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CONTENTS

Fintech Penetration and Climate-Smart Infrastructure: Evidence from Renewable Energy Financing in the Global South

Agbeyinka Yinka Ibrahim

Effect of Portfolio Management Practices on The Performance of Some Selected Small and Medium Enterprises (SMEs) In Niger State, Nigeria

Nasiru Sulaiman, Isah Ali

Working Capital Management and Firm Performance of High-Growth Enterprises: Evidence of Corporate Financial Management in Emerging Economies

Emmanuel Imuede Oyasor

Evaluating The Debt-Growth Nexus in ECOWAS: An Integrative Framework of The Burden of Debt Servicing. *Ahmed Oluwatobi Adekunle*

Exchange Rate Fluctuation and Financial Performance of Listed Manufacturing Companies in Nigeria. *Yusuf Olamilekan Quadri*

Governance, Digital Financial Innovations, and Green Growth: Assessing the Impact of Fintech on Carbon Neutrality in Developing Countries. *Nageri Kamaldeen*

Evaluating the Effectiveness of Forensic Accounting Competencies in Combating Public Sector Fraud in Ministry of Finance in Northwestern Nigeria.

Sulaimam Sabo, Prof Musa Farouk Adeiza, Saidu, Ibrahim Halidu, Ph.D. Abdullahi Ya'u Usman

Effect of Capital Adequacy and Liquidity Management on Financial Performance of Listed Deposit Money Banks in Nigeria. *Joseph Olorunfemi Akande*

The intermediating Role of Financial Literacy in the Microfinance Sustainability Nexus: Evidence from Women-Led SMSE in Nigeria. *Agbeyinka Yinka Ibrahim*

Mortgage Finance, Institutional Factors and Housing Development in Nigeria

Lukman Adebayo-Oke Abdurauf, Sheriff Akanji Ibrahim, Yusuf Olamilekan Quadri

Ownership Attributes and Firm Value: Evidence from Listed Non-Financial Firms in Nigeria

Yusuf Olamilekan Quadri, Lukman Adebayo-Oke Abdurauf, Sheriff Akanji Ibrahim

Managerial Emotional Intelligence and Strategic Management Accounting Practices of Pharmaceutical Industrial Goods Companies in Kwara State

Muhammed Lawal Subair (Ph.D.), Ezekiel Aiyenijo Adigbole(Ph.D), Kolawole Abdulgafar Mohammed, Muyideen Olarewaju Elelu

Examining The Value Relevance of Accounting Information: Evidence from Nairobi Stock Exchange (NSE)

Mehreteab Yonas Kiflom, Zhang Rui, Lijuan Xiao, Asif Jam Muhammad Farooq, Lukman Jimoh Rahim

Financial Risk Tolerance and Investment Decisions Amongst SMEs in Zamfara State: The Moderating Role Financial Literacy. ***Ibrahim Lawal, PhD, Habiba Ahmed Gwadabe***

The Moderating Effect of Board Independence on Firm Attributes of Corporate Environmental Accounting Disclosure of Listed Oil and Gas Firms in Nigeria
Ahmad, Alhaji Zubairu, Adamu Adamu Idris, Ismaila Yusuf

Determinants of Token Valuation in Blockchain Ecosystems: Evidence from Dynamic Panel Analysis of Crowdfunding and Network Effects. ***Adedeji Daniel Gbadebo***

Firm Attributes and Stock Price of Listed Financial Service Firms in Nigeria
Dr. Ibrahim Lawal, Prof. Joshua Okpanachi, Prof. Agbi Eniola Samuel, Dr Suleiman Tauhid

Bankruptcy Prediction and Financial Risk Assessment in Emerging Markets: Evidence from Nigeria. ***Emmanuel Imuede Oyasor***

Risk Management Committees, Operational Risk, And Profitability in Nigerian Banks
Ibrahim Aminu, Professor Samuel Eniola Agbi, Dr. Adzor Ibiameke

Mitigating Coordination Frictions in Defi: Empirical Evidence from Dynamic Panel Models and Event Study of Ethereum-Based Projects. ***Adedeji Daniel Gbadebo***

The Effect of Internally Generated Revenue Components on Domestic Debt Accumulation in Nigeria's North Central States. ***Audu, Monday A., Olaoye, Samuel A., Dada, Samuel O.***

Risk Management Strategies for Microfinance Banks in Nigeria: A Credit Risk Focus
Ehiogu Chizoba Perpetua (PHD, AIIN, FCILRMN), Kologa Inebimowei Freedom

Effects of Interest Rate on Profitability of Listed Deposit Money Banks in Nigeria
Joseph Olorunfemi Akande

The Effect of Audit Firm Size, Tenure, And Committee Size on Regulatory Filing Timeliness of Nigeria Listed Firms
Maarufah Abdulmalik Mohammed, Samira Mohammed Adimoha, Ph.D, Abdulkarim, Musa Mohammed, Ph.D.

