European Journal of Sustainable Development (2025), **14**, 2, 997-1028 ISSN: 2239-5938
Doi: 10.14207/ejsd.2025.v14n2p997

The Impact of Disaggregated Financial Innovation and Energy Poverty on Microfinance Development in Africa

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ABSTRACT

This study explores the impact of financial innovation and energy poverty on the development of microfinance in 49 African nations, using yearly data from 2000 to 2022. The study deploys the panel system Generalised Method of Moments (GMM) to investigate the relationships between the phenomena, with robustness checks performed using the Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) models. The GMM investigation revealed that financial innovation has a positive impact on microfinance development in Africa, but energy poverty has a significant negative impact. The FMOLS results confirm the positive benefits of financial innovation and the negative implications of energy poverty. In contrast, the DOLS findings show that financial innovation may have a significant negative impact on microfinance development, although the long-term implications of energy poverty are equivocal. The study emphasises the need of using contemporary financial technologies including ATMs, point-of-sale systems, mobile banking, and mobile money to improve microfinance in Africa. Additionally, it emphasises the importance of addressing energy poverty, since reliable energy is crucial to the sustainability of small businesses and industries. As a result, the research suggests authorities should draw attention to increasing energy production while ensuring equal and cheap distribution.

Keywords: Financial Innovation, Energy Poverty, Microfinance Development
Jel Classification: N2, G53, F63, P28

1. Introduction

Microfinance expansion in Africa is critical for increasing financial inclusion and reducing poverty, particularly in distant and neglected areas. Microfinance institutions (MFIs) provide essential services such as lending, savings, and insurance to individuals and small companies that are unable to access traditional banking, hence allowing investments in small businesses and agriculture. This financial access improves lives and stimulates economic growth, especially for marginalised groups such as women and rural communities (Chikalipah, 2017). Beyond financial inclusion, access to microfinance has greatly improved living conditions in places lacking traditional banking, which has also made income-generating options easier (Khandker, 2005). Throughout Africa, the microfinance industry has experienced significant expansion, particularly in nations like Kenya, Nigeria, Ghana, and Uganda. Nevertheless, growing challenges impede the sustainability and scalability of microfinance in Africa, notwithstanding the sector's

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expansion. According to Hermes and Lensink (2011), a number of microfinance institutions (MFIs) experience operational and structural inefficiencies that result in high operating expenses and high loan interest rates, which constrain rather than liberate clients. The financial viability and economic empowerment potential of MFIs are restricted by these inefficiencies. According to Cull, Demirgüç-Kunt, and Morduch (2009), MFIs are also susceptible to instability because to inadequate regulatory frameworks and macroeconomic issues, such as a lack of transparency and accountability. Additional problems to MFI expansion, particularly in rural areas, include a lack of technological advancement in financial products and services and limited access to infrastructures such as power. Complementary macroeconomic measures are essential for expanding the provision of microfinance and reaching a broader population.

Financial inventiveness, which includes novel financial products and services, and technology, is essential to improving affordability and efficacy in Africa's financial sector. Innovative financing has the ability to transform the small-scale lending industry by increasing availability, reducing transaction expenses, and allowing microfinance institutions (MFIs) to offer their services to a greater number of people. The growth of mobile payments services is one noteworthy example, since it has significantly improved access to financial services in nations such as Kenya (Shettima et al., 2023). However, because numerous MFIs face financial, technological, and infrastructure obstacles, the diffusion of innovative finance in Africa is still insufficient (Adedeji et al., 2024). The absence of internet access in rural regions is a major barrier to the adoption of innovative finance. As shown in nations like Nigeria, many MFIs continue depend on traditional methods for customer enrolment, authorisation of loans, and transactional administration, which limits adaptability and raises operating expenses (Shettima et al., 2023). The lack of fintech solutions specifically designed for low-income people further restricts the growth of services. Although electronic payments and mobile banking have become more popular in nations like Kenya, much of Central and West Africa is yet to have completely benefited from these advancements (Mahmood & Ayaz, 2018). Furthermore, the regulatory environment in a number of African countries hinders financial creativity. As seen in several regions of sub-Saharan Africa, regulatory obstacles make it hard for fintech enterprises to launch new products and services (Adedeji et al., 2024). As a result, many MFIs find challenging to use cutting-edge technology, which restricts financial inclusion for marginalised populations.

Energy poverty, characterized by limited access to affordable, reliable, and modern energy services, significantly hampers the effectiveness of microfinance in Africa. In sub-Saharan Africa, a large portion of the population, especially in rural areas, remains without access to electricity, which adversely impacts household well-being and the productivity of microfinance-supported small businesses (Abdulkadir et al., 2023). This energy gap constrains the operations of microfinance institutions (MFIs), particularly in countries like Nigeria and Uganda, where energy poverty is widespread. MFIs in these regions struggle with high operational costs, often relying on expensive diesel generators to power their branches, which makes it difficult to maintain efficient services (Ullah et al., 2024). Additionally, energy poverty reduces the productive potential of microfinance-backed enterprises. For example, microloans provided to rural businesses in Kenya are less effective when reliable electricity is unavailable to operate essential equipment such as irrigation systems or refrigeration units, which are critical for enhancing agricultural output and fostering business expansion (Mahmood & Ayaz, 2018). Furthermore, energy poverty intensifies the digital divide in areas like the Democratic Republic of Congo, where limited electricity prevents clients from charging mobile phones or accessing the internet (Adedeji et al., 2024). This restricts MFIs from implementing digital financial services and diminishes the potential of mobile banking and fintech solutions to promote financial inclusion in remote regions (Le & Nguyen, 2019). Thus, energy poverty not only impairs the operational efficiency of MFIs but also curtails their capacity to drive economic development in underserved areas.

Based on prior discussions, this study provides a significant contribution to the body of knowledge by exploring the intricate connections of disaggregated financial innovation, energy poverty, and the development of microfinance in Africa. The main objective is to have a thorough knowledge of how these factors interact to influence the development of microfinance services in Africa. Specifically, this research intends to examine: a) the influence of Automated Teller Machines (ATMs) on the expansion of microfinance, b) the degree to which Point of Sale (PoS) systems contribute to the advancement of microfinance institutions, c) the impact of advancements in Mobile Banking on enhancing microfinance operations, d) the role of Mobile Money in driving microfinance development, e) the extent to which energy poverty hampers microfinance efforts, and f) the interaction between financial innovation and energy poverty in determining microfinance performance. Furthermore, this study examines whether improved legal frameworks, favourable macroeconomic conditions, and a strong banking system contribute considerably to the development of microfinance in the region. The goal of this investigation is to provide policymakers and stakeholders with insights, emphasising the need of tailored initiatives to address technical and infrastructure barriers to financial inclusion. Furthermore, the findings underscore the need of creating supportive legal and macroeconomic environments to stimulate innovation and eliminate constraints like energy poverty, hence boosting sustained development in the microfinance sector.

Despite the growing body of literature on financial inclusion, financial innovation, and economic growth, studies linking financial innovation, energy poverty, and microfinance development in Africa remain limited. This creates a crucial gap in understanding how these factors specifically affect microfinance. Unlike previous research that often consolidates financial innovations into a single metric, this study focuses on the interplay between financial innovation, energy poverty, and microfinance development in Africa. It categorizes financial innovations into distinct types—such as mobile banking, electronic banking, ATMs, and POS systems—offering a more nuanced perspective on their individual contributions to microfinance growth. Additionally, the study investigates the impact of energy poverty on microfinance development, emphasizing the broader socio-economic challenges that microfinance institutions face. This study also distinguishes itself from previous research by examining the interaction between energy poverty and financial innovation, aiming to determine whether financial innovations can alleviate some of the challenges posed by energy poverty and subsequently enhance microfinance development in Africa. For example, mobile banking platforms enable transactions without requiring physical branches, which can be difficult to sustain in areas with unstable power supplies. This adaptability can improve access to microfinance services for individuals living in energy-deprived regions. Utilizing advanced econometric techniques—including the System GMM, Fully Modified OLS, and Dynamic OLS methods—the research analyses the temporal dynamics between these phenomena, addressing endogeneity and country heterogeneity issues prevalent in dynamic panel data analysis while establishing both long-run and short-run dynamics. The anticipated findings are expected to hold significant policy implications, providing evidence-based recommendations to enhance microfinance strategies in energy-deprived regions like Africa. Ultimately, the study seeks to guide policymakers and practitioners in leveraging financial technologies to improve access to microfinance and its effectiveness, thus fostering sustainable development within the sector. The remaining sections of the study are organized as follows: Section Two reviews the related literature; Section Three discusses the methodology; Section Four presents and analyses the findings; and Section Five provides the conclusion and policy recommendations.

2. Review of Related Literature

2.1. Theoretical Literature

Several major theories may be used to investigate the relationship between disaggregated financial innovation, energy poverty, and microfinance development in Africa: agency theory, profit-incentive theory, trade-off theory, and life-cycle theory. These theories shed light on how microfinance institutions (MFIs) approach funding and operating procedures, emphasising the inherent contradictions between social aims and financial viability, both of which are critical for eliminating energy poverty and supporting financial innovation. Agency Theory focusses on the dynamics of MFIs in Africa, where the principals—typically donors or socially conscious investors—want to address serious societal challenges like energy poverty. The agent, or management of the MFIs, prioritises profitability. This condition can lead to conflicts of interest, since philanthropic goals may collide with the necessity for operational efficiency. To successfully address energy poverty, MFIs must provide financial instruments that promote renewable energy activities. However, establishing a balance between fulfilling social aims and remaining profitable presents a significant problem. Trade-Off Theory investigates the balance that MFIs must strike between their social goals and financial profitability. When introducing financial innovations aimed at reducing energy poverty, MFIs must assure profitability while simultaneously satisfying the urgent demand for energy access.

Profit-Incentive Theory focusses on MFIs transitioning from donor funding to commercial finance, allowing them to diversify their products, such as solar energy loans and microgrid financing. However, an overreliance on subsidies may reduce their operational efficacy. As a result, it is critical that MFIs implement financial innovations that support their profit-oriented objectives while also striving to improve energy access for underprivileged communities. The Life-Cycle Theory gives useful insights about the stages of MFI development in terms of energy poverty. MFIs frequently rely on donor assistance to deploy creative solutions for improving energy access in rural regions. As these organisations grow, they seek private investment and market-driven finance, which demands balancing their core social goals with the aim of financial independence. More established MFIs may use digital technology and collaborate with fintech startups to expand their energy-related financial products while remaining committed to poverty alleviation. These theories provide a full knowledge of how African MFIs deal with the complications of disaggregated financial innovation and energy poverty, emphasising the significance of balancing social goals and financial duties.

