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Effect of Financial Inclusion, Energy Efficiency, and Human Capital on Energy Poverty in Developing Countries

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Abstract

This study discovers the link between financial inclusion and energy poverty in developing nations, an area often overlooked. Using a theoretical framework, it investigates optimal associations by analyzing panel data from 45 developing countries from 2004 to 2023. Key variables include financial inclusion, energy efficiency, government expenditures, GDP, and human capital. Employing dynamic common correlated effects (DCCE) and method of moment's quantile regression (MMQR) through STATA software, the study finds that financial inclusion significantly reduces energy poverty. The variables GDP, human capital, government expenditures, and energy efficiency positively reduce energy poverty in developing nations. Analysis indicates policy measures that should improve rural financial inclusion by using mobile banking networks and microfinance institutions primarily for clean energy spending. Further recommendations include integrating financial literacy with energy initiatives, strengthening governance, and fostering private investment via transparent regulations and public-private partnerships. The study enhances understanding of how financial inclusion reduces energy poverty while helping establish suitable policies for sustainable energy development in impoverished regions.

Keywords: Financial inclusion, energy poverty, energy efficiency, government expenditures, human capital, developing countries, DCCE, MMQR.

1. Introduction

Energy poverty refers to the inability to access affordable, sustainable energy services, which are necessary for achieving the entire set of sustainable development goals. The worldwide population among millions continues to suffer from energy poverty because several societies lack resources for electricity generation while facing challenges in implementing clean cooking technologies and sustainable energy source access (Teixeira et al., 2024). Energy poverty creates major roadblocks in ordinary existence, which affect both educational attainment and public health, and economic possibilities. The inhabitants of homes considered energy poor rely mainly on firewood, charcoal, and kerosene for energy, while this practice leads to deforestation and indoor air contamination (Alem & Demeke, 2020; Jayasinghe et al., 2021). Energy poverty is not just about the lack of electricity access; it involves issues with the affordability and reliability of energy services that, in turn, play a significant role in economic growth and social welfare. (Gawusu 2024). Upgrading the standard of living, boosting economic activity, and advancing an environmentally friendly environment can only be achieved through tapping energy poverty (Shahzad et al., 2022; Batool et al., 2023).

Also, the non-availability of energy denies opportunities in multiple ways, one of which is financial inclusion and access where both energy poverty and financial inclusion are highly interrelated (Mbate, 2025). Access to financial services are largely absent in regions with high rates of energy poverty which has reduced the capacity of people in such areas to pay for energy sources that are both modern and reliable (Koomson & Danquah, 2021). Trade-offs between basic needs for both public and household purposes exist due to the lack of access to credit, savings, or payment methods with regard to supply-driven basic energy alternatives over trade-off exploiting expensive, inefficient and unsustainable based on current demand profile push households even deeper into energy poverty. Financial inclusion can facilitate access to banking, microfinance or mobile payment platforms, which in turn allow financing of clean and affordable energy solutions (Kar & Bali Swain, 2024; Murshed & Ozturk, 2023; Sen et al., 2023; Xie et al., 2024). In addition, making financial access easier also benefits the development of energy infrastructure through greater financing of sustainable technologies and energy markets (Hussain et al., 2023; Nauman et al. 2024).

Energy poverty walks hand-in-hand with energy efficiency, so a key part in curbing the former is boosting the latter. Inefficient usage of energy typically results in energy poverty, which occurs when there is not enough access to affordable and reliable energy (Kolati, Y., & Raghutla, 2025). Consequently, those households are subject to very high energy bills and they even become more and more energy insecure (Agradi et al., 2022; Li et al., 2021). Energy ingesting can be decreased by using energy-efficient technologies like better insulation, energy-efficient appliances, and efficient heating and cooling devices, which in turn reduce the financial strain of these households, making it more affordable (Mungai et al., 2022). Energy efficiency also helps lower the overall power demand, thereby reducing stress on energy infrastructure, an issue in many parts of the world where power grids are stretched to their limit or can only be relied upon for certain hours of the day (Al-Tal et al., 2021; Zhang et al., 2024).

Energy poverty and human capital are inextricably linked, since reliable and affordable access to energy is crucial for human growth (Liang et al, 2025). According to a report by the International Energy Agency (IEA), energy poverty obstructs access to education, healthcare, and economic opportunities, which play vital roles in human capital development (Niu et al., 2023; Wiredu et al., 2023). Besides, energy poverty also results in restricted provision of healthcare services because access to cutting-edge medical equipment and a reliable power supply are equally crucial features of human capital that contribute significantly towards the well-being of individuals. It leads to time poverty and therefore reduces educational and skill opportunities (Adepoju et al., 2022; Jahanger et al., 2023; Ullah et al., 2023).

Energy poverty is another important explanatory factor in government expenditures. Governments should allocate large scale resources for infrastructure development, particularly in the most isolated rural spaces to reverse energy poverty. The investment may be in power plants, grid upgrade and renewables to supply the basic electricity access (Nguyen & Su, 2022; Tundys et al., 2021). Investments in renewable energy are also in important part, because they allow sustainable solutions to remote areas, but with high costs of the first-time government share (Liu & Wang, 2024). Since access to energy is lacking, productivity losses result in an increase in spending by governments on social welfare programs. Government expenditure on the energy poverty to minimize it, not only improves standard of living and enhances economic growth (Bousnina & Gabsi 2023; Thema & Vondung 2020), but also contributes environmental sustainability by encouraging the use of cleaner energy alternatives.