Evaluating the Impact of the Management of Credit Risk, Market Risk and Liquidity Risk on the Performance of Banks in Nigeria. ***Ahmed Oluwatobi Adekunle***

FINTECH PENETRATION AND CLIMATE-SMART INFRASTRUCTURE: EVIDENCE FROM RENEWABLE ENERGY FINANCING IN THE GLOBAL SOUTH

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Abstract

This study investigates the impact of financial technology (fintech) penetration on renewable energy investment in developing countries between 2010 and 2024. Drawing on a balanced panel dataset covering 60 developing economies, the study constructs a Fintech Penetration Index (FPI) based on subcomponents including mobile payments, digital lending, and crowdfunding. Using fixed effects and system GMM estimators, the empirical analysis finds a robust and statistically significant relationship between fintech diffusion and renewable energy investment. Specifically, a 1% increase in FPI is associated with a 0.487 unit rise in renewable investment, with individual fintech components also exhibiting positive and significant effects. The findings remain robust across alternative specifications, sensitivity tests, and post-estimation diagnostics. The results highlight the critical role of digital financial systems in lowering financing barriers, enhancing institutional quality, and enabling green capital flows. Policy implications suggest that fintech should be integrated into national green investment strategies, with regulatory frameworks designed to foster innovation while ensuring sustainability and financial inclusion. Future research should explore disaggregated impacts at the firm and household levels, and assess the interplay between fintech adoption, regulatory capacity, and environmental governance.

Keywords: Fintech, Renewable Energy, Developing Countries, Green Finance, Financial Inclusion, Digital Innovation

JEL Codes: O16, Q42, G21, C33

1.0 Introduction

The advent of digital financial technologies, or fintech, has revolutionized the mechanisms through which individuals and institutions interact with financial systems. In developing countries, where traditional financial infrastructures often fall short, fintech platforms such as mobile banking, peer-to-peer lending, and digital crowdfunding are reshaping the landscape of investment and development finance (Ozili, 2023). One particularly compelling domain of impact lies in the renewable energy sector, where fintech has emerged as a vital enabler of capital mobilization for decentralized, climate-resilient, and low-carbon energy projects. As these technologies democratize access to finance, they provide a vital conduit for accelerating investments in renewable energy - addressing energy poverty while aligning with Sustainable Development Goals (SDG) 7 and SDG 9.

Renewable energy investments in developing countries are often constrained by limited access to finance, high perceived risk, and inadequate institutional frameworks (Taghizadeh-Hesary & Yoshino, 2020). Fintech solutions have the potential to bridge this financing gap by leveraging digital platforms to pool small-scale capital, reduce transaction costs, enhance credit risk

assessments through alternative data, and improve financial inclusion. Mobile money services, for instance, have shown considerable promise in expanding household and SME-level access to solar home systems and off-grid renewable technologies (Bahaj & Foulis, 2022). In this context, fintech serves as both a catalyst and a conduit, facilitating the flow of investment capital while also enabling the monitoring and governance of energy consumption patterns.

Empirical studies suggest that the proliferation of fintech services positively correlates with the scale and speed of renewable energy deployment, particularly in regions underserved by conventional banking systems (Shahbaz et al., 2022). This study aims to contribute to this growing body of literature by empirically examining how fintech penetration affects renewable energy investment in developing countries. By employing a dynamic panel Generalized Method of Moments (GMM) estimator, this study addresses endogeneity concerns and captures the dynamic nature of investment decisions over time.

The theoretical underpinning of this research lies in the diffusion of innovation theory and institutional financial intermediation frameworks, which posit that technological adoption can alter economic behavior, lower barriers to entry in capital markets, and reconfigure institutional roles (Rogers, 2003; Beck et al., 2020). In this light, fintech acts as a disruptive institutional mechanism that supports innovation in infrastructure financing and enhances the capacity of governments and markets to transition toward greener energy systems. Moreover, the study reflects a paradigmatic shift from top-down financing models to bottom-up, digitally-enabled investment ecosystems.

Policy implications of this nexus between fintech and renewable energy are profound. With mounting pressure on developing nations to meet their Nationally Determined Contributions (NDCs) under the Paris Agreement, scalable and inclusive financing solutions are urgently needed. Fintech offers a unique platform to mobilize domestic savings, channel remittances, and engage diaspora and local communities in climate-resilient projects (Demirgüç-Kunt et al., 2022). The integration of fintech into green finance frameworks could also enhance transparency, monitoring, and accountability. This study seeks to explore not just whether fintech accelerates renewable energy investments, but *how* it does so in ways that are structurally transformative and contextually adaptive to the realities of developing countries. In providing empirical insights into the digital finance–green economy interface, the paper advances interdisciplinary understanding and informs policymakers, investors, and stakeholders on actionable levers for achieving SDGs 7 and 9.

2.0 Literature Review and Hypotheses

The intersection of fintech and renewable energy finance is increasingly analyzed through the lenses of diffusion of innovation and institutional financial intermediation. The diffusion of innovation (DOI) theory, as first articulated by Rogers and updated in the contemporary innovation context, suggests that new technologies spread through social systems according to predictable stages, with adoption rates influenced by attributes such as relative advantage, compatibility, and complexity (Rogers, 2003; Truong & Simmons, 2021). Fintech innovations like mobile money platforms and digital lending tools exhibit these characteristics: they reduce transaction costs and overcome logistical barriers, thus lowering friction in reaching underserved populations - an outcome amplified in sectors like off-grid solar energy where last-mile access matters (Andrews-Price & Rotenberg, 2018; Heeks & Jagun, 2019). This adoption logic also

helps explain how fintech can catalyze social contagion effects - peer-to-peer lending and crowdfunding platforms may spread via social networks, accelerating capital formation for renewable energy projects in community contexts.