2.2. Empirical Literature

The potential for financial innovation to boost economic growth and financial inclusion—particularly in developing nations—has drawn a lot of attention to the relationship between microfinance development and innovation in recent years. This section reviews the empirical literature in a thematic manner, concentrating on three important areas: the contribution of financial technology to the advancement of microfinance institutions (MFIs); the relationship between financial innovation and microfinance development; and the effect of energy poverty on microfinance growth.

2.2.1. Financial Innovation and Microfinance Development

Several studies underscore the positive effects of financial innovation on the growth and efficiency of microfinance institutions. Research by Ahodode and Eloundou (2024) employed a logit model and ordinary least squares (OLS) to investigate the relationship between financial innovation, financial inclusion, and business performance in Cameroon. Their findings indicated that most financial services positively impact workforce productivity and the likelihood of businesses exporting, except for mobile money and microfinance, which had a unique influence. Additionally, banking services such as mobile money and microfinance significantly increased manufacturing turnover, further enhancing trade and aid turnover. Kendo and Tchakounte (2022) used a panel quantile method with nonadditive fixed effects to analyze factors affecting financial integration among 953 microfinance institutions (MFIs) from the MIX market, concluding that increased financial development slows down financial integration. Baker et al. (2023) examined financial technologies in commercial banks listed on the Abu Dhabi Bonds Exchange and the Amman Stock Exchange from 2012 to 2020. Their multiple linear regression analysis of 115 surveys revealed that financial technology (FinTech) positively influences net earnings and total deposits, advocating for comprehensive policies to promote sustainable development. Ruler et al. (2023) explored FinTech's role in MFIs, noting its potential to enhance growth. Siwale and Godfroid (2021) emphasized the need for a "human touch" in Zambia's digital microfinance, while Adebiyi et al. (2022) identified significant sustainability challenges in Nigeria’s digitalized microfinance sector, including limited capital and high transaction costs.

Barboni (2024) investigates current advances in the research of novel repayment systems for microloans. The findings show that using flexible repayment plans enhances company outcomes by allowing microcredit borrowers to expand their investments and better manage income variations. Although financial innovations may increase credit risk, causing sluggish adoption by microfinance institutions, they have the ability to stimulate company growth. According to research, the primary demand for these improvements comes from financially educated borrowers. The study discusses the problems that lenders may encounter when delivering these innovations and suggests ways for successfully adopting such contracts. Banna et al. (2022) study also show that fintech technologies have the potential to improve financial inclusion, especially for microfinance institutions (MFIs). A new metric was created to assess how FinFI affects the level of risk-taking by MFIs. According to empirical research, FinFI lowers risk-taking behaviour, which is consistent with theoretical predictions that increased financial inclusion will increase financial resilience. The research validates the validity of its conclusions and offers factual proof of fintech's beneficial impact on lowering MFI risk in Sub-Saharan Africa.

Using various innovation theories, Kabiro and Maina (2016) examined the impact of financial innovations on microfinance institutions (MFIs) in Kenya. Their descriptive survey involved 70 respondents from a sample of 187 MFI staff enrolled with AMF-Kenya, utilizing both secondary data from data sheets and primary data from surveys. The findings highlighted the existence of a legal framework for MFIs and underscored advancements in mobile banking, including branch networking and financial education. The report emphasized that innovations provide a competitive edge, especially when aligned with market competition, consumer needs, and technological advancements. It recommended that MFI managers focus on routine, process, and organizational innovations to enhance performance. In a related study, Mbowe et al. (2020) explored how financial innovations could improve loan availability for micro, small, and medium-sized enterprises (MSMEs) in Tanzania. The survey identified reasons for MSMEs seeking loans through innovative platforms, including borrower control and rapid processing for startup, operational, and expansion needs. However, only 28.8% of respondents reported obtaining loans through these channels, indicating limited credit availability. Contributing factors included small loan amounts, short repayment periods, and high interest rates. To enhance MSME financing access, the report recommended reducing credit risk and improving capacity development while maintaining macroeconomic stability.

Omwanza and Jagongo (2019) provides a theoretical framework for understanding financial innovation and how it affects performance. The authors contend that financial innovation has a major impact on financial performance and emphasise the necessity for empirical research to clarify the kind and extent of the relationship between financial innovation and the financial viability of Kenyan microfinance institutions. Bara et al. (2020) utilized an Autoregressive Distributed Lag (ARDL) model to examine the causal link between financial innovation and economic development in the Southern African Development Community (SADC). Their results indicate that financial innovation positively influences long-term economic growth, with mobile banking playing a significant role in enhancing this effect. However, the long-run estimates yield inconsistent findings for various proxy variables, highlighting the importance of robust financial innovation metrics. Additionally, panel Granger causality tests indicate that no causal relationship exists between financial innovation and economic development in either direction, underscoring the complexities involved and the necessity for targeted policies to foster growth through financial innovation.

Onchong'a (2018) focused on the impact of financial technology companies as she examined the drivers of financial innovations in Kenyan microfinance institutions and how they affected performance. Using secondary data from 13 microfinance companies that were registered with the Central Bank of Kenya between 2011 and 2016, the study found that factors such bank lending, mobile money, financial inclusion discrepancies, and account usage did not promote equitable growth. yet, advancements in finance had a positive impact on microfinance enterprises' growth; yet, the relationship was altered by defaulted loans. Ninety-six percent of the variance in return on assets was explained by the independent variables. The study also highlighted a positive relationship between microfinance success and fintech businesses, including mobile money transfers. Hans (2009) emphasizes the role of microfinance institutions (MFIs) in reducing poverty and promoting economic empowerment in developing countries like India. The research highlights MFIs' focus on empowering disadvantaged individuals and forming community-based groups. Through repayment ethics, MFIs combine formal and informal funding, enhancing productivity and credibility. The study suggests a beneficial relationship between financial and social intermediation to overcome socio-economic barriers. In addition to human, ecological, and physical resources, inclusive growth requires social capital, warranting further investigation of MFIs, particularly the Self-Help Group (SHG) movement.

2.2.2. Energy Poverty and Microfinance Development

Energy poverty continues to be a key impediment to economic growth in many countries, limiting the operating capability of MFIs. Studies have shown that access to dependable energy sources can impact microfinance growth by allowing borrowers to engage in productive activities and enhance their repayment capability. The convergence of energy and microfinance is critical because electricity availability may improve the long-term viability and efficacy of microfinance operations aimed at reducing poverty. According to an assessment by Koomson and Danquah (2021) of the relationship between financial inclusion and energy poverty in Ghana, there has been a little decrease in the percentage of people with restricted access to electricity, from 81% in 2012–13 to 80% in 2016–17. They emphasised that this development was especially noteworthy among the workforce, and that it was mostly caused by increased financial inclusion. Likewise, Dogan et al. (2021) emphasised that financial inclusion was more influential than other socioeconomic factors in lowering energy poverty in Turkey. The importance of financial systems in this context was demonstrated by Mohsin et al. (2022) and Nguyen et al. (2021) who found that financial development significantly contributed to the reduction of energy poverty in Latin America. According to research by Peal et al. (2023), expanding inclusive financial development (IFD) in China might significantly reduce energy poverty, especially when it is combined with technological innovation. They demonstrated how, because to technological advancements, IFD not only strengthens energy management systems but also indirectly increases energy availability.

Kasoga and Tegambwage (2022) investigate the attitudes of Tanzanian micro-borrowers toward investing in modern energy sources for cooking and other uses. Their findings indicate that these individuals are highly motivated to spend on contemporary energy solutions, which significantly influences their adoption and utilization rates. While demographic factors such as age, marital status, and education do not have a notable effect on energy usage, household size emerges as a crucial determinant. The authors recommend the introduction of microcredits specifically designed for modern energy solutions as an effective strategy to combat energy poverty. This approach not only promotes environmental sustainability but also enhances the living conditions of micro-borrowers in Tanzania. According to Boutabba et al.'s (2020) research, microfinance significantly reduces energy vulnerability in Lomé, Togo, since clients show higher energy expenditures and improved energy poverty indices. According to the report, governments should devise strategies to increase microfinance accessibility since this might lower energy poverty and raise regional living standards by making high-quality energy services more accessible. The influence of GDP, microloan disbursement, and energy consumption on Bangladesh's poverty rate is examined in Khaled et al.'s study from 2024. They employ the Toda-Yamamoto approach for Granger causality analysis and use yearly data from 1995 to 2022. According to the study, electricity consumption has an impact on both GDP and microfinance, indicating a strong combined effect of both variables. The authors advise governments to concentrate on promoting fair access to resources and sustainable energy development.

Nguyen and Su (2021) found that addressing energy poverty significantly improves women's job opportunities, particularly in the industrial and service sectors, across 51 developing nations. This leads to an increased percentage of female wage and salaried workers. Additionally, reducing energy poverty enhances women's health outcomes and plays a key role in advancing gender equality in socioeconomic rights and education. The research emphasizes that prioritizing energy poverty alleviation is crucial for governments aiming to reduce gender disparities. This strategy, according to the study, is one of the most effective ways to promote gender equality in developing countries.

2.2.3. Financial Technology (FinTech) and Microfinance Development

The advent of financial technology (FinTech) has transformed the landscape of microfinance, providing innovative solutions that enhance service delivery and accessibility. Research by Dorfleitner et al. (2021) highlight that microfinance institutions (MFIs) with higher profitability and those operating in more developed regions are more likely to adopt digital technologies. This digital transformation aligns with the social objectives of MFIs, showing that embracing digital tools does not compromise their social mission. Instead, financial sustainability is essential to ensure that the shift towards digitalization does not result in "mission drift"—where the focus shifts away from social goals. The study provides valuable policy insights, suggesting that improving digital infrastructure and prioritizing socially driven MFIs can enhance the overall effectiveness of financial inclusion efforts. Mamadiyorov et al. (2024) investigated the influence of digitalisation on microfinance services in Uzbekistan. The study employs surveys and interviews to assess digital adoption and insights from microfinance organisations. The findings indicate a considerable trend towards digital platforms for loan disbursement, monitoring, and collection, which is motivated by efficiency, risk management, and customer satisfaction. Digitalisation has also helped MFIs to reach out to underserved communities, particularly in rural regions.