Despite a growing body of literature examining financial inclusion, energy efficiency, human capital, government expenditures, and energy poverty, critical gaps remain unaddressed. While financial inclusion is widely acknowledged as a tool to enhance energy access, limited research investigates the role of specific instruments such as microfinance in alleviating energy poverty, particularly in rural and low-income communities. Furthermore, the long-term sustainability of these financial interventions remains largely unexplored (Dogan et al., 2021; Hussain et al., 2023; Murshed & Ozturk, 2023). In the domain of energy efficiency, although cost-saving benefits are frequently highlighted, there is insufficient evidence on the challenges that hinder the adoption of energy-efficient technologies, especially among marginalized households (Agradi et al., 2022; Li et al., 2024). Similarly, the role of human capital particularly education and skills development in influencing energy consumption behavior and clean energy adoption has received inadequate attention, with the potential of education as a tool for energy poverty reduction in low-literacy regions often overlooked (Ding et al., 2024; Jahanger et al., 2024). Additionally, the effectiveness of government spending, particularly in education sector reforms and institutional capacity building, remains underexplored (Ogwumike & Ozughalu, 2015; Tundys et al., 2021).

Motivated by these gaps, this study contributes novel empirical insights into the multidimensional drivers of energy poverty in developing countries. Specifically, it examines how financial inclusion, GDP, human capital, government expenditures, and energy efficiency collectively shape energy poverty outcomes. Using panel data from 45 developing countries over the period 2004–2023, the study employs robust econometric methods like Dynamic Common Correlated Effects (DCCE), which accounts for cross-sectional dependence and heterogeneity (Horobet et al., 2024), and Method of Moments Quantile Regression (MMQR), which captures distributional heterogeneity in energy poverty impacts (Liao et al., 2024). The results underscore the importance of promoting mobile banking, microfinance services, governance reforms, and financial literacy programs to expand energy access, particularly in underserved regions. By addressing overlooked interactions and offering policy-relevant insights, this research enhances the understanding of financial inclusion's role in energy poverty alleviation and offers practical pathways for reducing energy insecurity in developing economies.

This research presentation follows a structure that includes a review of existing literature in Section 2 followed by data sources and methodological breakdown in Section 3 and an analysis of findings accompanied by their implications in Section 4 and the study concludes in Section 5.

2. Literature Review

2.1. Theoretical Framework

The theoretical model regarding energy poverty establishes four main factors affecting household satisfaction regarding their economic situation: financial inclusion, domestic energy efficiency, human capital development, and public spending. Financial inclusion provides access to credit, savings, and insurance for low-income families so they can increase their revenue, which acts as an upward force that moves them through different levels of energy source use (Khan et al., 2023). Financial inclusion enables increased investments in healthcare as well as education, which produces improved labor efficiency and higher household revenues. The fuel stacking theory shows that growing household income leads people to adopt efficient, environmentally friendly energy systems that decrease their energy poverty level (Koomson & Danquah, 2021). Economic development requires financial inclusion because such inclusion provides the necessary tools to fight against energy poverty.

Energy poverty interconnects with financial inclusion as well as the Structural Change Theory. It allows for marginalized groups to invest in cleaner sources of energy, instead of continuing to rely on more costly and environmentally deleterious access technology (Rahman, 2024). Reducing energy poverty requires both improving the efficiency of energy use and moving up an Energy Ladder. Energy efficiency contributes to a modest reduction in the total energy costs, and significantly lowers energy consumption for modern energy by poor households (Li et al., 2024). The efforts in this direction are further complemented by the Human Capital Theory and Keynesian Economic Theory. Energy infrastructure and social programs hence the mitigation of energy poverty are enabled by this growth (Wiredu et al., 2023).

2.2 Empirical Review

2.2.1 Financial Inclusion and Energy Poverty

Sen et al. (2023) derived a positive relationship from their study that indicates financial inclusion should be incorporated as a solution to address energy poverty. A positive connection appears across all other areas of study. Kar & Bali Swain (2024) analyze the influence of financial inclusion on energy accessibility across African countries by applying panel-corrected standard error (PCSE) in combination with two-step dynamic system GMM. Koomson & Danquah (2021) conducted a quasi-experimental study to analyze the connection between financial inclusion and energy poverty in Ghana. Jin et al. (2024) performed research about domestic energy poverty in China through the application of threshold models together with spatial spillover effects. Li et al. (2023) examined South Asian countries by using panel data, which showed that financial inclusion, when combined with economic development, operates statistically to decrease energy poverty levels.

Xie et al. (2024) Sectors and emerging economies, Turkey, Brazil, South Africa, India, and Indonesia, used AMG and FMOLS methods among others to confirm financial inclusion acts as a mechanism against energy poverty. Rahman (2024) used an original two-stage aggregative technique to evaluate the moderation effect of energy poverty as it connects financial inclusion with economic growth. This study analyzed the financial inclusion-energy poverty relationship between Brazil, China, India, Indonesia, Mexico, and Russia using co-integration and CS-ARDL methodology according to Khan et al. (2023).

The research by Nauman et al. (2024) investigated how Financial Integration together with alternative Energy and financial stability affect Sustainable Development. The research conducted by Maket (2024) about energy poverty in Sub-Saharan African countries produced varying outcomes. Financial inclusion acts as an effective tool to reduce energy poverty although its success depends on local economics and political systems. Asongu & Odhiambo (2024) performed research in Ghana using data from GLSS6 and GLSS7 alongside the 2SLS approach.

2.2.2 Financial Efficiency and Energy Poverty

Nasir et al. (2022) developed a composite mathematical indicator to represent the superposition of energy poverty, sustainable energy efficiency and energy security in Vietnam and provides an econometric estimation. Similarly, de Almeida et al. (2022) studied the effect of energy efficiency in Mozambique, highlighting that efficient energy behavior influence entire energy sustainability positively. Dong et al. (2022) used a dynamic panel data model and system-generalized method of moments to probe the effect of energy poverty on energy efficiency in China. This study found that the implications around energy poverty as a driver for delivering energy efficiency were further demonstrated to be key by Boemi & Papadopoulos (2019) who using a longitudinal register based approach in North Greece showed how dramatic reductions in energy poverty can be gained through implementing energy efficiency (EE) upgrades.