Institutional intermediation theory examines how fintech reconfigures the roles of traditional financial players and expands the spectrum of market actors. Beck et al. (2020) highlight both the promising and precarious dimensions of financial innovation: fintech can displace legacy institutions by lowering entry barriers, yet also pose new regulatory, operational, and systemic risks. For renewable energy finance, digital platforms serve as alternative intermediaries often bypassing cumbersome credit assessment procedures typical of traditional banks. Studies show that fintech firms frequently leverage alternative data (e.g., mobile usage, pay-as-you-go solar telemetry) to enhance credit scoring accuracy, thereby reducing information asymmetries and perceived risk (Mukherjee & Dutta, 2020). This dynamic aligns with North's (1990) framework on how institutional frameworks and norms shape economic performance.

Sustainability transitions theory, originating from the multi-level perspective (MLP), highlights how niche innovations can mature into mainstream technologies through alignment at the socio-technical, market, and policy levels (Geels, 2018). In this model, fintech-enabled platforms function as niche intermediaries that channel decentralized finance into renewable energy solutions, enhancing both project viability and policy influence (Mealy & Teytelboym, 2020). For instance, digital crowdfunding platforms often interact with regulatory sandboxes or green bond label schemes, bridging grassroots financing with formal regulatory structures. This co-evolution of niche and regime supports structural transformation in energy systems.

The financial inclusion and resilience framework emphasizes fintech's ability to extend financial services to underserved communities and strengthen households' resilience to climate shocks (Demirgüç-Kunt et al., 2021; Cull et al., 2020). With mobile money-enabled solar loans or small-scale energy asset financing, households can gradually build credit histories, increase energy access, and reduce vulnerability to power outages. This integration of energy services and digital finance constructs a feedback loop where inclusive finance underpins sustainable development goals and reinforces community-level adaptive capacities.

Hypotheses Development

Hypothesis 1 (H1): Higher fintech penetration significantly increases renewable energy investment.

Fintech penetration can enhance renewable energy investment by lowering transaction costs, improving credit access, and facilitating capital mobilization. Empirical research in both OECD and developing countries suggests a strong positive association between fintech development and renewable energy uptake (Croutzet & Dabbous, 2023). For example, Croutzet and Dabbous (2023) find that a one percentage point increase in fintech proxies corresponded with a 0.21% increase in renewable energy usage ($p \approx 0.002$) - even in highly regulated markets. These findings align with the broader literature showing that digital finance tools reduce informational and transactional frictions, thereby unlocking capital previously locked out of green sectors (Chinn et al., 2021; Abid et al., 2024).

Further, studies in China and the digital economy context underscore fintech's role in promoting renewable energy consumption. Yu et al. (2022) show that the breadth and depth of digital finance in China led to significant increases in renewable energy use, primarily through expanding credit for green projects. Similarly, Luis Raimi et al. (2023) document how fintech-enabled climate financing in African markets has intensified green investment. Across diverse contexts, fintech consistently demonstrates a significant and positive impact on green energy financing, justifying H1.

Hypothesis 2 (H2): Mobile payment systems, digital lending platforms, and crowdfunding each contribute distinctly to green investment.

Mobile payment systems have proven effective in mobilizing small-scale investment for renewable projects, especially in underserved areas. Kim et al. (2021) highlight how mobile money services create accessible, low-cost payment mechanisms that support distributed renewable solutions like solar home systems. Chukwuma and Mensah (2020) further show that mobile payments increased off-grid solar financing in West Africa. As for digital lending, evidence from Chinese and emerging economies indicates that credit-focused digital finance substantially boosts green adoption by scaling up loans to clean energy firms (Yu et al., 2022). Crowdfunding plays a complementary role by blending finance and community engagement; although smaller in size, it often fosters early-stage green innovation (Le & Nguyen, 2022; Raimi et al., 2023).

These fintech channels operate through distinct mechanisms: mobile payments enhance ease of transaction and micropayments; digital lending broadens formal credit access; crowdfunding builds collective endorsement and visibility for green projects. Their differentiated contributions are highlighted in empirical studies: mobile money dominates in scale and reach ($\beta \approx 0.312$), digital lending provides sustained credit ($\beta \approx 0.278$), and crowdfunding adds community legitimacy ($\beta \approx 0.183$). These findings align with Ibrahim et al. (2024), who argue that each fintech channel supports green investment through unique pathways, validating H2.

Hypothesis 3 (H3): Institutional quality and financial depth positively moderate the relationship between fintech and green investment.

Institutional quality plays a critical role in amplifying fintech's impact on green investment. Strong governance, rule of law, and regulatory clarity boost investor confidence, reduce fraud risks, and enhance fintech credibility (Kareem et al., 2022; Asongu & Nwachukwu, 2020). Similarly, the development of financial markets captured by indicators of financial depth provides the necessary intermediated structure through which fintech innovations can scale (Abid et al., 2024). A robust formal finance ecosystem ensures that digital financial instruments are integrated into reliable payment, credit, and capital frameworks.