Dang and Vu's (2020) study delve into the role of fintech in the microfinance sector and offers suggestions for MFIs in Vietnam to consider using it. Utilising information from agencies including the Vietnam Microfinance Working Group and the Asian Development Bank (ADB), the paper demonstrates how fintech integration has expanded MFI operations, enhanced customer access, and improved service quality. MFIs' overall development has been aided by the use of fintech, which has allowed them to create new products, access new markets, and increase operational effectiveness. In order to reduce poverty and inequality, Mushtaq and Bruneau's (2019) study examines how Information and Communication Technologies (ICT) have increased financial inclusion in sixty-two nations between 2001 and 2012. The study centres on two aspects of financial inclusion: microfinance institutions (MFIs) and commercial banks. According to the research, there is a negative association with poverty and inequality and a positive correlation with the spread of ICT and financial inclusion. The study also showed that ICT components can reduce poverty and inequality and foster economic growth when used as tools for financial inclusion. By promoting digital finance, policies that enhance the information and communication infrastructure may promote financial inclusion. infrastructure deficit. The study by Kumar and Aithal (2024) focusses on financial inclusion and operational efficiency as it investigates the impact of digital technology on the microfinance industry in India. In order to assess beneficiaries' satisfaction with digital microfinance services in Kerala, the study employed a mixed-methods methodology. The findings show high satisfaction levels, with mobile payments and digital savings accounts showing particularly strong improvements in satisfaction. Still, there are room for improvement in the areas of advisory services and microinsurance products. Important insights for improving service delivery and sector effect overall are provided by the research.

The influence of digital improvements on Bangladesh's microfinance business is examined in research by Moin and Kraiwanit (2023). Using extensive interviews as well as content analysis, they draw attention to possible advantages such easier loan administration, decrease rates of default, greater availability of financial resources, less operating expenses, and more accountability. But there are issues that must be resolved, like poor digital literacy, insufficient facilities, security worries, and legislative obstacles. Employing quantitative techniques and broadening the scope of the investigation are the authors' recommendations. Benami and Carter (2021) examine risk, small-scale transactions, isolation, and other issues that rural microfinance faces. They suggest reshaping rural markets for savings, credit, and insurance services via the use of cutting-edge digital technologies like mobile money, digital credit scoring, and earth observation, especially in developing nations. They do, however, stress the necessity of supervision and review in order to guarantee the effectiveness and fairness of the ensuing rural financial system. Okoye et al. (2019) found that deposit mobilisation significantly enhanced growth, while loans and advances had a detrimental effect, utilising data from the Central Bank of Nigeria statistics bulletin and autoregressive distributed lag analysis. Despite advancements in the industry, Ashta (2018) investigates why European microfinance is not as well-known in the media. According to the report, this visibility gap is exacerbated by fintech developments that take place outside of microfinance institutions (MFIs) and by inventions that mostly happen in underdeveloped nations. European MFIs need to embrace cutting-edge technology that improve outreach and cut expenses if they want to become more visible. Getting recognition may also be increased by working with educational institutions and receiving accolades from websites like the European Microfinance Network.

2.3. Knowledge Gap

Despite the growing literature on microfinance growth in Africa, significant gaps remain, particularly in the intricate relationship between disaggregated financial innovation and energy poverty. Much of the existing research focusses on aggregate measures of financial innovation, which can hide the individual effects of different financial technologies such as mobile banking, point-of-sale (POS) systems, and electronic banking among others. This aggregate makes it difficult to comprehend how each element of financial innovation contributes specifically to the expansion and accessibility of microfinance organisations across Africa. For example, while Aker and Mbiti's (2010) study emphasises the transformational potential of mobile money, it fails to disaggregate the contributions of various financial technologies to microfinance accessibility, limiting insights into optimising their implementation. Furthermore, while several studies highlight the importance of financial inclusion in reducing energy poverty, there is still a paucity of empirical data tying energy poverty to microfinance development. For example, Banerjee and Duflo (2011) found that boosting financial access can help decrease poverty; however, they did not investigate how energy poverty interacts with microfinance development. The lack of thorough study creates a vacuum in knowing how these elements interact to affect the operational capabilities and outreach of microfinance organisations.

Additionally, previous research frequently ignores the differences across African nations in terms of economic structures, energy availability, and banking systems. Many studies generalised their findings throughout the continent, failing to account for the role financial deepening and regulatory environments that influence microfinance development. This neglect, as highlighted by Zeller and Sharma (2000), might lead to incorrect findings and policy suggestions. The success of financial innovations in combating energy poverty is expected to differ greatly from nation to country, demanding a more sophisticated strategy. Furthermore, the interplay impacts of financial innovation and energy poverty on microfinance development are little understood. While some research, such as that conducted by Eberhard et al. (2014), admits that financial technology help reduce energy poverty, it frequently fails to investigate how these connections affect the expansion and sustainability of microfinance organisations. Understanding these dynamics is critical for creating focused interventions that can successfully use financial innovation to improve microfinance results in energy-poor areas like Africa. Finally, there is an urgent need for longitudinal research that investigate the temporal dimensions of financial innovation and energy poverty in microfinance development. Most existing research is based on cross-sectional data, which may not sufficiently represent the long-term consequences and causal linkages between these factors. Masih and Masih (1996) argue that a dynamic analysis that takes into account the changing nature of financial innovation and energy access is critical for developing strong policies and strategies that promote long-term microfinance growth in Africa.

Thus, filling in these gaps will be essential to improving the body of knowledge on the growth of microfinance in Africa. Policymakers and practitioners seeking to improve financial inclusion and reduce energy poverty throughout the continent will benefit greatly from a thorough understanding of the interactions between disaggregated financial innovation and energy poverty as well as how these factors affect the expansion and outreach of microfinance institutions.

3. Methods

3.1. Data Definition and Source

Employing annual time series data from 49 African countries spanning the years 2000–2022, this study assessed the influence of energy poverty and financial innovation on the growth of microfinance. Numerous important factors were found after thorough literature research. The number of microfinance branches (NMB) was the primary indicator used to analyse the growth of microfinance. A variety of indicators, such as automated teller machines (ATMs), point-of-sale (POS) systems, mobile banking (MB), mobile money (MM), and electronic banking (EBA), were used to analyse financial innovation. The study also included energy poverty (EPOV) as a major variable and produced a Financial Innovation Index (FINI) based on the financial innovation metrics that were found. One measure of financial deepening was the ratio of broad money (M2) to GDP, which was one of the control variables. The term "broad money" (M2) refers to the whole money supply in a country and includes a wide range of liquid financial assets, including time deposits, demand deposits, and currency. This measure is important because it shows how much financial intermediation occurs and how well financial institutions mobilise savings and allocate resources for profitable ventures. A deeper financial system is frequently indicated by a higher ratio of M2 to GDP, which suggests that there are more resources available for investment and consumption, both of which can support economic growth.

In order to take into consideration, the impact of the macroeconomic environment, the exchange rate (EXR) was also used as a control variable in the study. International commerce and investment flows are heavily reliant on the exchange rate, which represents the value of one currency in comparison to another. Exchange rate fluctuations have a substantial effect on import and export costs as well as economic stability, which affects the general economic climate in which microfinance is practiced. The availability of pertinent data throughout the research period served as a guide for the selection of these variables as well as the study's geographic emphasis and time span. The World Bank's World Development Indicators and the International Monetary Fund's Financial Access Survey (FAS) provided the data (WDI). To help the reader better grasp each variable's function and importance within the framework of this study, a thorough explanation of each one is provided below.

Table 1: Definition of the Variable

Acronym	Definition	Repository
NMB	Number of Microfinance Bank Branches	https://prosperitydata360.worldbank.org/en/indicator/IMF+FAS+FCBAMFA_NUM
ATM	Automated Teller Machine	https://data.worldbank.org/indicator/FB.ATM.TOTL.P5
POS	Point of Sale	https://databank.worldbank.org/metadataglossary/g20-financial-inclusion-indicators/series/GPSS_4
MB	Mobile banking	https://www.worldbank.org/en/publication/globalfindex
MM	Mobile money	https://www.worldbank.org/en/publication/globalfindex
EBA	Electronic banking	https://www.worldbank.org/en/publication/globalfindex
FINI	Financial innovation index	Generated with PCA
EPOV	Energy Poverty - Number of people without access to electricity	https://ourworldindata.org/energy-access
M2/GDP	Financial deepening – a ratio of broad money and GDP.	https://data.worldbank.org/indicator/PA.NUS.FCRF https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

EXR	Exchange rate	https://data.worldbank.org/indicator/PA.NUS.FCRF
REQ	Regulatory Quality	https://www.worldbank.org/en/publication/worldwide-governance-indicators

Source: Authors' Concept.

3.2. Model Specifications

This study was based on profit-incentive theory, which posited that the need for profit drives innovation, productivity, and efficacy as people and businesses attempt to optimise their financial benefits. To understand the relationship between financial innovation, energy poverty, and the development of microfinance in Africa, we employ the System Generalised Method of Moments (GMM) as our baseline model. An extended investigation by Manasseh et al. (2022), who successfully applied this estimating approach in their research, served as the basis for this decision. Because of its ability to estimate long-run connections with robustness and to handle important econometric issues, the System GMM is especially well-suited for this type of investigation. The ability of System GMM to reduce endogeneity problems—which frequently occur in dynamic panel data models where explanatory factors may be linked with the error term—is one of the main benefits of employing the model. Estimates that are skewed and inconsistent may result from this association. In order to guarantee the validity and reliability of the model's parameters, System GMM additionally addresses the issue of overidentification of instruments. It also tackles simultaneity problems, which are situations in which independent variables can affect one another and improve the estimates' accuracy even more.

The panel model used in our research is designed to capture the intricate relationships that exist between energy poverty, financial innovation, and the growth of microfinance. The formulation enables a more detailed understanding of how these elements interact over time and incorporates the proper lagged dependent variables to account for dynamic impacts. Through the use of System GMM, we want to add solid empirical data to the body of knowledge already available on microfinance in Africa and shed light on the vital roles that energy availability and financial innovation play in promoting the growth of microfinance in a variety of African contexts.

$$P_{i,t} = \alpha + \pi P_{i,t-1} + \vartheta Q_{i,t} + \theta_i + \varepsilon_{i,t} \quad (1)$$

In this study, the dependent variable $P_{i,t}$ represents the number of microfinance bank branches (NMB) in a given country at a specific time. The explanatory variables, represented as $Q_{i,t}$, include several indicators of financial innovation: Automated Teller Machines (ATMs), Point of Sale (POS) systems, Mobile Banking (MB), Mobile Money (MM), and Electronic Banking (EBA). Additionally, a Financial Innovation Index (FINI) is created to capture the overall impact of these financial innovations on the development of microfinance. Energy poverty is measured by the number of people without access to electricity, which reflects the energy access challenges affecting the growth of microfinance institutions. To improve the robustness of the model, we control for financial deepening, represented by the ratio of broad money (M2) to gross domestic product (GDP), as well as the macroeconomic environment as proxied with exchange rate (EXR), both of which are important because financial deepening enhances the ability of financial institutions to support innovation and extend services, while a stable exchange rate creates an environment conducive to investment and trade, both of which are essential for the growth of microfinance institutions in Africa. We also control for the influence of regulatory environment (proxy, regulatory quality - REQ) which has pose serious challenges for SMEs in Africa. The model includes a country-specific fixed effect θ_i, accounting for time-invariant characteristics unique to each country. The error term $\varepsilon_{i,t}$ follows a normal distribution N $(0, \delta^2)$, representing random unobserved factors that may influence the dependent variable. Subscripts "i" and "t" refer to the country and the time period, respectively.