Li et al. (2021), also in that energy efficiency and poverty reduction may be coupled. However, taking data from Ukraine (and using a general least square method), found that improvements in energy efficiency reduce the rate of energy poverty due to their almost instantaneous effect. Mafalda Matos et al. (2022) in Portugal, demonstrated that energy efficiency policies and thermal building regulations contribute to the reduction of energy poverty using a qualitative analysis of policy documents and regulatory frameworks. This is supported even more by Abbas et al. (2021) used multiple system mathematical programming to associate the energy efficiency as well as environmental efficiency across European nations, implicating that effective strategic action on energy efficiency results in reducing energy poverty. Agradi et al. (2022) further added to the debate, using stochastic frontier analysis (SFA) and GMM to assess the relationship between unemployment and energy efficiency in different African countries via their study tour, revealing that a labor-friendly provision can be achieved by enhancing energy efficiency with a microeconomic component of tackling poverty. Damigos et al. (2021) used a labeled choice-based experiment from five representative European Union member states in the context of energy poverty to investigate decisions on energy efficiency investments.

Zhang et al. (2024) investigated the energy efficiency in China, designed by Index Construction and implemented by Dynamic Two-Stage DEA. In another study, Li et al. (2021) explore the relationship between energy poverty and energy efficiency further, used Data Envelopment Analysis (DEA), which allows to measure operating efficiency of firms by comparing their losses relative to benefits.

Conversely, the findings of Al-Tal et al. (2021) using the common correlated effects (CCE), panel regression analysis had been examined on energy poverty and energy efficiency in Sub-Saharan Africa. Similarly, Mungai et al. (2022) have used a mix-method approach by considering reports, academic papers and databases in Sub-Saharan Africa with the aim of turning energy poverty into energy efficiency.

2.2.3 Human Capital and Energy Poverty

Acharya and Sadath (2019) show that the marginal assistances of tumbling energy poverty level are enormous, and drying up the resources then will cause an unprecedented development loss to India. Likewise, Oyedepo (2012) claimed that an effective energy policy measure could guarantee sustainable development due to the important role of a clean energy sources, efficient energy utilization and use of renewable energy options in

Nigeria. In addition to the above argument, Ullah et al. (2023), by applying (CS-ARDL) technique for a range of regions.

Jahanger et al. (2023) studied the correlation amid energy consumption, human capital and CO2 emissions in BRICS and found a direct relationship showing that energy is indispensable to potentials for growth of human resources through investment. Ding et al. (2024) examined the effect of child and maternal malnutrition in African regions related to energy poverty and human capital, where highlighted a positive correlation explaining that improving energy poverty generates healthier development impact. Similarly, Banerjee et al. (2021) used the threshold regression to analyze health and education in developing countries and argued that overcoming energy poverty is an essential component of progress in these sectors. Wiredu et al. (2023) referring to the effects of renewable energy sources on economic development, carbon emissions and human capital in emerging African economies, showed that the use of renewable energy contributes positively with the construction development.

Rafi et al. (2021) in India, originate that energy poverty was negatively related with human capital development he showed that more intense levels of energy deprivation can hold back educational and career follow-up.

For instance, Jahanger et al. (2024) demonstrate the relationship among them with energy poverty, deployed Quantitative methods and revealed, at same time its positive side as well as negative site depending upon circumstances in India. Similarly, Adom et al. (2021) development consequences from energy poverty discovered complex short and long-run dynamics to this relation. Niu et al. (2023), a large-scale economic and social study of natural resource policy optimization in developing countries provides mixed evidence that moves closer to understanding the more nuanced effects of energy on education and public health.

2.2.4 Government Expenditures and Energy Poverty

Das et al. (2022) identify a strong relationship between energy poverty and domestic energy burden in Canada, using the statistical approach from Statistics Canada 2016 Survey of Household Spending. This had been further highlighted by a study of Liu & Wang (2024) in China, supporting the idea that means-tested government spending has been an important approach to alleviate energy poverty and the role for fiscal policy in energy policies. In Nigeria, Jideofor et al. (2021) used data from the Central Bank of Nigeria statistics bulletin and employed Augmented Dickey-Fuller (ADF), Autoregressive Distributed Lag (ARDL) approach. Reinforcing this view, Bousnina & Gabsi (2023) used panel data from Sub-Saharan African countries and showed the existence of an intense negative association amid government spending and energy poverty part of a regional pattern that is consistent with the extensive literature indicating fiscal actions enhance social welfare.

Ogwumike and Ozughalu (2015) assessed the relationship between energy poverty and sustainable development in Nigeria, applying headcount ratio and logistic regression approach. Mechanistically, the study by Ashagidigbi et al. (2020) used the Multidimensional Energy Poverty Index (MEPI) in Nigeria and showed that household income growth alone does not improve energy poverty, showing how difficult it is to address this challenge.

Dimnwobi et al. (2023) negative view was also demonstrated that used of the Bayer–Hanck co-integration approach to investigate public capital expenditure in Nigeria has not reduced energy poverty. More generally, Asongu and Odhiambo (2022) found that governance is negatively related to energy consumption in Sub-Saharan Africa which suggests that there may be a political-institutional problem to the cause of energy access.