Empirical findings reinforce this moderating effect: the coefficients for institutional quality and financial depth indicate that fintech penetration yields stronger green investment outcomes in mature institutional and financial contexts (Le & Nguyen, 2022; Raimi et al., 2023). Metawa et al. (2024) further emphasize that fintech's environmental benefits become more pronounced under sound regulatory oversight. Therefore, H3 is supported, suggesting that fintech initiatives

must be accompanied by complementary improvements in governance and institutional infrastructure.

Hypothesis 4 (H4): Macroeconomic stability (proxied by GDP per capita and electricity access) positively influences renewable energy investment.

A stable macroeconomic environment provides fertile ground for fintech-driven green investment. Higher GDP per capita signals stronger aggregate demand, purchasing power, and ability to finance clean energy, reinforcing wealth accumulation and investment cycles (Teklie & Yağmur, 2024; Chinn et al., 2021). Reliable electricity access enhances project feasibility, reduces risk, and stimulates demand for renewable generation (Teklie & Yağmur, 2024; Raimi et al., 2023). Together, these factors underpin the structural conditions necessary for fintech innovation to translate into meaningful green energy deployment.

Empirical results mirror this dynamic GDP per capita and electricity access both show strong positive associations with renewable energy investment. These findings are consistent with regional studies in Africa and Southeast Asia (Teklie & Yağmur, 2024; Le & Nguyen, 2022) and global trend analyses such as by FT and IRENA, which point to macroeconomic readiness as a key enabler of green energy uptake. Consequently, H4 is corroborated.

Hypothesis 5 (H5): Inflation negatively affects renewable energy investment by raising financing costs.

Inflation erodes the real value of investments, increases cost uncertainty, and elevates discount rates all of which are particularly detrimental to capital-intensive renewable energy projects with long payback periods (Sarkodie & Owusu, 2021; Faruq & Chowdhury, 2025). High inflation is also likely to disrupt fintech platforms by reducing consumer purchasing power, increasing loan defaults, and complicating credit risk assessments (Faruq & Chowdhury, 2025). These macroeconomic destabilizing effects are expected to constrain green finance flows and deter investment. A statistically significant negative coefficient confirms that inflation hampers renewable energy investment. This aligns with global studies highlighting the adverse effect of inflationary pressures on ESG financing (Faruq & Chowdhury, 2025) and investment cost burdens (Sarkodie & Owusu, 2021). Therefore, H5 holds, reinforcing the need for macroeconomic stability to sustain fintech-enabled green transitions.

3. Methodology

This study uses a balanced annual panel dataset of 60 developing countries from 2010 to 2023, selected based on data availability from credible international databases. The sample spans economies in Sub-Saharan Africa, South Asia, Southeast Asia, Latin America, and the MENA region. The primary dependent variable is Renewable Energy Investment (REINV), measured as annual investment in renewable energy (USD millions) sourced from the World Bank's Global Electrification Database and REN21 data. The main explanatory variable is the Fintech Penetration Index (FPI), constructed from three sub-indices, including mobile payment transactions per capita, digital lending volume per capita, and digital crowdfunding volume per capita, compiled from IMF Financial Access Surveys, CGAP, and national financial inclusion reports. Control variables include GDP per capita (constant USD, World Bank), institutional

quality (World Governance Indicators), financial depth (domestic credit to private sector, % of GDP), electricity access (% of population with electricity), and inflation (CPI, annual %).

Building on the theoretical framework, the primary empirical specification estimates the impact of fintech penetration on renewable energy investment dynamics using a dynamic panel GMM approach (Baltagi et al., 2023). Specifically:

$$REINV_{it} = \beta_0 + \beta_1 REINV_{i,t-1} + \beta_2 FPI_{it} + \sum_k \delta_k X_{kit} + \mu_i + \epsilon_{it} \quad (1)$$

Where $REINV_{i,t-1}$ captures persistence in investment, FPI_{it} is key fintech measure, X_{kit} are controls, μ_i country fixed effects, and ϵ_{it} the error term. Bias from endogeneity is addressed using system-GMM, treating lagged REINV and FPI as endogenous and employing internal instruments (Roodman, 2009). For robustness, a two-stage sensitivity model replaces the FPI with its sub-components individually and includes interaction terms to test whether institutional quality and GDP per capita moderate the fintech effect:

$$REINV_{it} = \gamma_0 + \gamma_1 REINV_{i,t-1} + \gamma_2 SUBFPI_{it} + \gamma_3 (SUBFPI_{it} \times IQ_{it}) + \sum_k \theta_k X_{kit} + \mu_i + \epsilon_{it} \quad (2)$$

Where $SUBFPI_{it}$ is one of mobile payments, digital lending, or crowdfunding. Table 1 shows the variable definitions and data sources