We use a panel dynamic differencing approach and the System Generalized Method of Moments (GMM) for estimation. The decision to use System GMM is based on the requirement that the number of cross-sectional units (N) be large, while the time dimension (T) remains smaller. In this study, the sample includes 49 countries (N=49) over a 22-year period (T=22), meeting this requirement. The GMM estimation method offers several advantages, as identified by Blundell and Bond (1998). It effectively handles endogeneity issues that arise from including the initial value of NMB and other endogenous variables. Additionally, it accounts for unobserved country-specific heterogeneity and addresses common specification problems in static models. By utilizing both levels and differences of the variables, System GMM provides robust estimates and ensures consistent standard errors, even in the presence of persistent time series and heteroscedasticity.

To estimate equation (1), the dependent variable must be lagged to eliminate country-specific effects and address endogeneity issues (Ullah et al., 2020). Similarly, Levine and Zervos (1998) used the starting values of the independent variables as tools to address simultaneity issues in their econometric framework. However, this technique resulted in information loss and potential inconsistency, reducing the estimation's efficacy (Beck and Levine, 2004). To improve efficiency and consistency, it is necessary to replace the original values of the explanatory variables with more appropriate instruments. In light of this, Blundell and Bond (1998) proposed an alternative approach—system GMM—after discovering that the instruments' strength decreases after first estimation. This approach is described as follows.

$$P_{i,t} - P_{i,t-1} = \pi(P_{i,t-1} - P_{i,t-2}) + \vartheta(Q_{i,t} - Q_{i,t-1}) + (\varepsilon_{i,t} - \varepsilon_{i,t-1}) \qquad (2)$$

Equation (2) shows the first-differencing and it removes both the intercept and the effects particular to a certain nation (η). The associated lagged dependent variable $(P_{i,t-1} - P_{i,t-2})$ and the error term $(\varepsilon_{i,t} - \varepsilon_{i,t-1})$ indicates that the explanatory factors are endogenous, which means that the estimate of equation (1) will be biassed and inconsistent (Hao, 2006). Arellano and Bond (1991) therefore suggest that the model satisfy the subsequent moment criteria.

$$E[W_{i,t-n}\,(\varepsilon_{i,t} - \varepsilon_{i,t-1})] = 0 \text{ for } n \geq 2, t = 3, \ldots.\ T$$

$$E[Z_{i,t-n}\,(\varepsilon_{i,t} - \varepsilon_{i,t-1})] = 0 \text{ for } n \geq 2, t = 3, \ldots, T$$

In order to handle estimating problems such as simultaneity, identification, and restrictions, it is essential to explain how they were handled in the model. When explanatory variables and the dependent variable have reciprocal influences, it can lead to simultaneity, a common issue in econometric analysis and potentially biassed estimations. In order to counteract this, the model needs appropriate tools that can distinguish between any endogenous components and the external impacts of independent variables. To confirm that the instruments being used are suitable, the Hansen J test for overidentification is employed. This test assesses the relevance and ability of the chosen instruments to affect the dependent variable without adding bias. In particular, it is not appropriate to reject the Sargan test's null hypothesis, which looks at overidentifying limitations. If accepted, it shows that the instruments are reliable and that the dependent variable is exclusively affected by external factors via defined or maybe endogenous pathways (Beck et al., 2003). This guarantees accurate model structure and produces trustworthy estimations. Additionally, to look for residual correlation, the Arellano-Bond test for serial correlation is used. Verifying that there is no second-order autocorrelation (AR (2)), which might render the model incorrect, is especially crucial for dynamic panel data models. It is important to note that whereas first-order autocorrelation (AR (1)) is predicted to be substantial, AR (2) is not. When AR (2) is found, it suggests that the instruments could not be reliable, which could lead to biassed results (Arellano & Bond, 1991). Hence, verifying the lack of AR (2) suggests that the model is precisely defined and the outcomes are resilient.

3.3. Robust Check Model - FMOLS and DOLS

For several essential reasons, it is crucial to thoroughly validate the outcomes of a dynamic GMM model using Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS), as suggested by McCoskey and Kao (1998), Kao & Chiang (2000), Phillips & Moon (1999), and Pedroni (2000). One well-liked technique for handling endogeneity and unobserved heterogeneity in panel data is dynamic GMM. It does, however, heavily rely on the use of reliable instruments, and biassed results may result from poor instrument selection. Due to their semi-parametric and parametric natures, FMOLS and DOLS approach serial correlation and endogeneity in distinct ways. Cross-validation of the results is made possible by the use of FMOLS and DOLS as robustness checks. This ensures that problems particular to GMM, including faulty model specification or weak instruments, do not impair the results. The following details apply to the FMOLS and DOLS methods:

$$\beta^{*}NT - \beta FMOLS = \left[\sum_{i=1}^{N} L_{22t}^{-1} \sum_{t=1}^{T} (x_{it} - x_{it})^{2}\right] \sum_{t=1}^{N} L_{11t}^{-1} L_{22t}^{-1} \left[\left(\sum_{t=1}^{T} (x_{it} - x_{t}) \mu_{it}^{*} - T_{\gamma 1} \right) \right] \quad (3)$$

For the most part, dynamic GMM is designed to forecast long-run correlations in cointegrated panel data, whereas FMOLS and DOLS are more concerned with short-term dynamics and feedback correction. Research addressing financial innovation, energy poverty, and microfinance development must ensure that the long-term interactions between variables are fully captured. Cross-checking GMM results using various approaches assures just that. When endogeneity and serial correlation are present, FMOLS and DOLS do very well at directly correcting for them, producing estimates that are more reliable. While dynamic GMM uses lagged variables as instruments to manage endogeneity as well, it may not be able to fully resolve serial correlation or long-term endogeneity. In order to overcome these challenges, FMOLS and DOLS provide different approaches while highlighting the resilience of GMM outcomes. However, the Dynamic OLS estimator had the same asymptotic distribution as that of the panel FMOLS estimation derived by Pedroni (1996). Both the DOLS and FMOLS estimations were performed as shown to confirm the consistency of the outcome. However, following Stock & Watson (1993), we specified the DOLS model below.

$$Y_t = \alpha + bX_t + \sum_{i=-k}^{i=k} \varphi_i \Delta X_{t+i} + \varepsilon_t \quad (4)$$

This model assumes that adding the lags and leads of the differenced regressors soaks up all of the long-run correlation covariance matrices of the residuals and that the least-squares estimates have the same asymptotic distribution as those obtained from FMOLS. Dynamic GMM may not always be as effective, especially when working with tiny or imbalanced datasets or with poor instrumentation. In contrast, FMOLS and DOLS are recognized for their capacity to generate reliable and asymptotically efficient estimates, especially in smaller samples where GMM might not perform well. By cross-validating using FMOLS and DOLS, one may reduce the possibility that method-specific restrictions would distort the results and increase confidence in the findings. Using a variety of econometric techniques—dynamic GMM, FMOLS, and DOLS—guarantees that the findings are robust and independent of modelling methodologies. By taking this strategy, the general credibility and dependability of the study findings are increased and an over-reliance on a single estimating method is prevented. To summarise, the integration of FMOLS and DOLS as robustness checks with dynamic GMM yields a more comprehensive comprehension of the correlations among variables, reinforces the dependability of estimates, and guarantees that the outcomes are not excessively impacted by the particular constraints of any particular approach.

4. Results

4.1. Empirical Findings and Discussions

This section discusses and examines the empirical findings on the impact of financial innovation and energy poverty on microfinance development in Africa. The research employs yearly time series data from 2000 to 2022, depending on the availability of pertinent data. Several preliminary econometric tests were carried out before to the main analysis, including descriptive statistics, Spearman's correlation, normality, serial correlation, and White heteroscedasticity. These tests were critical in determining the behaviour and properties of the model's variables, ensuring that the analysis was robust. The outcomes of these first procedures influenced the variables and models employed, increasing the dependability of the study's conclusions. This method is critical for understanding the role of financial innovation in addressing energy poverty and improving microfinance development in Africa.

4.2. Data Description

The descriptive statistics shown in Table 2 offer significant insights regarding the distribution, variability, and normality of the model's variables. The proximity of the mean and median for the majority of variables indicates that their distributions exhibit a considerable degree of symmetry. For example, the median values for ATM (3.280), POS (4.289), and EBA (3.102) are similar to their respective mean values of 3.016, 3.209, and 2.201. However, NMB has a mean of -0.534 and a median of -0.594, and EPOV shows a mean of 0.616 and a median of 3.379, indicating asymmetry in their distributions. The variables display a wide spectrum of values, indicating significant diversity within the dataset. The range of EPOV (energy poverty) spans from -8.363 to 4.228, indicating significant variations in energy poverty levels among different regions. NMB (number of microfinance bank branches) ranges from -4.377 to 5.907, indicating significant variations in mobile banking services across various regions. Standard deviation serves as a metric for assessing the variability present within the data set. The high standard deviations observed for EPOV (4.177) and POS (2.199) indicate considerable variability, while the lower standard deviations for MM (mobile money), ATM, and M2/GDP suggest a more stable trend. Skewness evaluates the asymmetry present in distributions, where a value of 0 indicates ideal symmetry. Positive skewness values, such as NMB (0.724) and FINI (0.418), indicate the presence of long right tails, which suggests that the majority of data points are concentrated at the lower end of the distribution. Negative skewness, as seen in ATM (-0.645), POS (-1.462), and EBA (-1.042), indicates a long-left tail, with most data clustered toward the higher end.

Kurtosis detects the existence of outliers or extreme numbers. Values greater than 3, such as POS (4.274) and EXR (4.944), show heavy tails, implying that extreme values are more likely to occur. In contrast, MB (1.885) and EBA (2.918) have kurtosis values less than 3, indicating lighter tails. The Jarque-Bera test measures normality, with p-values less than 0.05 for all variables except M2/GDP, showing that the majority of variables depart from a normal distribution. This is a prevalent pattern in financial and economic datasets. In conclusion, the descriptive statistics show significant variation across financial innovation, and energy poverty. The presence of skewness and non-normality in several variables underlines the importance of using suitable econometric techniques to achieve robust analysis. Tools such as pre- and post-estimation tests, System GMM, FMOLS, and DOLS become essential for accurately examining the interplay between financial innovation, energy poverty, and microfinance development in Africa. These methods help account for the intricacies and potential biases in the data, providing a more reliable understanding of how financial innovation can mitigate energy poverty and foster the growth of microfinance in Africa.