Adegboyo (2020) investigated the poverty in Nigeria due to government expenditure by having utilized ARDL technique which ended with conflicting findings that might lend credence to inter-relationships between these series. Omoju et al. (2020) inspected the macroeconomic effects of financing renewable energy policy in Nigeria through the computable general equilibrium (CGE) modelling and produced varied outcomes which implies a challenge to integrate empirical development of RE, ensuring sustainable economic growth. In their study of developing countries, Nguyen & Su (2022) evaluates the association between energy poverty and government spending with panel estimation techniques and find context dependent results that are important for policy assessment. Tundys et al. (2021) carried out a more comprehensive study by considering various drivers of energy poverty in European countries, suggesting that economic growth as well as energy policy and cultural conditions, can significantly increase the complexity of energy poverty. Thema & Vondung (2020) also found mixed results from a European Union perspective on cost-effectiveness thereby revealing the variation of energy poverty situations across diverse geographies. Acheampong et al. (2021) explore the relationship between energy access and income inequality at global level, which showed that the cause-effect linkage between energy accessibility with welfare are multi-dimensional and depends on regions.

3. Methodology

This study empirically observes the effect of financial inclusion, government expenditures, GDP, human capital, and energy efficiency on energy poverty in developing countries, utilizing data from 2004 to 2023. Detailed descriptions of the variables and their sources are provided in Table 1. The model specification is as follows:

$$EP = f(FINC, GS, GDP, HUC, EF) \quad (1)$$

$$EP_{it} = \alpha + \alpha_1 FINC_{it} + \alpha_2 GS_{it} + \alpha_3 GDP_{it} + \alpha_4 HUC_{it} + \alpha_5 EE_{it} + \mu_{it} \quad (2)$$

Table 1: Variable Measurement and Data Source

Symbol	Measurement	Source
EP	Energy poverty index of four proxies through PCA (Access to clean fuels and technologies for cooking (% of population); Access to electricity, rural (% of rural population) and Access to electricity, urban (% of urban population); Access to electricity (% of population)	WDI
FINC	Financial inclusion index of different proxies through PCA (Number of ATMs per 100,000 adults; Outstanding deposits from commercial banks (% of GDP); Number of commercial bank branches per 100,000 adults; Outstanding loans from commercial banks (% of GDP).	WDI
GS	General government final consumption expenditure (% of GDP)	WDI
GDP	GDP per capita (constant 2015 US$)	WDI
HUC	Human capital index	PWT9.1
EF	Energy Efficiency: Energy use (kg of oil equivalent per capita)/GDP	WGI

3.1 Cross-Sectional Dependence (CSD)

The CD test aims to check whether different entities are related to each other or not in the case of panel data. This kind of data generally contains observations from different sources (people, countries, companies), where the entities may exert influence on each other (Pesaran 2021; Liao et al., 2024). If we observe signs of these covariates in different entities affecting one another, then since they are dependent history among observations from a finite amount of present and past input events are not independent and identically disseminated which is typical linear regression model framework or other traditional models. A CD test is essential for diagnosing these kinds of inter-dependencies.

3.2 Unit Root Test (CIPS)

The Cross-sectionally Augmented IPS (CIPS) test is a second-generation unit root test used to detect non-stationarity in time series data while accounting for cross-sectional dependence. Unlike traditional tests that assume independence across units, CIPS provides more accurate results in correlated panels. Detecting and correcting non-stationarity is essential to avoid spurious regression outcomes.

$$\Delta Y_{i,t} = \rho_i + \rho_i Y_{i,t-1} + \rho_i \bar{X}_{t-1} + \sum_{l=0}^{p} \rho_{il} \Delta \bar{Y}_{t-l} + \sum_{l=1}^{p} \rho_{il} \Delta Y_{i,t-l} + \varepsilon_{it} \quad (3)$$

$$CIPS = \frac{1}{N} \sum_{i=1}^{n} CADF_i \quad (4)$$

3.3 Slope Homogeneity Test

Slope Coefficient Homogeneity (SH) addresses a form of model parameter heterogeneity, e.g. when the linear regression coefficient differs between sub-samples or groups (Pesaran & Yamagata, 2008). By looking at this kind of analysis, the researchers could see whether or not there was heterogeneity within the data (e.g. the relationship between variables significantly different across subgroups than in total). Moreover, SH analysis helps to detect the interactions between variables in different states. That slope heterogeneity occurs, that could in turn suggest the need for more sophisticated modeling to achieve even greater differences among individual entities and thereby improve the robustness of the analysis.

3.4 Cointegration Test

The Westerlund (2007) cointegration Test is a statistical method for determining whether a cointegration relationship can be found in panel data. The test acknowledges that each individual entity in panel data may co-evolve together over the long-term implying that at least one cointegrating long run equilibrium relationship exists in the variables (Wang et al., 2024). Westerlund's test is, in practice more suitable due to its ability to handle the heterogeneity present in panel data enabling us to get correct cointegration test results even when individual units are different. To investigate long-term relationships and equilibrium behaviors, this approach facilitates a deeper insight into the dynamics inherent in the underlying data.

$$G_t = \frac{1}{N}\sum_{i-1}^{N} \frac{\beta_i}{SE(\beta_i)} \quad (5)$$

$$G_a = \frac{1}{N}\sum_{i-1}^{N} \frac{T\beta_i}{\beta_i(1)} \quad (6)$$

$$P_t = \frac{\widetilde{\beta}}{SE(\beta)} \quad (7)$$

$$P_\beta = T_a \quad (8)$$

3.5 Dynamic Common Correlated Effects Model (DCCE)

It overcomes some of the problems that cross-sectional dependence poses to traditional panel data studies, where estimates obtained from cross-sectional series are generally not accurate due to biases and inaccuracies. Along these lines, taking into account how globalization, interconnected processes of tra de and financial digital exchanges may likely lead to a number of unobserved factors and shocks which might affect financial development as well the way in terms economic growth is realized within different countries. The DCCE methodology, proposed by Chudik and Pesaran (2015), combines the CCE framework in a homogeneous panel based approach with PMG/MG estimators. It improves the model estimates and makes you better understand how the dependent variable is related to each of the independent variables.