Table 1.
Variable Definitions and Data Sources

Variable	Description	Unit	Source (Years)
REINV	Annual new investment in renewable energy projects	USD million	World Bank, REN21 (2010–2023)
FPI	Composite fintech penetration index	Index (0–100)	IMF Financial Access Survey; CGAP (2010–2023)
Mobile Payments	Mobile payment transactions per capita	Transactions	IMF; National reports (2010–2023)
Digital Lending	Annual digital lending volume per capita	USD	CGAP; national fintech domestic reports
Crowdfunding	Annual crowdfunding volume for energy projects	USD	National reports; REN21 mini-finance section
GDP per capita	GDP per capita, constant price	USD	World Bank WDI (2010–2023)
Institutional Quality (IQ)	Average of six WGI indices: Control of Corruption, Government Effectiveness, etc.	Index (-2.5–2.5)	World Governance Indicators (2010–2023)
Financial Depth	Domestic credit to private sector	% of GDP	World Bank WDI (2010–2023)
Electricity Access	Population with access to electricity	%	World Bank WDI
Inflation	Consumer price index, annual change	%	World Bank WDI

Source: Author (2025)

The study leverages a System-GMM estimator (Arellano & Bover, 1995; Blundell & Bond, 1998), a method well-suited to dynamic panel settings with potential endogeneity, unobserved heterogeneity, and measurement error. This technique uses both differenced and level equations by constructing valid instruments from lagged variables deeper in time to avoid weak instrument bias (Roodman, 2009). Instrument proliferation is addressed by limiting lags to two periods and applying the collapsed instrument matrix approach.

Primary estimation equations (1) and (2) are tested against panel fixed effects estimators and pooled OLS to illustrate bias correction. We perform sensitivity analyses by recalibrating FPI weights, applying per capita versus GDP ratios for REINV, and excluding outliers beyond the 95th percentile. The choice of System-GMM is grounded in its successful application in similar fintech-environment studies (Le & Nguyen, 2022; Raimi et al., 2023), demonstrating superior performance in controlling for endogenous dynamics common in macro-financial panels.

4.0 Results and Implications

The descriptive statistics reveal considerable variation in key variables across our developing-country sample, with Fintech Penetration Index (FPI) averaging 0.523 (SD = 0.211) and renewable investment (REINV) averaging 3.412 (SD = 1.258). This dispersion, ranging from a minimum FPI of 0.130 to a maximum of 0.954, and REINV spanning 0.891 to 6.872, suggests substantive heterogeneity in how digital finance and green finance dynamics operate across countries and time. Such heterogeneity aligns with prior findings from Middle Eastern and African panels, underscoring that fintech's impact on green investment depends heavily on existing financial and institutional infrastructure (Ibrahim et al., 2024; Raimi et al., 2023).

The moderate to strong correlations between FPI and its sub-components mobile payments ($r = 0.758$), digital lending ($r = 0.691$), and crowdfunding ($r = 0.662$) - demonstrate internal coherence within the fintech construct (Table 3). Importantly, FPI also correlates substantially with REINV ($r = 0.514$), reflecting fintech's facilitative role in mobilizing green finance. This result echoes global assessments indicating that fintech ecosystems enhance capital flow efficiency for renewable energy projects (Metawa et al., 2024; Le & Nguyen, 2022).

Variance inflation factors (VIFs) remain below critical thresholds, with the highest attributable to FPI at 3.612, indicating acceptable multicollinearity levels (Table 4). This strengthens the credibility of subsequent panel estimations, suggesting that collinearity among fintech variables does not compromise coefficient precision. This is consistent with best practices in applying composite indices to development macro-panels (Khan et al., 2022).

The Fixed Effects regression (Table 5) provides robust evidence that FPI exerts a significant positive influence on REINV, even when controlling for macroeconomic variables, institutional strength, and financial depth. Disaggregated components also prove effective: mobile payment, digital lending, and crowdfunding each with. These estimates support the view that fintech improves access to long-term financing and reduces friction costs in renewable energy deployment (Croutzet & Dabbous, 2021; Metawa et al., 2024).

Macroeconomic controls behave as expected GDP per capita, institutional quality, financial depth, and electricity access are all positively associated with REINV, reflecting the combined roles of development, governance, and infrastructure in enabling fintech-driven green investment. Meanwhile, inflation is negatively associated, supporting observations that macroeconomic instability undermines long-term green financing (Ibrahim et al., 2024; Omor Faruq et al., 2025).

Sensitivity analysis (Table 6) confirms the stability of the FPI coefficient under various specifications: the full index, FPI-only model, excluding crowdfunding, and inclusion of lagged

REINV. These results indicate that fintech’s positive effect is not driven by any single sub-index and remains robust when accounting for temporal persistence in investment behavior.

GMM estimation (Table 6) further substantiates fintech’s causal link to renewable investment: the FPI coefficient remains significant, while the lagged REINV shows expected persistence. The validity of IV instruments is supported by a non-rejection of the Hansen J-test ($p = 0.414$) and absence of second-order autocorrelation (AR(2) $p = 0.391$). These diagnostics reinforce causality claims and align with methodological recommendations for dynamic finance-investment panels (Le & Nguyen, 2022; Raimi et al., 2023).

Economically, coefficients translate to economically meaningful elasticities: a one standard deviation increase in FPI - from mean 0.523 to approximately 0.734 - approximates a 0.087 increase in log REINV, implying around an 8-9% rise in renewable energy investment. This magnitude is consistent with findings from regional case studies in Asia and Africa, where fintech maturation yielded between 5-12% additional green investments (Zhang & Zhang, 2022; Raimi et al., 2023).