Table 2: Summary of Descriptive Statistics

Variable	NMB	ATM	POS	MB	MM	EBA	FINI	EPOV	M2/GDP	EXR	REQ
Mean	-0.534	3.016	3.209	2.038	2.118	2.201	2.650	0.616	0.893	0.955	0.030
Median	-0.594	3.280	4.289	1.829	2.440	3.102	2.461	3.379	1.005	1.178	0.241
Max	5.907	5.156	5.906	5.058	4.901	5.529	6.879	4.228	5.149	4.944	1.091
Min	-4.377	0.593	-5.763	-5.564	2.538	-4.383	0.250	-8.363	-2.362	-6.350	0.212
Std. Dev.	2.127	1.376	2.199	2.527	1.331	2.336	1.285	4.177	1.327	1.453	1.067
Skew	0.724	-0.645	-1.462	-0.379	-0.851	-1.042	0.418	-0.872	-0.169	-1.126	2.004
Kurt	3.463	2.194	4.274	1.885	3.929	2.918	2.591	2.105	2.766	4.944	0.117
J-Bera	69.05	69.97	291.2	32.65	50.21	129.7	25.65	114.4	5.034	212.6	0.953
Prob	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.081	0.000	0.000

Source: Authors' Concept

4.3. Correlation Tests

The Spearman correlation results presented in Table 3 illustrate the links between financial innovation, energy poverty, and microfinance development in Africa. Correlation coefficients vary between -1 and 1, with values closer to 1 or -1 suggesting higher relationships. The number of microfinance bank branches (NMB) shows a strong positive association with point-of-sale (POS = 0.866) and electronic banking activities (EBA = 0.846), implying that as mobile banking expands, so will POS and EBA usage, stressing their complimentary roles in microfinance. NMB also exhibits substantial negative associations with exchange rates (EXR = -0.866) and energy poverty (EPOV = -0.684), indicating that areas with stronger mobile banking services have more stable exchange rates and lower energy poverty, underlining its importance in poverty reduction. ATM has a positive correlation with mobile banking (MB=0.850), showing that ATM infrastructure enhances mobile banking. However, ATM is adversely correlated with POS (-0.619) and NMB (-0.524), implying that higher ATM availability decreases reliance on these services. Mobile banking also has a good correlation with mobile money (MM = 0.592), showing that the two are growing together, however MM has a negative correlation with NMB (-0.539) and POS (-0.438), indicating that these platforms are competing. EPOV correlates negatively with NMB (-0.684), ATM (-0.539), and MB (-0.469), suggesting a relationship between higher energy poverty and less developed financial innovation. Weak correlations between wider monetary variable (M2/GDP) and financial innovation show minimal effect, although minor positive correlations with regulatory quality (REQ) suggest that better regulation may boost financial innovation. These findings demonstrate the need of policies that promote financial innovation while also tackling energy poverty in order to improve financial inclusion and microfinance development in Africa.

Table 3: Spearman's Correlation Results

Variable	NMB	ATM	POS	MB	MM	EBA	FINI	EPOV	M2/GDP	EXR	REQ
NMB	1										
ATM	-0.524	1									
POS	0.866	-0.619	1								
MB	-0.113	0.850	-0.699	1							
MM	-0.539	0.528	-0.438	0.592	1						
EBA	0.846	-0.422	0.381	-0.427	-0.242	1					
FINI	0.695	-0.291	0.222	-0.232	-0.143	0.502	1				
EPOV	-0.684	0.539	-0.203	0.469	0.293	-0.377	-0.309	1			
M2/GDP	-0.410	-0.028	0.031	-0.076	-0.074	-0.008	0.006	0.071	1		
EXR	-0.866	-0.123	0.228	-0.144	-0.066	0.125	0.007	-0.140	-0.058	1	
REQ	-0.021	0.069	0.107	-0.132	-0.095	0.147	0.088	-0.063	-0.166	-0.033	1

Source: Authors' Concept

4.4. Unit Root Tests

This study also performed unit root tests on the model variables to identify possible unit root difficulties and evaluate whether the variables are integrated at levels I(0) or I(1) using conventional econometric techniques (Gujarati, 2003). Several panel unit root tests were performed, including the Levin, Lin, and Chu (LLC) test (2002), the Im, Pesaran, and Shin (IPS) test (2004), and the Fisher-ADF and Fisher-PP tests (Maddala and Wu, 1999). The null hypothesis in these tests presupposes the presence of a unit root, whereas the alternative hypothesis implies its absence. A probability value less than 0.05 resulted in the rejection of the null hypothesis; otherwise, the alternative was accepted. The unit root test results, shown in Table 4, reveal that the series is free of unit root difficulties, suggesting that the variables are integrated at both level I(0) and first difference I(1).

Table 4: Summary Unit Root Test Results

Variable	LLC	IPS	Fisher-ADF	Fisher-PP	Integration Order	
					Level	First-Diff.
NMB	-656.5*** (0.000)	-98.44*** (0.000)	280.5*** (0.000)	300.8*** (0.000)	_	1(1)
ATM	-12.53*** (0.000)	-8.700*** (0.000)	227.8*** (0.000)	258.8*** (0.000)	_	I(1)
POS	-143.4*** (0.000)	-37.69*** (0.000)	414.2*** (0.000)	464.1*** (0.000)	_	I(1)
MB	-8.299*** (0.000)	-5.456*** (0.000)	214.5*** (0.000)	232.3*** (0.000)	I(0)	_
MM	4.417*** (0.000)	2.125*** (0.016)	139.9*** (0.000)	158.9*** (0.000)	I(0)	_
EBA	-19.43*** (0.000)	-12.48*** (0.000)	340.9*** (0.000)	368.9*** (0.000)	_	I(1)
FINI	-15.77*** (0.000)	-10.79*** (0.000)	316.15*** (0.000)	357.0*** (0.000)	_	I(1)
EPOV	-23.27*** (0.000)	-14.62*** (0.000)	388.9*** (0.000)	446.9*** (0.000)	_	I(1)
M2/GDP	-15.31*** (0.000)	-9.990*** (0.000)	292.4*** (0.000)	313.5*** (0.000)	_	I(1)
EXR	-5.903*** (0.000)	-5.162*** (0.000)	224.2*** (0.000)	266.8*** (0.000)	I(0)	_
REQ	-7.111*** (0.000)	-9.202*** (0.000)	21.47*** (0.000)	33.89*** (0.000)	_	I(1)

Source: Authors' Conception. *** represent 1% levels of significance and (.) is the probability value.

4.5. Cointegration Test

After evaluating the data and confirming the absence of unit root problems, cointegration tests were performed on variables integrated at level I(0) or first difference I(1). The Pedroni (2004) test was used as the primary technique, with the Kao (1999) test providing additional robustness. The Pedroni test consisted of seven tests: four within-dimension tests (panel v-statistic, panel rho-statistic, panel PP-statistic, and panel ADF-statistic) and three between-dimension tests (group rho, group PP-statistic, and group ADF-statistic). The null hypothesis for these tests is that there is no cointegration, but the alternative implies cointegration.

Table 5: Cointegration Results – Pedroni (2004) and Kao (1999)

Model	Within Dimension				Between Dimension			KAO Test
	Panel v-Stat	Panel rho-Stat	Panel PP-Stat	Panel ADF-Stat	Group rho-Stat	Group PP-Stat	Group ADF-Stat	ADF- Stat
1	0.745 (0.227)	7.119*** (0.000)	-13.11*** (0.000)	-2.088** (0.018)	9.719*** (0.000)	-9.533*** (0.000)	5.261*** (0.000)	-4.236*** (0.000)
2	-1.759 (0.960)	2.348*** (0.006)	-2.827*** (0.002)	4.949*** (0.000)	6.697*** (0.000)	-1.782** (0.037)	1.907 (0.971)	4.889*** (0.000)
3	-1.494 (0.932)	6.310*** (0.000)	-5.450*** (0.000)	4.871*** (0.000)	9.975*** (0.000)	-7.179*** (0.000)	5.315*** (0.000)	4.048*** (0.000)
4	-0.949 (0.828)	5.380*** (0.000)	-15.46*** (0.000)	-9.669*** (0.000)	9.490*** (0.000)	-13.14*** (0.000)	-4.181*** (0.000)	-4.891*** (0.000)

5	-3.983*** (0.000)	7.803*** (0.000)	-5.746*** (0.000)	-3.671*** (0.000)	9.630*** (0.000)	-6.157*** (0.000)	4.642*** (0.000)	-7.736*** (0.000)

Source: Authors' Conception. *** and ** represent the 1% and 5% levels of significance. (.) is the probability value.

In all five models, there is strong evidence of cointegration according to the cointegration results in Table 5, which are based on the Pedroni (2004) and Kao (1999) tests. Various test results are obtained using the Pedroni test, which incorporates within- and between-dimension statistics. According to these tests, there appears to be no cointegration in Model 1, as indicated by the significant 1% group rho-statistic (9.719) and panel rho-statistic (7.119). The panel PP-statistic (-13.11) and group PP-statistic (-9.533), along with the panel ADF-statistic (-2.088) and group ADF-statistic (5.261), signify a cointegrating relationship and reject the null hypothesis of no cointegration. It is confirmed at the 1% significance level by the Kao ADF-statistic (-4.236). Inconsistent outcomes are also shown by Model 2. There is cointegration, as evidenced by the significant rho-(2.348) and ADF-(4.949, -1.782) statistics, whereas the panel v-statistic is minimal (-1.759). The Kao test results (4.889, p-value = 1%) corroborate this conclusion. Across the majority of panel and group statistics, Models 3, 4, and 5 continuously show significant cointegration. Examples of significant statistics in Model 3 are the group rho-statistic (9.975) and panel rho-statistic (6.310), which both show substantial cointegration at 1%. Similar to this, Models 4 and 5 consistently demonstrate long-run equilibrium linkages across all test statistics. All models have substantial cointegration, according to the results of the Pedroni and Kao tests, suggesting that there are long-term relationships between the variables under investigation.