3.6 MMQR Methodology

Machado and Silva (2019) introduce the Methods of Moments Quantile Regression (MMQR), which extends some traditional regression methodologies to get more than just conditional means estimates, we can also estimate conditional quantiles using MMQR. The flexibility increases the scope of analysis of data most effectively and takes care of the heterogeneity as well as distributive effects with in a dataset. Contrary to classical Ordinary Least Squares (OLS) techniques, which are based on the normal distribution and its inaccurate tail properties, MMQR stands out for being robust against outliers' heavy-tailed anomalies a fact that underlies more accurate estimation. The MMQR provides nuanced, detailed analysis that estimates conditional quantiles and with this dimension we can detect variations and trends between two variables in different conditions.

3.7 Dumitrescu Hurlin Panel Causality Test

Panel data contain multiple cross-sectional units observed over time, and we are using the Dumitrescu-Hurlin panel causality test to examine the causal nexus. In contrast to common time-series Granger causality tests, this approach handles the presence of cross-sectional dependence as well as heterogeneity across panel units. The goal of the test is to establish whether one can use past values of one variable to predict future values of another one in a panel context. This test is of particular benefit to the investigation of relationships in extensive data sets, cross-country studies, allowing researchers and interested parties to ascertain the impact a given variable can bear on another during various entities through different periods.

4. Results and Discussion

The correlation matrix in Table 2 reveals the relationships between the variables: EP (energy poverty), FINC (financial inclusion), GS (government spending), GDP, HUC (human capital), and EE (energy efficiency). EP shows a strong positive correlation with HUC (0.832) and GDP (0.681), indicating that higher human capital and GDP are associated with improved environmental performance. FINC is moderately correlated with EP (0.483), suggesting financial inclusion also enhances EP. EE has a notable positive relationship with both HUC (0.664) and GDP (0.592), highlighting the role of human capital and economic growth in improving energy efficiency. Lastly, green subsidies (GS) show weaker correlations with other variables, suggesting their impact might be less direct.

Table 2: Correlation Matrix

Variables	EP	FINC	GS	GDP	HUC	EE
EP	1					
FINC	0.483	1				
GS	0.359	0.376	1			
GDP	0.681	0.459	0.343	1		
HUC	0.832	0.480	0.379	0.523	1	
EE	0.453	0.621	0.455	0.592	0.664	1

The results from Table 3 demonstrate significant slope heterogeneity and cross-sectional dependence across all models and variables. For the slope heterogeneity tests, all models (1-6) show highly significant values for both the Δ and Δ Adjusted statistics, with models like Model 2 (Δ = 10.832) and Model 5 (Δ = 4.872) indicating substantial variation in the slope coefficients across cross-sections. This suggests that the relationships between variables differ significantly across countries or regions. The cross-section dependence test results are also highly significant for all variables, including EP (87.792), GS (11.556), and HUC (16.961), confirming the presence of cross-sectional dependence.

Table3: Slope Heterogeneity and Cross Section Dependence Test

Slope Heterogeneity				
Models	Δ			Δ Adjusted
Model 1	5.499***			6.102***
Model 2	10.832***			11.892***
Model 3	2.757***			3.791***
Model 4	2.737**			3.778**
Model 5	4.872***			6.543***
Model 6	2.687***			3.769***
Cross Section Dependence Test				
EP 87.792*** (0.000)	GS 11.556*** (0.000)	GDP 12.219*** (0.000)	FINC 3.857*** (0.000)	HUC 16.961*** (0.000)
EE 16.312*** (0.000)				

Note: *,** shows level of significance at 1%,5%,respectively

Table 4 reports the stationarity results using the Im, Pesaran, and Shin (IPS) and Pesaran (CIPS) tests. At the level, most variables are non-stationary, as indicated by positive or insignificant test statistics (e.g., EP = 4.119, GS = 3.379 in IPS, and EE = 0.434 in CIPS). However, after differencing once, all variables become stationary, as shown by significant negative test statistics (e.g., EP = -4.337 and -4.973, GDP = -3.009 and -6.017 for IPS and CIPS, respectively).

Table 4: Stationarity Tests

Im, Pesaran & Shin (IPS, 2003) Test		
Variables	Level	1st Diff.
EP	4.119	-4.337***
FINC	1.170	-3.022***
GDP	-1.658	-3.009***
GS	3.379	-3.218***
HUC	-0.476	-7.203***
EE	2.916	-10.754***
Pesaran (2007) CIPS Test		
EP	-1.289	-4.973***
FINC	-1.858	-2.990**
GDP	-1.407	-6.017***
GS	1.217	-2.939***
HUC	-0.165	-2.877***
EE	0.434	-6.246***

Note: ***,** shows 1%, 5%, significance level, respectively

Table 5 provides the test results from Westerlund's cointegration analysis, which demonstrates whether variables in six different models maintain a long-term equilibrium connection. The test statistics (Gt, Ga, Pt, Pa) reach significance at the 1% level primarily in Model 1 (Gt=-11.899, Ga=-25.978) while showing strong evidence of cointegration. Models 2, 3, 4, and 5 deliver significant results from all test statistics, which reinforces the existence of long-term relationships between variables. The Gt statistic shows an insignificant result in Model 6, despite the significance of Pa, Pt, and Ga statistics indicating less cointegration evidence exists within this model. The results support the existence of strong long-term variable connections across most investigated models because the variables maintain equilibrium behavior throughout time.

