



Financial Inclusion and Energy Poverty in Sub-Saharan Africa: Does Institutional Quality Matter?

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Abstract

Despite worldwide efforts to combat energy poverty (EP), many economies, notably emerging nations in Africa, continue to struggle. This research aims to explore the potential benefits of Financial Inclusion that could contribute to energy poverty alleviation in Sub-Saharan Africa (SSA) due to its prevalence in African economies. To fulfil the purpose of this research, secondary data were collected from the World Bank Databases for 24 African countries over the extended period from 2011 to 2020. The Dynamic System GMM approach was used for data analysis to unfold the nexus between financial inclusion, institutional quality and energy poverty. The study further employed the Driscoll-Kraay regression and the method of moments quantile regression (MMQR). Study results reveal that supply-side financial inclusion (SFI) and demand-side financial inclusion (DFI) drive energy poverty alleviation in SSA, especially for access to clean fuels and electricity. For the regional effect, SFI and DFI enhance energy poverty alleviation in the Eastern and South African regions. Moreover, the results indicate that the quality of the institutions was a factor that favoured the energy poverty alleviation, especially at higher quantiles. The significant role of institutional quality in the financial inclusion-energy poverty alleviation nexus was observed in the West African region. According to the results, quality institutions help financial inclusion reduce energy poverty in SSA. To foster sustainable energy development and investment in SSA, governments should strengthen regulatory frameworks, streamline bureaucratic processes, and promote transparency and accountability. This study contributes to financial inclusion literature relating to energy poverty alleviation and fulfils the research gap to some extent by examining the potential effect and role of institutional quality in shaping the relationship between financial inclusion and energy poverty in SSA.

Keywords Energy poverty · Financial inclusion · Institutional quality · Sub-Saharan Africa

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Introduction

It is worth noting that the concept of energy poverty has always been talked about in developed countries where the problem is most widespread and developing countries where the problem is acute. Moreover, energy poverty has become an international matter that is considered in the Sustainable Development Goals (SDGs) of the UN (Tabata & Tsai, 2020), thereby attracting the attention of political, economic, and academic circles. To support this statement, energy poverty is becoming the subject matter in Europe and SSA as well as in other areas including healthcare management and climate change (Princ et al., 2021; Rademaekers et al., 2016).

Energy poverty represents a situation where people do not have access to affordable, sufficient, and modern forms of energy services required to meet their basic needs including cooking, lighting, heating, among others (Hou et al., 2022). The issue is prevalent among approximately 1.2 billion people worldwide, mainly developing countries, and it is one of the major obstacles to reducing poverty and achieving sustainable development (IEA, 2020). Energy poverty can cause negative impacts on health conditions, education, and socioeconomic opportunities. For instance, when one uses biomass and other traditional sources including wood, charcoal, and kerosene for cooking and heating purposes, there is a risk of acquiring respiratory diseases, pollution in the house, and burning (Hou et al., 2022). In addition, it can impact learning and productivity rates due to more hours that one spends collecting fuel and conducting domestic chores manually. Throughout the world, 2.5 billion people use traditional biomass for cooking. About 120 million people use kerosene, while 170 million people use coal (Koomson & Danquah, 2021). Around 905 million people in SSA are without access to safe cooking fuel, and 578 million people are without access to electricity (IEA, 2020). This is what creates the energy poverty situation in many countries in SSA. The largest energy poor region in the world, SSA, can gain from this concept. The policymakers should understand the causes of energy poverty through adequate research before addressing the issue in an economic bloc such as SSA.

There are numerous benefits in addressing energy poverty, especially for the problems of generalized poverty, poor health conditions, climate change, and inefficient use of residential energy (Khan et al., 2023). As energy poverty is an instance of social inequality and injustice (Simcock et al., 2016), studying energy poverty is necessary for enhancing energy efficiency and combating poverty (Lin & Wang, 2020) among diverse households (Aristondo & Onaindia, 2018). Previous researches like Koomson and Danquah (2021) and Ntow-Gyamfi et al. (2020) have argued that energy poverty emerges due to the lack of financial inclusion. Financial inclusion, according to the World Bank (2018), means that individuals are able to access and use financial services and products including savings accounts, credit, insurance, and other financial tools. The absence of financial inclusion may result in restricted growth and development since people cannot save, invest, or manage their finances effectively. In addition, the authors stated that the lack of financial inclusion may cause social exclusion and poverty since individuals who do not have access to any formal finance institutions will be forced to look for other financial means, like loan sharks and money lenders.