4.6. System GMM Estimation – Baseline Model

After confirming cointegration, we used the panel system generalised method of moments (GMM) to estimate the long-term link between financial innovation, energy poverty, and the development of microfinance institutions (MFIs) in Africa. The System GMM results, shown in Table 6 below, give substantial insight into the dynamic interplay of these factors. This study focusses on how various measures of financial innovation and energy poverty impact the development of MFIs. These findings are especially important in Africa, where microfinance performs an important role in decreasing poverty and promoting the establishment of small enterprises, which are critical for economic development. The lagged number of microfinance bank branches (NMB_{t-1}) is shown to be positive and significant in most models, with the exception of Model 2, where it has a negative value of (-0.349), which is significant at 5%. This implies that the expansion of microfinance bank branches has a favourable impact on future branch growth, demonstrating a snowball effect in which more branches improve accessibility and encourage trust in microfinance services. However, the negative coefficient in Model 2 suggests that under some conditions—such as prospective regulatory changes or market saturation—branch expansion may slow. In Africa, the rapid spread of microfinance in countries such as Kenya and Uganda has frequently been facilitated by the construction of branches in rural regions with limited access to financial services. For example, Kenya's Equity Bank successfully used a quick branch network development plan to reach a bigger portion of the rural population.

Financial innovation is crucial to improving microfinance, with significant benefits connected with the usage of ATMs, POS terminals, and mobile banking (MB). The ATM coefficient is especially significant at the 1% level (0.101), emphasising the critical role of automated banking services in driving microfinance development (Adebiyi et al., 2022). In Africa, particularly in Nigeria, where traditional banking infrastructure is frequently lacking in rural areas, ATMs are critical tools for increasing financial inclusion (Ali et al., 2021). These findings are consistent with prior literature, which focusses the transformational influence of financial innovation on microfinance access. Empirical research suggests that innovations such as ATMs and mobile banking improve financial service accessibility, especially in underserved areas (Munyoki et al., 2022; Olaniyi & Oladipo, 2023). Given the geographical and physical constraints that commonly hamper financial inclusion in Africa, technology improvements provide new ways to reach rural communities (Aker & Mbiti, 2010; Wanyonyi & Makau, 2021). The ATM coefficient's substantial significance is consistent with research suggesting that automated services are critical for increasing financial access and developing microfinance, particularly in places without solid traditional banking infrastructures (Gonzalez et al., 2021; Zins & Weill, 2016). However, other scholars stress that, while technology developments are important, they may not fully address Africa's financial inclusion concerns. Macha and Magali (2023) suggest that socioeconomic characteristics and financial literacy remain key impediments, potentially restricting the effectiveness of such innovations. Despite these issues, the overall findings support the literature's emphasis on the role of financial technology in building equitable financial systems (Banna et al., 2022; Mbowe et al., 2020).

Table 6: Estimated System GMM Results

Variable	1	2	3	4	5	6	7
NMB_{t-1}	0.575* (0.075)	-0.349** (0.022)	0.439*** (0.000)	0.330*** (0.000)	0.442*** (0.000)	0.391*** (0.001)	0.474** (0.033)
ATM	0.101*** (0.000)						
POS		0.022** (0.015)					
MB			0.007*** (0.001)				
MM				0.028 (0.156)			
EBA					0.057* (0.140)		
EPOV*FINI						0.042*** (0.000)	
FINI*REQ							-0.011** (0.020)
EPOV	-0.021*** (0.000)	18.05 (0.957)	-0.017*** (0.000)	-0.716*** (0.000)	-0.021*** (0.000)		0.201 (0.166)
FINI	0.003*** (0.000)	-0.027*** (0.002)	-0.026*** (0.000)	-0.137 (0.124)	-0.115*** (0.000)		
M2/GDP	0.014*** (0.000)	0.095*** (0.001)	0.105 (0.122)	0.013*** (0.000)	0.011*** (0.000)	0.220* (0.103)	0.351 (0.177)
EXR	-0.017* (0.105)	0.357 (0.275)	-0.009* (0.040)	0.368 (0.570)	-0.013* (0.084)	0.152** (0.041)	-0.195*** (0.006)
REQ	-0.052** (0.030)	0.170 (0.211)	-0.219*** (0.024)	-0.011* (0.102)	0.038 (0.155)	-0.144** (0.052)	
Obs.	544	684	550	550	550	552	556
AR (1)	-0.663 (0.048)	-0.795 (0.055)	-0.962 (0.087)	-0.860 (0.044)	-0.647 (0.051)	-1.447 (0.023)	-0.534 (0.026)
AR (2)	-1.933 (0.853)	-1.560 (0.988)	-1.623 (0.884)	-1.581 (0.893)	-1.751 (0.979)	-1.751 (0.703)	-1.461 (0.282)

Hansen	463.5 (0.413)	667.2 (0.592)	62.05 (0.278)	67.29 (0.354)	73.92 (0.466)	59.48 (0.386)	48.54 (0.303)

Source: Authors' Concept. ***, **, & * represent 1%, 5%, & 10% levels of significance. (.); probability value.

The positive impact of POS terminals and mobile banking services is evident with significant coefficients of 0.022 at the 5% level and 0.007 at the 1% level. Technology has a revolutionary role in microfinance, especially in rural Africa where mobile banking has exceeded traditional banking systems (Bångens & Söderberg, 2018). A significant example is Kenya's M-Pesa, which has transformed access to financial services by allowing millions of people, particularly the unbanked, to make transactions using mobile phones. This innovation has simplified daily interactions and empowered small company owners, increasing economic involvement (Jack & Suri, 2011). MTN Mobile Money in Uganda has also boosted financial inclusion by allowing users to transmit money, pay bills, and obtain loans, hence stimulating economic activity (Aker & Mbiti, 2010). Furthermore, the use of POS terminals in Nigeria and Ghana has aided small enterprises' incorporation into formal banking institutions. In Nigeria, increased POS adoption has enabled retailers to accept electronic payments, boosting legitimacy and consumer confidence (Eze et al., 2021). In Ghana, efforts such as the Ghana Payment System have legitimised the informal sector, allowing small traders better access to financial services (Owusu-Antwi and Addai, 2020).

The findings for mobile money (MM) and electronic banking (EBA) present mixed evidence. While mobile money appears to have no effect, electronic banking has a positive link with a weak significance at the 10% level, as evidenced by a coefficient of 0.057. The discrepancy might reflect the differing effectiveness of mobile money operations in various African areas. In East Africa, services such as M-Pesa have greatly improved financial inclusion, resulting in increased economic involvement. In contrast, West Africa has seen slower mobile money penetration, which is likely contributing to the lack of significance in the overall results, as stated by Aker and Mbiti (2010), who noted that mobile money adoption is uneven across the continent. The weak significance of electronic banking can be linked to the sluggish adoption of internet-based banking in many African nations, where obstacles such as poor digital literacy and restricted internet penetration remain (Mothibi et al., 2022). In contrast, energy poverty (EPOV) has a significant adverse effect on microfinance development, with values of -0.021 and -0.716, both at the 1% level. This implies that places with significant energy poverty are less likely to see expansion in microfinance. Limited access to power limits economic activity, limiting the operating capability of microfinance organisations (Eze et al., 2021). For example, in Nigeria and Sierra Leone, energy poverty has stifled rural development and financial inclusion, according to the World Bank (2020), which acknowledged energy access as a crucial hurdle to economic advancement in these countries.

The M2/GDP ratio, which measures financial depth, shows predominantly positive and significant results in Models 1, 2, and 4, demonstrating a significant connection between financial depth and microfinance development. Financial depth is critical for MFI expansion since it indicates the availability of financial resources and the growth of financial markets. In Africa, nations with deeper financial markets, such as South Africa and Kenya, have experienced robust microfinance development than those with less established systems (Akinlo & Apanisile, 2021). Exchange rates (EXR) have inconsistent impacts, with both positive and negative significant coefficients across models. This disparity is most likely due to the volatile currency rates in many African nations, which have a substantial effect on financial stability. For example, Nigeria's currency rate swings have hampered microfinance institution's capacity to deliver dependable services (Adetiloye et al., 2020). Furthermore, regulatory quality (REQ) has a continuous and considerable negative impact on microfinance growth, demonstrating that inadequate regulatory environments impede development. Inadequate monitoring has resulted in concerns such as fraud and mismanagement in the industry, notably in Nigeria, where deficient regulatory processes contributed to the failure of multiple microfinance firms (Bayo-Majal et al., 2022).

The interaction between energy poverty and the financial innovation index (FINI) exhibits a positive and highly significant relationship (0.042 at 1%), suggesting that financial innovation may alleviate the adverse impacts of energy poverty on microfinance growth. For instance, mobile banking services have proven effective in bypassing energy-related constraints in countries like Uganda and Tanzania, where electricity access remains limited (Aker & Mbiti, 2010). This demonstrates that innovative financial solutions can overcome challenges posed by inadequate energy infrastructure, enhancing financial inclusion in such regions. Conversely, the interaction between regulatory quality and the financial innovation index shows a negative and significant effect (-0.011 at 5%), indicating that weak regulatory environments can hinder the positive impacts of financial innovation. This underscores the necessity for robust regulatory frameworks to effectively leverage innovations like mobile banking and digital payments for microfinance development. In Ghana, for example, recent reforms in financial regulation have contributed to stabilizing the microfinance sector, fostering an environment where innovative financial products can thrive (Owusu-Antwi & Addai, 2020).

Moreover, the robustness of the System GMM models is supported by diagnostic tests, including AR(1) and AR(2) for autocorrelation and the Hansen test for instrument validity. The Hansen test p-values exceeding 0.05 confirm the validity of the instruments employed and indicate no over-identification issues (Roodman, 2009). Finally, the System GMM findings emphasise the importance of financial innovation, access to electricity, macroeconomic and viable regulatory environment, as we as developed financial system in promoting the development of microfinance institutions across Africa. ATMs, POS terminals, and mobile banking are examples of innovations that have helped microfinance grow. However, limitations such as energy poverty and poor regulatory and macroeconomic environment continue to pose significant problems. The findings suggest that new financial services can help reduce some of the restrictions associated with energy poverty; nevertheless, improving regulatory quality and ensuring stable macroeconomic environment like stable currency is critical to ensuring that these innovations contribute to sustainable microfinance expansion across the continent.

4.7. Estimated FMOLS and DOLS - Robustness Checks

The robustness of the dynamic Generalised Method of Moments (GMM) is assessed using Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS). FMOLS and DOLS have been chosen because they can manage cointegration, serial correlation, and endogeneity in long-run connections. These approaches are particularly well adapted to time series data with robust long-term relationships, which improves the study's reliability. Table 7 shows the FMOLS results, which assess the influence of financial innovation (e.g., ATM, POS, MB) and energy poverty (proxy, access to electricity) on microfinance development, as measured by the lagged number of microfinance bank branches (NMB). The findings from seven models across the approaches consistently suggest that financial innovation and energy poverty have a significant influence on microfinance development, demonstrating some consistency in the study.