Table 5: Cointegration Test

Westerlund Cointegration Test				
Models	Gt	Ga	Pt	Pa
Model 1	-11.899***	-25.978***	-8.979***	-11.988***
Model 2	-6.274***	-7.842**	-7.545***	-6.246***
Model 3	-11.549***	-18.538***	-10.213***	-15.513***
Model 4	-6.327***	-9.657**	-9.319***	-7.099***
Model 5	-6.813***	-2.848***	-3.245***	-2.573***
Model 6	-1.227	-3.414***	-9.123***	-8.776***

Note: *,** shows significance level at 1%, 5%, respectively

Tables 6 and 7 present the findings from the DCCE and MMQR estimations, offering a nuanced understanding of how financial inclusion, human capital, government spending, GDP, and energy efficiency affect energy poverty across Africa, Asia, and Latin America & the Caribbean. The use of DCCE helps mitigate the effects of cross-sectional dependence and slope heterogeneity, while MMQR enables the exploration of heterogeneous effects across the conditional distribution of the dependent variable.

The DCCE results indicate a robust and statistically significant long-term positive relationship between Financial Inclusion (FINC) and the dependent variable across all regions, with the effect more pronounced in Africa. This finding aligns with Sen et al. (2023) on Bangladesh, Koomson & Danquah (2021) on Ghana, and Wang et al. (2023) on China, supporting the financial development theory that underscores the role of financial access in improving economic resilience and social welfare. The heightened impact in African countries may reflect deeper financial exclusion and the higher marginal returns of financial integration in these settings.

GDP emerges as a critical determinant with strong positive effects, especially in African economies, reflecting the Solow growth model's emphasis on capital accumulation and macroeconomic stability. These results are consistent with Das et al. (2022) and Liu & Wang (2024), who argue that economic expansion reduces deprivation through increased public infrastructure and services.

Human Capital (HUC) and Government Spending (GS) also exhibit positive effects. Importantly, the interaction term (FINC*HUC) is significantly positive across all regions, implying that financial inclusion and human capital reinforce one another, amplifying their influence on energy poverty. This synergistic relationship supports the endogenous growth theory, which posits that human capital investment enhances the returns of other development drivers. Our results echo findings from Jideofor et al. (2021), who stress the joint role of education and financial access in improving living standards.

Energy Efficiency (EE) also shows a consistent positive impact across all regions. This complements the environmental Kuznets curve (EKC) hypothesis in its optimistic trajectory—arguing that with development and technological improvement, societies use energy more efficiently, reducing poverty. These results correspond with Nasir et al. (2022), Boemi & Papadopoulos (2019), and Li et al. (2021), who highlight EE as a catalyst for sustainable development and poverty alleviation.

Table 6: DCCE Estimation Method

Variables	**Model 1** (Overall Without interaction)	**Model 2** (Overall With interaction)	**Model 3** (AFRICA Without interaction)	**Model 4** (AFRICA With interaction)
Long Run Estimation Results				
FINC	0.6586*** (0.1147)	0.1229*** (0.0323)	0.4421*** (0.0447)	0.8409* (0.4120)
GDP	0.1105** (0.0401)	0.2409* (0.1112)	0.4577*** (0.0655)	0.8212*** (2052)
GS	0.0139* (0.0073)	0.2052*** (0.0528)	0.4673*** (0.1362)	0.7783** (0.2889)
HUC	0.1952*** (0.0663)	0.4273** (0.1862)	0.4929*** (0.1629)	0.4388** (0.1910)
EE	1.1523** (0.4944)	0.5697** (0.2104)	0.2232** (0.1006)	0.3656* (0.1968)
(FINC*HUC)	-	1.5454** (0.6789)	-	0.8242** (0.3264)
Short Run Estimation Results				
D(FINC)	0.6453*** (0.1148)	0.0745* (0.0382)	0.4963*** (0.1460)	0.9464*** (0.0321)
D(GDP)	0.1085** (0.0399)	0.1249* (0.0631)	0.3213** (0.1338)	0.9556** (0.4234)
D(GS)	0.1875** (0.0664)	0.4899** (0.1835)	0.3378** (0.1410)	0.0385 (0.0357)
D(HUC)	0.3820** (0.1627)	1028** (0.0401)	0.4139** (0.1775)	0.9434*** (0.0466)
D(EE)	0.0330* (0.0154)	0.1797** (0.0664)	0.5516** (0.2113)	0.4728** (0.0649)
(FINC*HUC)	-	1.4701** (0.5538)	-	0.4498** (0.0715)

Note: *, ** and *** denotes significance level at 10%, 5% & 1%, respectively. Values in ( ) denote S.E.

Table 6: DCCE Estimation Method (continued from previous table)

Variables	**Model 5** (LATIN AMERICA AND THE CARIBBEAN Without interaction)	**Model 6** (LATIN AMERICA AND THE CARIBBEAN With interaction)	**Model 7** (ASIA Without interaction)	**Model 8** (ASIA Without interaction)
Long Run Estimation Results				
FINC	0.4546** (0.1049)	0.5123** (0.0116)	0.4457*** (0.1325)	1.3987*** (0.0772)
GDP	0.4383** (0.1008)	0.3248** (0.0108)	0.5480 (0.3751)	1.2836*** (0.1667)
GS	0.3349** (0.0527)	0.6355** (0.0202)	1.4874*** (0.2901)	1.7313*** (0.1225)
HUC	0.2401** (0.0520)	0.4487** (0.009)	0.8642*** (0.0889)	0.3719*** (0.1107)
EE	0.3818** (0.0279)	0.2718** (0.0058)	0.4088*** (0.0738)	0.8501*** (0.0828)
(FINC*HUC)	-	0.2576** (0.0106)	-	0.4425*** (0.0535)
Short Run Estimation Results				
D(FINC)	0.0796* (0.0417)	0.0978** (0.0179)	0.8178*** (0.0931)	0.4425*** (0.0535)
D(GDP)	0.1174* (0.0519)	0.1169** (0.0195)	0.5544*** (0.1068)	0.8059*** (0.0848)
D(GS)	0.9025*** (0.0504)	0.1617** (0.0307)	0.7121*** (0.0521)	0.6468*** (0.0465)
D(HUC)	0.0445 (0.0349)	0.7634 (1.4887)	1.0756*** (0.1391)	0.9698*** (0.1367)
D(EE)	0.6867** (0.1081)	0.5497** (0.1932)	0.7225*** (0.0826)	0.5458*** (0.0296)
(FINC*HUC)	-	0.4092** (0.1907)	-	0.7827*** (0.0593)

Note: *, ** and *** denotes significance level at 10%, 5% & 1%, respectively. Values in ( ) denote S.E.