The topics of financial inclusion and energy poverty are two interconnected problems, which affect the life of millions of people all over the world. Indeed, financial exclusion results in energy poverty since people do not have the opportunity to use their financial services for investing in more energy-efficient or clean energy technologies (Wang et al. 2023a, b). At the same time, energy poverty can also become one of the reasons for financial exclusion since those households that spend most of their budget on energy cannot save money for other purposes (Koomson & Danquah, 2021). Koomson and Danquah (2021) state about three channels through which financial inclusion can influence energy poverty. First, there is a channel of poverty, inequality and income of households, which determines the ability to consume high-quality energy sources. The second channel is related to the fields of health, education and labour outcomes. With improved earnings from better investments in education, there will be improvement in socioeconomic status and standard of living for the families. Therefore, increased standards of living resulting from investment in health and education can assist the households to switch into other alternatives for their energy sources and thus reduce energy poverty (Khan et al., 2023). Finally, economic development and energy efficiency can have an effect on energy poverty through savings, investment, and distribution of resources in productive sectors. Increased income follows economic development. Availability of cleaner energy is due to high income (Koomson & Danquah, 2021).

Institutions act as the focus through which money is transferred to households in order to solve energy poverty as per Nsiah and Tweneboah (2024). The effectiveness of financial inclusion in addressing energy poverty can be improved by good institutions as far as prudent governance, law abiding, and efficient allocation of clean energy resources are concerned (Cummins & Gillanders, 2020). Weaker institutions in any economy have been found to be major contributors to market failure, inadequate energy conversions, and misallocation of necessary resources, and hence cause an increase in energy poverty rate in the developing world (Aracil et al. 2022; Shah et al. 2023 a, b; Asongu & Odhiambo, 2024). According to Aracil et al. (2022), Institutional quality denotes the quality and effectiveness of formal institutions overseeing a particular society. This is the institutional arrangement through which economic and social affairs operate, and its quality may have an immense impact on the economic growth of the country (Ullah et al., 2021). Quality institutions are those that are transparent, accountable, consistent, and impartial. These provide an environment that is favorable for carrying out economic activities and respect the property rights of all parties involved, hence ensuring enforcement of contracts (Van et al., 2022).

On the other hand, weak institutions are typified by corruption, inefficiencies, and a lack of transparency and accountability (Farooq et al., 2022). They may pose serious obstacles to economic operations, deter investments and inhibit economic growth and development. Several authors have addressed the issue of Energy poverty (EP) using various angles: income inequality and EP (Acheampong, 2019; Acheampong et al., 2022); education and EP (Banerjee et al., 2021; Stein & Yannelis, 2020); green energy investments (Skordoulis et al., 2020); health and EP (Kose, 2019; Recalde et al., 2019; Tod & Thomson, 2017); as well as transport (Zafeiriou et al., 2014; Alonso-Elpelde et al., 2023), marriage (Asongu et al., 2024; Asongu & Asaloko, 2024).

Other relevant works of literature by Zheng et al. (2025), Mbate and Fall (2025), Liu et al. (2024), Kabutey-Ongor et al. (2025), and Zhong et al. (2024) may also be considered as sources of information for putting the present study into context as they provide insight into the different relationships that have been made between financial inclusion and energy. The study by Zheng et al. (2025) was on the relationship between financial inclusion and renewable energy efficiency. The study by Mbate and Fall (2025) analyzed financial inclusion and energy access using data from Kenya. The study by Liu et al. (2024) focused on the relationship between financial inclusion and ICT and mobile banking in Ghana. The study by Kabutey-Ongor et al. (2025) examined the relationship between financial inclusion and energy poverty in Ghana through the informal sector. Zhong et al. (2024) on the other hand considered the issue of financial inclusion and energy consumption using information provided from OECD nations. The two studies combined highlight that the link between financial inclusion and energy has indeed been studied across different geographic locations (ranging from individual SSA nations to OECD nations), via different aspects of financial inclusion (ranging from mobile banking/ICT to indices) and different aspects of energy (ranging from efficiency/consumption to access/poverty). None of these studies, however, have considered a cross-national and SSA-wide approach to address the effect of institutional quality as a moderator.