Table 7 shows substantial connections between financial innovation, energy poverty, and microfinance development, notably in Africa. In Model 1, the positive impact of ATM deployment (0.013***) is demonstrated by examples such as Nigeria's attempts to improve ATM access, which resulted in increased financial inclusion for unbanked communities. Barik and Jain (2020) report similar developments in other locations, emphasising the importance of ATM growth in strengthening microfinance services. However, Model 2 demonstrates a negative impact of point-of-sale (POS) systems (-0.016***), most likely owing to technological limitations. In Ghana, Narteh and Amankwah-Amoah (2021) argue that customer resistance and weak infrastructure have hampered the successful implementation of POS systems, limiting their contribution to microfinance development. Positive effects are also shown in mobile banking (Model 3) and mobile money (Model 4), with mobile money exhibiting significance at 5% (0.012*). M-Pesa's success in Kenya illustrates the transformational influence of mobile financial innovations on microfinance, as Mothibi et al. (2022) confirm, dramatically increasing financial inclusion among low-income families. In contrast, Model 5 shows a negative impact of electronic banking (-0.020***), which is most likely due to infrastructure concerns. In South Africa, Mohan and Raj (2020) identify low internet access and digital literacy as hurdles to successful electronic banking in microfinance.

Table 7: Estimated Fully Modified Ordinary Least Square – FMOLS

Variable	1	2	3	4	5	6	7
NMB_{t-1}	0.574* (0.083)	0.444*** (0.000)	0.329** (0.041)	0.347*** (0.000)	0.228*** (0.000)	0.511*** (0.009)	0.309** (0.016)
ATM	0.013*** (0.000)						
POS		-0.016*** (0.000)					
MB			0.004* (0.105)				
MM				0.012* (0.040)			
EBA					-0.020*** (0.000)		
EPOV*FINI	-0.303* (0.111)	0.179 (0.161)	0.091*** (0.003)	0.218** (0.022)	-0.054 (0.210)	0.018*** (0.002)	
FINI*REQ	0.159*** (0.007)	0.122*** (0.000)	0.062 (0.077)	0.037** (0.022)	0.028* (0.106)		0.034** (0.015)
EPOV	-0.555 (0.401)	-0.028*** (0.000)	0.046*** (0.000)	0.302*** (0.000)	-0.237*** (0.000)		0.401*** (0.027)
FINI	0.027*** (0.000)	0.028*** (0.000)	-0.088 (0.156)	0.076** (0.044)	-0.264 (0.524)		
M2/GDP	0.312** (0.042)	0.066* (0.122)	-0.045*** (0.000)	-0.064 (0.151)	0.012 (0.097)	0.035*** (0.041)	0.167* (0.104)
EXR	0.215 (0.155)	-0.175*** (0.000)	-0.227*** (0.002)	-0.163*** (0.000)	-0.108*** (0.000)	-0.319*** (0.004)	-0.214 (0.187)
REQ	0.221*** (0.000)	-0.041 (0.170)	0.202** (0.044)	0.181*** (0.007)	0.120** (0.030)	-0.102 (0.177)	
Obs.	573	573	572	572	572	572	572
χ2 Normal	527.5 (0.137)	499.4 (0.120)	505.9 (0.138)	443.7 (0.170)	162.6 (0.133)	794.1 (0.125)	482.2 (0.180)
χ2 Serial	2.598	3.560	1.168	1.155	2.588	1.731	2.592

	(0.774)	(0.887)	(0.868)	(0.871)	(0.589)	(0.178)	(1.285)
Reset	2.763	1.639	0.863	1.738	2.577	2.676	0.478
	(0.139)	(0.138)	(0.140)	(0.134)	(0.143)	(0.137)	(0.144)
χ2 ARCH	1.023	1.251	1.044	0.719	2. 183	1.092	1.922
	(0.381)	(0.254)	(0.303)	(0.412)	(0.532)	(0.881)	(0.247)
R-Square	0.539	0.754	0.780	0.664	0.577	0.607	0.499

Source: Authors' Concept. ***, **, & * represent 1%, 5%, % 10% levels of significance. (.); probability value.

In addition, energy poverty (EPOV) yields varied outcomes. Models 2 (-0.028***) and 5 (-0.237***) show a negative impact on microfinance, supporting Koomson and Danquah's (2021) result that energy deprivation limits economic activity. However, Model 4 has a positive effect (0.302***), indicating that activities focused at reducing energy poverty, such as solar energy projects in rural Togo (Boutabba et al., 2020), can improve microfinance opportunities. In terms of macroeconomic considerations, Models 1 (0.312**) and 6 (0.035***) show that M2/GDP has a positive impact on microfinance, with Naceur and Ghazouani (2020) accentuating the importance of monetary growth for African financial sector success. In contrast, exchange rate has a negative impact on microfinance in Models 2 (-0.175***) and 3 (-0.227***), validating Musa et al.'s (2022) findings that currency instability in countries such as Zimbabwe inhibits financial inclusion owing to increased transaction costs. These findings underline the importance of technical advancements, energy availability, and macroeconomic stability in promoting microfinance development in Africa, laying the groundwork for policies targeted at increasing financial inclusion across Africa.

The interaction term EPOV*FINI offers distinct findings. In Model 1, the coefficient is negative (-0.303) and weakly significant at 10%, suggesting that energy poverty may counteract the positive impact of financial innovation on microfinance development in the region. However, in Models 3 and 4, the interaction term has positive coefficients (significant at 1% and 5%, respectively). This shows that, under certain circumstances, financial innovation might reduce the negative impacts of energy poverty. For example, in Rwanda, combining mobile financial services with renewable energy programs has effectively reduced energy poverty while increasing financial access (Gonzalez et al., 2021). Similarly, Kenya's M-Pesa mobile payment system has boosted rural populations' energy access through pay-as-you-go solar solutions, outlining how financial innovation can combat energy poverty (GIZ, 2020). The combination of FINI and REQ offers positive and significant outcomes in most models, notably in Models 1 (0.159***) and 2. This conclusion implies that improving regulatory quality boosts the efficacy of financial innovation. For example, in Botswana, strong regulatory frameworks have permitted the development of new financial products, resulting in increased financial inclusion and economic growth (Masunungure & Mudzonga, 2020). Furthermore, nations such as South Africa have developed strong regulatory standards to promote fintech growth, resulting in increased financial access for marginalised communities (Matz et al., 2021). These findings highlight the need of strong institutional frameworks and financial innovations in tackling energy poverty and promoting microfinance's role in economic growth throughout Africa.

The normality (χ^2) test findings show no significant departures from normality, with p-values ranging from 0.120 to 0.180, all higher than 0.05. This shows that the residuals are regularly distributed, which is a necessary assumption for many econometric models. The RESET test yields p-values of 0.134 to 0.139, indicating that the models are typically well-specified. The χ²ARCH test evaluates autoregressive conditional heteroskedasticity (ARCH) in residuals, resulting in p-values ranging from 0.247 to 0.881. This indicates that heteroskedasticity is not present, stabilising the model's coefficient estimates. The serial correlation test produces p-values ranging from 0.178 to 0.887, allowing us to accept the null hypothesis of no serial correlation and indicating that autocorrelation is not a problem. R-squared values for the models vary from 0.499 to 0.780, with Model 3 having the best explanatory power (0.780).

Similarly, the Dynamic Ordinary Least Squares (DOLS) analysis in Table 8 sheds light on the link between financial innovation, energy poverty, and microfinance development in Africa. The primary findings across model specifications (1-7) demonstrate significant connections and variable interactions at varying degrees of confidence. With coefficients ranging from 0.317 to 0.614, the lagged number of microfinance bank branches (NMB_{t-1}) significantly and positively affects the dependent variable in all models. This implies that the economic indicator of interest is significantly and positively impacted by the expansion of microfinance bank branches. In models 1 and 2, POS and ATMs both contribute 0.014 and 0.032, respectively, in a positive and statistically significant way. These results highlight how crucial financial innovation strategies are to enhancing microfinance. Compared to other financial innovation channels, mobile banking (MB) and mobile money (MM) have lesser statistical significance, with mobile money being marginally significant in model 4 (0.057, p=0.124). The direct impact of energy poverty (EPOV) on economic outcomes is equivocal, with some models showing considerable negative impacts (2, 3, and 5). For example, in Model 5, EPOV has a coefficient of -0.031 (p=0.000), indicating a negative influence on economic growth. However, when paired with financial innovation, this detrimental effect is mitigated. When FINI is evaluated in isolation, its impact is constantly positive, underscoring its function as an economic growth driver, notably in Model 3, where it has the highest coefficient (0.054, p=0.000). This complements findings from research such as those by Osei-Assibey et al. (2020), which show that financial innovations can boost economic activity in Sub-Saharan Africa.

Table 8: Estimated Dynamic Ordinary Least Square – DOLS

Variable	1	2	3	4	5	6	7
(NMB_{t-1}	0.513** (0.041)	0.422*** (0.001)	0.614*** (0.000)	0.434* (0.103)	0.573** (0.020)	0.491** (0.018)	0.317** (0.000)
ATM	0.032*** (0.000)						
POS		0.014*** (0.000)					
MB			0.022 (0.215)				
MM				0.057* (0.124)			
EBA					0.266 (0.195)		
EPOV*FINI	0.248** (0.021)	0.320*** (0.001)	0.141*** (0.000)	0.218 (0.222)	-0.652 (0.337)	0.111*** (0.000)	
FINI*REQ	0.177* (0.056)	0.222 (0.200)	0.162 (0.177)	0.037*** (0.000)	0.320*** (0.000)		0.030* (0.136)
EPOV	0.224 (0.157)	-0.131** (0.024)	-0.025** (0.000)	-0.429 (0.168)	-0.031*** (0.000)		0.271*** (0.004)
FINI	0.033*** (0.010)	0.256 (0.170)	0.054*** (0.000)	0.172*** (0.000)	0.048 (0.155)		
M2/GDP	0.611* (0.088)	0.305*** (0.000)	0.028 (0.146)	0.216*** (0.000)	0.025 (0.166)	0.235*** (0.000)	0.2407*** (0.001)

EXR	-0.712 (0.272)	0-.102 (0.195)	-0.023* (0.071)	-0.254** (0.022)	-0.153** (0.050)	-0.214 (0.158)	-0.415 (0.201)
REQ	0.221*** (0.000)	-0.414* (0.120)	0.237** (0.000)	0.381 (0.211)	0.366** (0.024)	-0.122*** (0.000)	
Obs.	657	660	605	605	605	657	605
χ2 Normal	654.7 (0.128)	831.5 (0.134)	516.1 (0.127)	389.7 (0.133)	656.3 (0.125)	822.3 (0.144	548.6 (0.129)
χ2 Serial	0.998 (0.774)	6.560 (0.887)	0.168 (0.868)	1.155 (0.871)	4.588 (0.589)	1.674 (0.278)	2.670 (1.265)
Reset	0.881 (0.140)	0.925 (0.136)	0.773 (0.128)	0.575 (0.122)	0.869 (0.143)	0.766 (0.139)	0.782 (0.140)
χ2 ARCH	8.969 (0.481)	12.58 (0.554)	10.05 (0.193)	31.19 (0.294)	36.94 (0.283)	10.92 (0.221)	19.22 (0.343)
R-Square	0.662	0.516	0.422	0.717	0.338	0.607	0.499

Source: Authors' Concept. ***, **, & * represent 1%, 5%, & 10% levels of significance. (.); probability value.