The MMQR estimates (Table 7) further reveal heterogeneity in the distributional effects of these variables on energy poverty. FINC consistently exerts a positive influence across all quantiles (0.1 to 0.4), with stronger effects at the lower quantiles. This finding suggests that financial inclusion is more effective in reducing energy poverty in the most deprived segments, resonating with pro-poor finance theory and studies by Alkire & Kanbur (2022).

GDP retains its strong significance throughout all quantiles, reaffirming its robust and broad-based impact regardless of the severity of energy poverty. Similarly, GS remains significantly positive but shows a marginal decline in impact as we move to higher quantiles, suggesting diminishing marginal returns at upper distribution levels. HUC's stable and significant influence across quantiles aligns with human capital theory, suggesting that educational and skill development uniformly improves energy access and household welfare.

Energy Efficiency (EE) displays a unique pattern: its impact increases slightly at higher quantiles, indicating that while initially moderate, its benefits become more evident as communities transition from lower to mid-income levels. This supports the innovation diffusion theory, where technology adoption scales with development.

Notably, the FINC*HUC interaction term remains strongly significant across all quantiles, reinforcing the critical interdependence between financial systems and human resource development in tackling energy poverty.

Table 7: MMQR Estimation Results

	Locat.	**Scale**	**0.1**	**0.2**	**0.3**	**0.4**
FINC	0.4914** (0.2472)	1.7113*** (0.5956)	0.3201* (0.0854)	0.2778*** (0.0945)	0.2725*** (0.0887)	0.2711*** (0.0742)
GDP	0.8898*** (0.3077)	2.9639*** (0.1517)	0.3324*** (0.0156)	0.3382*** (0.0172)	0.3395*** (0.0161)	0.3399*** (0.0143)
GS	0.0109*** (0.0022)	0.1889*** (0.0212)	0.9931*** (0.1199)	0.9716*** (0.0762)	0.9545*** (0.0978)	0.9238*** (0.0789)
HUC	0.4065*** (0.0101)	0.5854*** (0.0132)	0.3481*** (0.0442)	0.3499*** (0.0368)	0.3712*** (0.0581)	0.3951*** (0.0778)
EE	1.4661*** (0.1005)	1.5052*** (0.0918)	0.3584*** (0.0194)	0.3775*** (0.0219)	0.3784*** (0.0240)	0.3832*** (0.0238)
(FINC*HUC)	0.7722*** (0.0183)	0.8209*** (0.0191)	0.1415*** (0.0208)	0.1421*** (0.0257)	0.1373*** (0.0304)	0.1329*** (0.0407)
Constant	-4.2670*** (0.8461)	4.0129*** (0.0462)	4.0222*** (0.0534)	4.0315*** (0.0654)	4.0522*** (0.0781)	4.0774*** (0.1043)

Note: ***,** shows significance level at 1%, 5%, respectively. Values in ( ) denote S.E.

Table 8 displays Pairwise Dumitrescu Hurlin Panel Causality Tests that reveal various important relationships between Energy Poverty (EP) and other variables. Financial Inclusion (FINC) significantly causes EP at the 5% level (p-value = 0.0126), but EP does not significantly influence FINC. GDP has a bidirectional relationship with EP, where GDP causes EP (p-value = 0.0054) and EP causes GDP (p-value = 0.0005), indicating a strong feedback loop. Government Spending (GS) does not significantly cause EP (p-value = 0.0703), but EP strongly influences GS (p-value = 0.0000). Human Capital (HUC) has a strong causative effect on EP (p-value = 0.0000), while EP does not significantly impact HUC. Lastly, there is a bidirectional relationship between Energy Efficiency (EE) and EP, with both variables significantly influencing each other (p-values = 0.0000 for both directions), indicating mutual causality.

Table 8: Causality Test

Pairwise Dumitrescu Hurlin Panel Causality Tests			
Null Hypotheses	**W-Stat**	**Z-Stat**	**P-Value**
FINC does not cause EP	6.2278	2.4955	0.0126
EP does not cause FINC	2.6216	0.1994	0.8419
GDP does not cause EP	5.5176	2.7832	0.0054
EP does not cause GDP	7.7168	3.5013	0.0005
GS does not cause EP	4.4112	1.8102	0.0703
EP does not cause GS	8.8414	10.1132	0.0000
HUC does not cause EP	8.8837	10.1690	0.0000
EP does not cause HUC	2.0578	1.1931	0.2328
EE does not cause EP	4.0337	3.7538	0.0000
EP does not cause EE	10.8603	12.7836	0.0000

5. Discussion and Concluding Remarks

The research establishes that financial inclusion works alongside government expenditures, GDP levels, human capital, and energy efficiency variables to lower energy poverty within developing nations. According to empirical research spanning the 2004 to 2023 period for 45 developing states, financial inclusion constantly reduces energy poverty most strongly in African nations because human capital combines with financial inclusion to make this positive impact more pronounced. Various statistical relationships exist between energy poverty reduction and GDP growth and government expenditures, and human capital development, although these factors display regional differences in their impact. Energy efficiency remains crucial for sustainable development since it shows consistent importance across all regions. The study confirms the stable relationships observed by recent research conducted in different settings. The data justifies policy decisions that need to improve financial inclusion, together with human capital development, as well as explore the interconnected influences of these elements. The recommendation involves spending government funds strategically alongside investing in energy-efficient solutions to eliminate energy poverty by developing area-specific policies.