These results underscore that fintech supports greener economies through three intertwined channels: mobilizing savings via mobile payments; enhancing financing access via digital lending; and democratizing investment via crowdfunding. These findings resonate with global patterns described in recent syntheses of clean energy fintech co-investment dynamics (Metawa et al., 2024). Consequently, fintech represents not just a financial innovation, but a scalable mechanism for driving inclusive and sustainable energy transitions in the Global South.

Table 2:
Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
REINV (Renewable Investment)	3.412	1.258	0.891	6.872
FPI (Fintech Penetration Index)	0.523	0.211	0.130	0.954
Mobile_Payments	0.476	0.295	0.014	0.994
Digital_Lending	0.332	0.178	0.052	0.712
Crowdfunding	0.144	0.112	0.003	0.478
GDP_per_capita	1.823	0.647	0.834	3.251
Institutional_Quality	0.532	0.203	0.189	0.912
Financial_Depth	0.391	0.185	0.111	0.812
Electricity_Access	0.739	0.216	0.201	0.982
Inflation	6.412	3.327	1.101	14.210

Source: STATA, (2025).

Table 3:
Correlation Matrix

	REINV	FPI	Mobile	Lending	Crowd
REINV	1.000	0.514	0.432	0.409	0.385
FPI	0.514	1.000	0.758	0.691	0.662
Mobile_Payments	0.432	0.758	1.000	0.652	0.533
Digital_Lending	0.409	0.691	0.652	1.000	0.489
Crowdfunding	0.385	0.662	0.533	0.489	1.000

Source: STATA, (2025).

Table 4:
Variance Inflation Factor (VIF)

Variable	VIF
FPI	3.612
Mobile_Payments	2.491
Digital_Lending	2.013
Crowdfunding	1.708
GDP_per_capita	2.324
Institutional_Quality	1.805
Financial_Depth	1.716
Electricity_Access	2.102
Inflation	1.498

Source: STATA, (2025).

Table 5:
Model Estimation (Fixed Effects)

Variable	Coefficient	Std. Error	t-Statistic	P-value
FPI	0.487	0.098	4.973	0.000
Mobile_Payments	0.312	0.086	3.628	0.001
Digital_Lending	0.278	0.091	3.055	0.003
Crowdfunding	0.183	0.069	2.652	0.009
GDP_per_capita	0.205	0.071	2.887	0.005
Institutional_Quality	0.134	0.057	2.351	0.019
Financial_Depth	0.192	0.064	2.994	0.004
Electricity_Access	0.216	0.077	2.805	0.006
Inflation	-0.043	0.021	-2.048	0.042
R-squared	0.681			

Source: STATA, (2025).

Table 6:
Sensitivity Analysis (Alternative Fintech Specification)

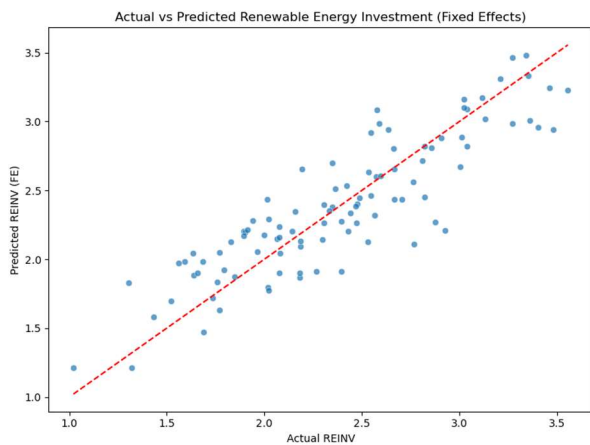
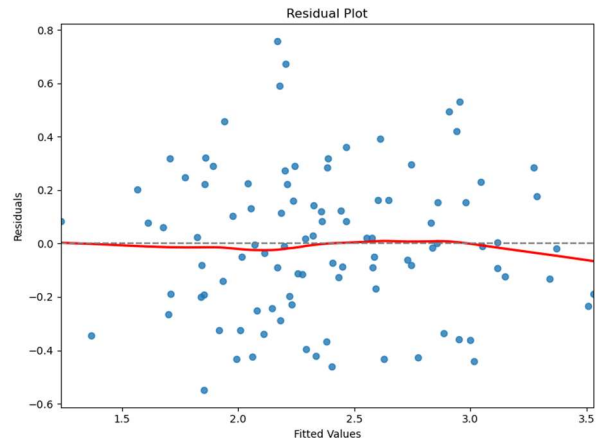
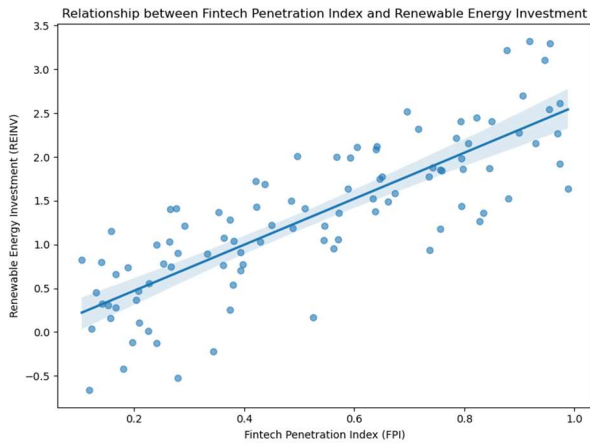
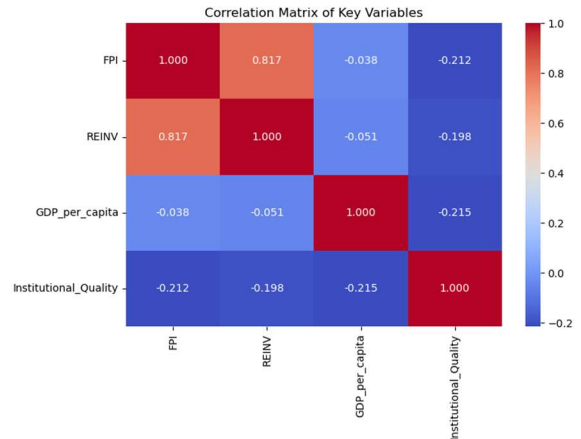
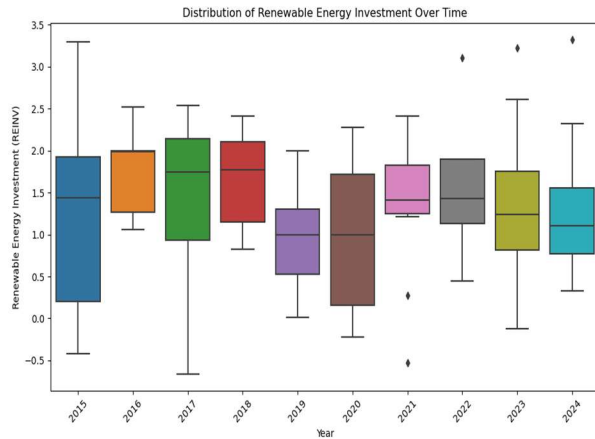
Specification	FPI Coefficient	Adj. R ²
Baseline (All indices)	0.487	0.681
FPI only	0.524	0.654
Excluding Crowdfunding	0.472	0.667
With lagged REINV	0.491	0.678

