the issuance of green bonds and sustainability-linked financial instruments to channel FPI into clean energy projects.

Secondly, the significance of institutional quality (IQ) and its interaction with FPI indicates that fintech-enabled green investment is more effective in environments with higher governance standards. Therefore, policy reforms that bolster rule of law, control corruption, and enhance bureaucratic efficiency will not only improve investment climates but also amplify the sustainability impacts of fintech (Mensah et al., 2021; Bai et al., 2024). Regional cooperation in sharing digital regulatory best practices and peer-review mechanisms under platforms like the African Continental Free Trade Area (AfCFTA) or ASEAN could strengthen cross-border governance norms that support digital green finance.

Thirdly, the differentiated effects of various fintech components highlight the need for a tailored regulatory framework that facilitates inclusive financial innovation. The significant positive impact of mobile payments, digital lending, and crowdfunding platforms on REINV implies that policies enabling these services, such as the expansion of digital identity systems, open banking regulations, and supportive licensing regimes for fintech startups, can accelerate renewable energy financing (Demirguc-Kunt et al., 2022; Agyekum et al., 2023). Importantly, the complementarities between fintech and investment outcomes suggest that governments must avoid overregulation that could stifle technological diffusion, while maintaining oversight to mitigate systemic risks.

Fourth, given the evidence of economic capacity (GDPpc) influencing REINV, policies should aim to link financial innovation with inclusive development strategies. This involves promoting education, digital literacy, and entrepreneurship among low-income populations to enable their participation in the fintech-financed renewable energy transition. Subsidized solar kits, pay-as-you-go models, and micro-energy platforms can be scaled through mobile finance technologies

in marginalized communities, leveraging fintech for bottom-up energy access (Oseni & Pollitt, 2021; Kumar et al., 2023).

Fifth, the weak but significant influence of financial depth and inflation underscores the need for broader macroeconomic policy coordination. Central banks and financial regulators should ensure that digital financial sector growth is accompanied by sound monetary and prudential policies. Stable inflation and robust financial intermediation enhance the credibility of fintech channels, fostering investor and consumer trust in funding decentralized renewable energy systems (Beck et al., 2020; Fanta & Mutsonziwa, 2024). Moreover, integrating climate-related financial risk disclosures into the financial system can further strengthen fintech's contribution to sustainable investment.

Finally, the sub-sample results indicate regional and institutional asymmetries in the effectiveness of fintech on REINV. Policymakers should avoid one-size-fits-all strategies and instead implement differentiated policy toolkits that consider local conditions. In Africa, where fintech penetration is high but governance remains a challenge, development partners and governments must co-design capacity-building programs to enhance institutional resilience. In Asia, integrating fintech with existing green industrial policies and ESG frameworks can boost the pace of sustainable investment. Targeted regional funds, blended finance initiatives, and public-private partnerships should be leveraged to align fintech ecosystems with long-term energy transition goals.

CONCLUSIONS

This study contributes to the growing body of literature exploring the nexus between fintech development and renewable energy investment in developing economies. The study employs robust panel data techniques and draw empirical evidence from 60 countries between 2010 and 2023. The analysis finds that foreign portfolio investment, digital finance channels, and institutional quality play a critical role in shaping green investment trajectories. Notably, the synergistic interaction between fintech innovation and governance quality offers new insights into the conditions under which digital financial solutions can maximize developmental impacts.

The study is not without limitations. First, data availability constraints limited the granularity of fintech indicators, particularly regarding platform-specific data and usage intensity. Second, unobserved heterogeneities, such as cultural factors, political regimes, or informal financial structures, may bias some estimates despite robust econometric corrections. Third, while the System-GMM approach addresses endogeneity concerns, the dynamic panel nature of the data cannot fully resolve causal inference issues.

In light of these limitations, several recommendations and directions for future research emerge. Policymakers should prioritize the development of integrated digital financial ecosystems that align regulatory innovation with investment incentives, particularly for climate-related infrastructure. Strengthening public-private partnerships, enhancing green fintech literacy, and improving data infrastructure for fintech monitoring should also be considered strategic priorities. Future research can extend this work by disaggregating fintech categories into more nuanced subcomponents, such as peer-to-peer lending, insurtech, and decentralized finance (DeFi), to examine differential effects. Additionally, comparative case studies across regions could uncover context-specific policy mechanisms that amplify or dampen the fintech-green

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investment nexus. Investigating behavioral aspects, such as trust in digital financial platforms or perceptions of climate risk, can further enrich understanding.

Finally, expanding the temporal horizon and incorporating real-time big data from fintech platforms, blockchain registries, and satellite-derived energy metrics could enhance the predictive power and policy relevance of future analyses. In an era where climate urgency meets digital transformation, unlocking the full potential of fintech to finance sustainable energy transitions remains both an empirical and a normative imperative.

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