The research presents suggestions for developing countries to decrease energy poverty through improved financial inclusion. Officials should enhance rural financial access by increasing mobile banking as well as microfinance services to facilitate clean energy investments, particularly in areas without power grids. The expanded financial service network allows households, together with small companies in underserved areas, to secure funding toward renewable energy components such as solar panels alongside energy-efficient equipment.

The implementation of financial literacy educational programs should proceed alongside energy initiative development. The education of both people and communities will produce the knowledge they need for wise decisions regarding their energy use, together with sustainable technology investments. Team financial management skills, alongside renewable energy knowledge requirements within extended educational curricula for better decision-making on domestic fiscal control and energy sustainability practices. The efforts to eliminate energy poverty require governance reforms so that financial resources reach their intended purposes for poverty reduction in the energy sector.

The implementation of transparent and accountable institutions builds trust between stakeholders so they invest effectively in energy infrastructure and services. Clear energy sector regulations should support private investments because they are essential for the development of the sector. Governments should support private companies through dependable regulatory institutions that merge fair business opportunities with safety measures for users of energy services.

The promotion of public-private partnerships (PPPs) offers essential potential to combine both private and public sector capabilities when handling energy poverty. The collaboration between entities generates combined resources as well as technological and knowledge assets for implementing extensive energy projects that target rural regions lacking access to energy infrastructure. Provided that collaboration between governments and private companies, and international organizations through PPPs enables substantial development of clean energy solutions within developing nations.

This research paper contains valuable exposure to policymakers in developing nations since it has shown how financial inclusion can be adopted to alleviate energy poverty. It points out to increase access to financial services for rural people through mobile banking and microfinancing to facilitate investments in clean energy solutions. These efforts need to be accompanied by financial literacy programs that allow households and small businesses to make better decisions using energy and sustainable technologies. Moreover, there is a need to establish responsible institutions and specific laws, as noted by the study, to have effective spending in society and make use of the participation of the private sector in the energy sector.

The study corroborates the Human Capital Theory in the sense it demonstrates that education and skills training work best when financial inclusion is implemented in predominantly African countries. It is partially consistent with Structural Change Theory, meaning that the GDP growth and government expenditure reduce energy poverty, but these factors do not have the same impacts across the regions, i.e., because of institutional variety. The study also supplements the Fuel Stacking theory, where it was found that ‘financial access creates a situation whereby slow increment of using cleaner sources is achieved because households cumulatively invest in the renewable technologies rather than doing a total replacement in one process.

The results are relevant in terms of attaining Sustainable Development Goals as well as SDG 1 and SDG 7. They point out why it is necessary to merge financial inclusion, energy policy, and education policy so that long-term energy poverty solutions can be developed. The governments are urged to stimulate partnerships between the public and the private sector, invest in human capital, and introduce specific policies per region that would integrate the idea of financial instruments and clean energy. Such an intersectoral strategy can be used to create fair and sustainable energy access in developing countries.

This research provides valuable empirical results on the connection between financial inclusion and energy poverty; it is essential to note that these studies have some weaknesses. The data analysis is carried out at the household dynamics can be hidden, as well as the variation within different contexts. The type of empirical models used mainly presupposes linear relationships; the complex interaction and threshold effects may be neglected that might be inherent among the variables. Given these constraints, when conducting future studies, researchers should contemplate the use of primary data collection at the household or community level, which will offer finer and locally contextual information on the impact of financial inclusion and energy access. The analysis based on gender disengagement would provide a more universal and just perspective on the topic in areas where structural obstacles to financial and energy services particularly challenge women. Future research can be improved methodologically by introducing high econometric methods, such as non-linear modeling, structural equation modeling, or other algorithms of machine learning to utilize interaction terms and unobserved heterogeneity better. Also, the study can be extended in the future by researchers to have wider theoretical orientations. Other theories, including the Capability Approach and the Institutional theory, or the Energy Justice theory, may give a more comprehensive picture of the interaction of the institutional, social, and ethical aspects with financial levers to contribute to energy access. Moreover, the new directions that can also contribute to the policy relevance of future research on the global transformation towards sustainable energy are the development of digital financial services, green microfinance, and climate resilience financing.

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Appendix

List of Countries				
AFRICA				
Algeria	Angola	Mexico	Sierra Leone	South Africa
Cameroon	Congo, Rep	Senegal	Zambia	Zimbabwe
Gambia	Ghana	Tunisia	Burkina Faso	
Mali	Mauritius	Botswana	Gabon	
Niger	Nigeria	Egypt	Madagascar	
Sudan	Togo	Mozambique	Namibia	
ASIA				
Bahrain	Bangladesh	Brunei Darussalam	Myanmar	Turkey
India	Indonesia	Iran	Qatar	United Arab Emirates
Jordan	Kuwait	Malaysia	Thailand	China
Nepal	Pakistan	Philippines	Saudi Arabia	Singapore
Sri Lanka				
LATIN AMERICA AND THE CARIBBEAN				
Argentina	El Salvador	Jamaica	Paraguay	Barbados
Chile	Guatemala	Bolivia	Costa Rica	Uruguay
Colombia	Peru	Haiti	Nicaragua	Brazil
Ecuador	Honduras	Panama	Venezuela, RB	