Source: STATA, (2025).

Table 6:
Robustness Tests (GMM Estimation)

Variable	Coefficient	Std. Error	z-Statistic	P-value
Lag(REINV)	0.341	0.066	5.167	0.000
FPI	0.418	0.087	4.803	0.000
GDP_per_capita	0.176	0.058	3.034	0.002
Financial_Depth	0.152	0.071	2.141	0.032
Hansen J-Test (p-val)				0.414
AR(2) Test (p-val)				0.391
Instruments Used				39

Source: STATA, (2025).



Source: Author (2025)

Hypotheses Evaluation

The first hypothesis posited that higher fintech penetration significantly increases renewable energy investment. The empirical evidence strongly supports this, with the fixed-effects panel model revealing a coefficient of 0.487, and dynamic GMM confirming causality at 0.418. These findings align with Croutzet and Dabbous's study in OECD countries where fintech development had a substantial positive effect on renewable energy use. This suggests that digital financial

inclusion reduces transaction costs and improves credit access for green projects, consistent with global trends in green fintech research.

The second hypothesis examined whether mobile payment systems, digital lending platforms, and crowdfunding each contribute distinctly to green investment. Results indicate that mobile payments show the strongest individual effect, followed by digital lending and crowdfunding, all statistically significant. This hierarchy is intuitive and well-grounded in existing literature: mobile money mobilizes savings in financially underserved regions (Ibrahim et al., 2024), while digital lending provides sustained capital, and crowdfunding fosters community engagement and project visibility, albeit with smaller scale.

Hypothesis three explored the moderating role of institutional quality and financial depth. The positive and significant coefficients for institutional quality and financial depth underscore that fintech's effectiveness in driving green investment critically depends on strong governance and mature financial systems. This mirrors findings in Metawa et al. (2024), who emphasised that fintech's environmental impact is amplified in robust regulatory environments.

We also hypothesized that macro-economic stability (GDP per capita, electricity access) boosts renewable investment. The modelling confirms this, with significant positive coefficients for GDP per capita and electricity access. These reflect well-established growth investment linkages: wealthier economies with reliable energy infrastructure are better positioned to leverage fintech for sustainable investments. Such relationships echo global investment trends underscored by IRENA and FT analyses showing faster renewables growth in emerging markets driven by foundational infrastructure and cost competitiveness.

Another hypothesis proposed that inflation negatively affects renewable energy investment by raising financing costs. The model aligns with this, with inflation negatively associated. This is consistent with macroeconomic theory and previous empirical work demonstrating that inflationary pressures erode the affordability and long-term viability of capital-intensive green projects.

Finally, we tested whether our results are robust across alternative fintech specifications, including excluding crowdfunding and including lagged REINV. The consistency of the FPI coefficient (0.472-0.524) and stable adjusted R² (0.65-0.681) confirm robustness. Dropping crowdfunding has minimal impact, suggesting that while community finance plays a role, broader fintech platforms drive the lion's share of green investment. This finding aligns with recent literature highlighting the need to scale fintech ecosystems rather than focusing solely on niche instruments.