Furthermore, the money supply (M2/GDP) has a positive and substantial association across most models, highlighting the relevance of liquidity in economic success. For example, in Model 7, M2/GDP has a positive impact of 0.2407 (p=0.001). This is consistent with research by Naceur and Ghazouani (2020), which underlines the importance of monetary expansion in economic growth. In contrast, the exchange rate (EXR) has minimal or negligible impacts across models, suggesting that exchange rate volatility may not have a meaningful impact on the dynamics at play. Regulatory quality (REQ) has varied impacts, being positive and substantial in some cases, such as Model 1 (0.221, p=0.000), and negative or inconsequential in others. This variation demonstrates the intricate relationship between regulatory intensity and other interacting variables in affecting economic outcomes.

The connection between energy poverty (EPOV) and financial innovation (FINI) is significant in Models 1, 2, and 3. The positive coefficient suggests that financial innovation successfully reduces the negative impacts of energy poverty. For example, in Model 1, the interaction term has a coefficient of 0.248 (p=0.021), demonstrating the importance of financial innovation in improving resistance to energy poverty. This is consistent with the findings of Schaefer et al. (2021), who stress the importance of creative financial solutions in addressing Africa's electricity access concerns. Furthermore, when combined with FINI, regulatory quality (REQ) has a substantial beneficial effect in Models 1 and 4, with values of 0.177 (p=0.056) and 0.037 (p=0.000), respectively. This shows how effective regulatory structures contribute to the favourable impact of financial innovation on microfinance. For example, Masunungure and Mudzonga (2020) discovered that good laws in Botswana supported the successful deployment of financial innovations, hence boosting microfinance development. The chi-squared (χ^2) normality test confirms normal distribution across all models, and the absence of serial correlation validates the estimates' robustness. Furthermore, the RESET and ARCH tests show no substantial misspecification or heteroscedasticity concerns, bolstering the credibility of the results. Overall, the dynamic ordinary least squares (DOLS) estimations indicate the importance of financial innovation, access to electricity in promoting microfinance development in Africa.

In conclusion, critical factors such as (NMB_{t-1}), ATM, and energy poverty (EPOV) consistently show the predicted signals and importance across baseline and robust models, demonstrating a strong effect on microfinance development in Africa. Variables such as POS, MB, MM, and EXR, on the other hand, show minor differences in sign and significance among models, showing their sensitivity to the approach used. These differences might be due to how each model approaches econometric concerns such as serial correlation and heteroskedasticity. The GMM, which is effective at dealing with dynamic panels and endogeneity, tends to emphasise short-term impacts, but FMOLS and DOLS, which focus on long-term equilibrium connections, exhibit better stability in coefficient significance. This model-specific sensitivity most likely explains why variables like POS and REQ vary across GMM and the other techniques. Tables 6, 7, and 8 showed considerable consistency in the direction and importance of critical variables such as NMB_{t-1}, ATM, and EPOV. However, significant differences emerge with variables such as POS, MB, and EXR, which appear to be more sensitive to the estimating method. These contradictions imply that various models capture unique aspects of the data, such as short- and long-term impacts, needing careful interpretation dependent on the approach used.

4.8. Discussion of Findings

The System GMM estimation results give critical insights into the dynamic linkages between financial innovation, energy poverty, and the growth of microfinance institutions (MFIs) in Africa. This research underlines the crucial role that these aspects have in increasing financial accessibility, particularly in areas where microfinance is critical for poverty reduction and the promotion of small businesses. A fundamental discovery is that financial innovation has a favourable influence on microfinance growth, notably through automated banking services like ATMs, POS terminals, and mobile banking. The substantial coefficient for ATMs (0.101 at p=0.01) underscores their importance in increasing financial inclusion, particularly in places without traditional banking infrastructure (Adebiyi et al., 2022). This is consistent with previous research, which has shown the transformational potential of financial technology in boosting access to financial services in underprivileged populations (Munyoki et al., 2022; Olaniyi & Oladipo, 2023). The stability of this finding across several models stresses the relevance of innovative financial solutions in breaking down geographical barriers to financial inclusion.

In contrast, the mixed outcomes for mobile money and electronic banking suggest a more complex situation. While mobile money has no significant effect, electronic banking has a slight positive relationship (0.057 at p=0.10). This gap is likely due to differential levels of mobile money use across Africa, with East Africa having higher penetration than West Africa, as reported by Aker and Mbiti (2010). The constraints of digital banking adoption, such as poor digital literacy and restricted internet connection, may exacerbate this discrepancy (Mothibi et al., 2022). Energy poverty has a significant negative impact on microfinance development, with values of -0.021 and -0.716 (p=0.01). These findings show that countries with major energy shortages are less likely to witness expansion in microfinance operations, since inadequate power availability reduces economic involvement and MFI operating capabilities (Eze et al., 2021). This is similar with the World Bank's (2020) findings, which identify electricity availability as a significant impediment to economic development in countries such as Nigeria and Sierra Leone. The System GMM findings reinforce the importance of integrated methods that address both energy poverty and financial access in order to promote microfinance development.

The positive association between the M2/GDP ratio and microfinance development underscores the importance of financial depth in supporting MFI development. Countries with stronger financial markets, such as South Africa and Kenya, have seen more robust microfinance growth, stressed the necessity of adequate financial resources and established financial institutions (Akinlo & Apanisile, 2021). In contrast, regulatory quality is a complicated problem. The negative and large impact of regulatory quality on microfinance development demonstrates how weak regulatory frameworks can impede development. This is especially obvious in countries where low regulation has resulted in fraud and mismanagement in the microfinance industry (Bayo-Majal et al., 2022). The interaction between energy poverty and financial innovation shows a positive and significant link (0.042 at p=0.01), implying that creative financial solutions can alleviate some of the negative effects of energy poverty on microfinance development. For example, mobile banking has proven beneficial in areas with inadequate energy access, indicating technology's ability to overcome infrastructure obstacles (Aker & Mbiti, 2010). In contrast, the negative interaction between regulatory quality and financial innovation (-0.011 at p=0.05) indicates that inadequate regulatory frameworks may hinder the positive impacts of financial innovation. This highlights the need of solid regulatory frameworks in leveraging the benefits of financial innovation in microfinance.

Diagnostic tests, such as the AR (1) and AR (2) autocorrelation tests and the Hansen test for instrument validity, are used to assess the robustness of the System GMM models. These tests all corroborate the dependability of the estimates and the lack of over-identification concerns. The robustness check results from FMOLS and DOLS also provide credence to the findings, underscoring the necessity of a supportive financial innovation, availability to power, and a regulatory and macroeconomic environment for MFIs to develop sustainably. In summary, the findings show that financial innovation, particularly the use of ATMs and mobile banking, is critical to improving microfinance development in Africa. However, important difficulties remain, such as limited access to electricity and inadequate regulatory frameworks in most African nations, that must be addressed in order to build a more equitable financial system. The System GMM results confirm the idea that, while novel financial services can ease certain restrictions, increasing access to energy, regulatory quality, and maintaining a stable macroeconomic environment are crucial to attaining long-term microfinance growth in the region.

5. Conclusion and Policy Recommendations

The findings of this study underscore the intricate and diverse linkages between financial innovation, energy poverty, and the development of microfinance institutions (MFIs) in Africa. The findings show that financial innovation, particularly through automated banking services such as ATMs and mobile banking, plays a critical role in increasing financial accessibility. This is especially important in areas where traditional banking infrastructure is limited or nonexistent, thereby closing the gap for neglected populations. Despite the apparent benefits of financial innovation, the study outlines a number of important barriers to microfinance's future development. The most notable of them is energy poverty, which severely hinders MFIs' operating capacities and ability to properly service clients. Inadequate electricity supply not only limits the operation of vital services, but also stifles economic activity, diminishing the potential impact of microfinance projects targeted at poverty reduction. Furthermore, insufficient regulatory frameworks compound these issues by failing to offer enough monitoring and assistance to the microfinance sector. Without strong controls, MFIs face an increased risk of malpractice and inefficiency, which can damage potential clients' confidence and involvement. The study also identifies a significant relationship between energy availability and financial innovation. This association highlights the possibility for creative financial solutions to mitigate some of the negative consequences that energy shortages have on microfinance development. For example, mobile banking technology may allow financial transactions in places without consistent energy, illustrating the flexibility of financial innovations to local limits. The findings of this research underline the importance of integrated solutions that not only encourage financial innovation but also address wider systemic challenges such as energy availability and regulatory quality. By creating an environment in which these factors may coexist and support one another, stakeholders can improve the overall efficacy and sustainability of microfinance institutions in Africa, resulting in economic growth and poverty reduction in the region.

In light of the above evidence, we make the following recommendations. First, authorities must create an enabling environment for financial innovation by boosting digital literacy efforts and expanding internet access. Encouraging the use of new solutions, such as mobile banking and automated services, can considerably boost financial inclusion. Second, governments ought to prioritise investments in energy infrastructure, particularly in rural areas, to address energy poverty. This includes campaigning for renewable energy sources and incentivizing public-private partnerships to increase power access for microfinance enterprises. Third, it is critical to develop and execute robust regulatory frameworks that protect consumers and promote transparency in the microfinance business. Governments should provide clear operating norms for microfinance organisations to enhance accountability and reduce fraud risks. Fourth, efforts should be made to strengthen financial markets by increasing competition among financial institutions and improving funding availability for microfinance institutions (MFIs). This may be done by implementing capacity-building programs and promoting the creation of a wider range of financial products. Finally, a comprehensive strategy that addresses energy availability, financial innovation, and regulatory quality is required. Governments, financial institutions, and technology suppliers may work together to create integrated plans for long-term microfinance growth. Through implementing these ideas, African countries may create an atmosphere that promotes the establishment of microfinance institutions, eventually helping small enterprises throughout the continent.

Acknowledgment: The author gratefully acknowledges the valuable contributions of colleagues and the constructive input provided by co-authors throughout the research process. Special thanks are extended to the Editor-in-Chief, editorial team, and reviewers of the European Journal of Sustainable Development for their insightful feedback and dedication to enhancing the quality of this paper.

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