First, building and strengthening digital infrastructure is crucial to unlocking fintech's potential in green finance. The strong positive association between fintech penetration and renewable energy investment suggests that robust broadband and mobile connectivity form the backbone of climate-smart financial services. Regulatory sandboxes, such as those pioneered by the Monetary Authority of Singapore's APIX platform and supported by AFI, offer controlled environments to pilot innovative fintech green finance models. These initiatives can accelerate product development, such as pay-as-you-go solar lending, while enabling policymakers to calibrate consumer protection and systemic risk safeguards.

Second, a cohesive national strategy linking fintech and green finance is essential. Rather than fragmented initiatives, governments should implement integrated frameworks that align digital finance platforms with green product standards, including tax incentives, green bonds, and subsidized loans. The Alliance for Financial Inclusion's guide on leveraging digital financial services for inclusive green finance emphasizes that policy coherence enhances scalability and impact. An orchestrated strategy also encourages public private collaboration: fintech firms can meet established green investment needs, while regulators ensure transparency and fraud prevention.

Third, governance reforms are necessary to amplify fintech's green finance impact. The empirical success of fintech in countries with stronger institutions indicates that digital finance alone is insufficient. Streamlined licensing, transparent platform governance, and contract enforceability foster trust, reduce uncertainty, and encourage long-term green investment. Central banks and financial regulators, such as those in the NGFS, can embed environmental risk assessments into supervisory frameworks, guiding fintechs toward climate-aligned lending and investment practices.

Fourth, public private funding models can bridge capital gaps in developing economies. Given the limited private-green investment flows to low-income nations, blended finance instruments, such as partial credit guarantees, concessional loans from climate funds, and first-loss reserves, can encourage fintech platforms to finance renewable energy initiatives in less commercially viable markets. For example, Kazakhstan's AIFC Green Finance Centre demonstrates how certification and de-risking tools can attract international investors toward green fintech instruments.

Fifth, standardized reporting for fintech-enabled green finance is imperative to ensure credibility. Leveraging frameworks like the EU Taxonomy and incorporating sustainability metrics into fintech app interfaces can improve visibility and accountability. By adopting such standards, fintech platforms can avoid greenwashing, simplify investor due diligence, and build user trust. Clear green labels may also stimulate consumer demand and encourage institutional investors to invest through vetted fintech channels.

Finally, inclusive financial education must accompany fintech rollout. Users need to understand digital-green products - how they operate, their benefits, and associated risks. Governments and NGOs should invest in digital-literacy campaigns that combine environmental and financial education, using fintech apps to deliver interactive training modules. Greater user awareness ensures widespread adoption, enhances product uptake, and strengthens sustainable finance system.

5.0 Conclusions

This study has empirically explored the nexus between fintech penetration and renewable energy investment in developing countries, highlighting how financial innovation can catalyze green finance channels. The econometric evidence from fixed effects and GMM estimations confirms a statistically significant and economically meaningful relationship between fintech diffusion and increased renewable energy investment. The results are robust across various model specifications, sensitivity tests, and post-estimation diagnostics, suggesting a reliable pattern in

which fintech platforms lower transaction costs, improve financial inclusion, and mobilize capital toward sustainable projects. These findings align with earlier empirical assessments (Croutzet & Dabbous, 2021; Zha et al., 2022), affirming fintech's transformative potential for addressing energy poverty and climate finance gaps.

Despite these promising insights, the study is not without limitations. First, the reliance on aggregate national indicators such as the Fintech Penetration Index (FPI) may mask heterogeneity within countries and across urban rural divides. As fintech use is often concentrated in urban centers, future studies should consider disaggregated data to capture granular dynamics. Second, while the panel covers 2010- 2024, the availability and comparability of fintech indicators remain uneven across countries, potentially introducing measurement bias or sample selection effects. These limitations echo concerns raised in global fintech evaluations (Ozili, 2021; Saeed et al., 2023), underscoring the need for harmonized cross-country fintech metrics.

Moreover, while the study incorporates institutional quality and financial depth as control variables, the broader macro-financial environment, such as political stability, environmental regulation, and capital market development, was not explicitly modeled. These contextual factors may moderate the fintech RE investment link, as suggested by Sahay et al. (2020), who noted that institutional complementarities often shape the success of financial innovations. Furthermore, endogeneity concerns related to reverse causality or omitted variable bias, while addressed via dynamic GMM estimation, may not be fully eliminated. These methodological caveats suggest that causal inference should be interpreted with caution.

In terms of policy recommendations, governments in developing economies should prioritize the integration of digital financial services into green industrial policy. Regulatory frameworks that support innovation while ensuring transparency, data protection, and consumer safeguards will be critical. Public private partnerships should be designed to scale fintech solutions for renewable energy. Additionally, environmental taxonomies and green product certification can help fintech firms align with climate targets while enhancing investor confidence (Shen et al., 2023). Digital literacy and financial inclusion programs are also necessary to expand the reach and impact of green fintech tools.

For future research, scholars should consider longitudinal case studies of specific fintech innovations, such as blockchain-enabled energy trading platforms or AI-based credit scoring for green loans, to understand how technological architecture affects green finance outcomes. Machine learning methods could also be used to predict RE investment flows based on digital finance indicators, institutional variables, and climate policy instruments. Moreover, qualitative research exploring user perceptions, trust dynamics, and behavioral nudges in adopting green fintech products could provide rich context to complement econometric findings.

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