However, there exist three vital research gaps in this area. First, there is a shortage of literature regarding the influence of Financial Inclusion (FI) on EP since there exist very few studies that have investigated the effect of FI on EP such as Khan and Majeed (2023) and Koomson and Danquah (2021). These studies are either generalised globally or based on the experiences of certain countries while ignoring the FI-EP connection in the context of the whole SSA. Second, and even more important, there is no research related to the potential moderating effect of Institutional Quality (IQ) in the FI-EP relation. The study most closely related to this gap, Maket (2024), examines the moderating role of institutional quality and climate change risk in the financial inclusion-energy poverty alleviation nexus, but restricts its measure of energy poverty to only two dimensions access to electricity and access to clean technology fuels which cannot fully capture the multidimensional nature of the phenomenon. Third, existing studies tend to treat SSA as a homogeneous bloc, overlooking the possibility that the FI-EP-IQ relationship may vary systematically across sub-regions with differing institutional and financial-sector characteristics, such as West Africa, East Africa, and Southern Africa.

Motivated by these gaps, this study extends the two-dimensional energy poverty measure used in Maket (2024) into a broader, six-indicator composite index energy intensity level of primary energy, population with access to clean fuel and technology for cooking, population with access to electricity, rural population with access to electricity, urban population with access to electricity, and renewable energy consumption and uses it to assess the impact of FI on EP in SSA countries while explicitly testing the moderating role of IQ. This paper further performs a heterogeneity analysis based on regions by sub-dividing the sample into West Africa, East Africa and Southern Africa. The study focused on SSA countries because about 600 million population in SSA are without electricity as of the first quarter of 2022 (Murshed & Ozturk, 2023). Also, the region is heavily dependent on dirty fuels, creating gover-

nance and financial issues (Nguea & Fotio, 2024). The present study bears significant implications for policymakers. By understanding the effect of IQ on FI and EP relationship, it becomes possible for intervention efforts to consider the context in which they will take place, recognizing the strengths and weaknesses of the institutions and making use of their positive features.

The contributions made to the existing literature through this paper are as follows: (i) A composite index of energy poverty which consists of a multi-facet of six dimensions is built for the SSA nations, which goes a step further than the previous studies on moderating roles (e.g., Maket (2024) that have developed a two-dimension measure of energy poverty; (ii) Empirical evidence concerning the effect of financial inclusion on energy poverty is provided from a sample covering the entire SSA, which helps to fill in the gap of the existing research on the impact of financial inclusion on energy poverty at the regional level; (iii) The effect of institutional quality is tested as a moderator in the FI-EP relationship, addressing the lack of investigation on this issue in the existing FI-EP literature; (iv) Regional heterogeneity is examined by sub-dividing the sample into West African, East African, and Southern African groups, which enables the understanding of the differences between the FI-EP-IQ relationship in these three regions; and (v) Policy implications are derived based on how to combine FI programs with institutional strengthening efforts in the fight against energy poverty in these three regions.

The rest of the study is organised as follows. The empirical review is covered in Sect. 2 while the data and methodology are discussed in Sect. 3. Section 4 focuses on the empirical results and corresponding discussion while Sect. 5 concludes with implications and future research directions.

Literature Review and Hypotheses Development

Financial Inclusion and Energy Poverty Nexus

In the past few years, many research works have been carried out on the relationship between FI and EP. These have been varied based on whether they focused on certain countries or certain regions within continents. According to Mohsin et al. (2022), EP rises with low financial development in all quantiles in Latin America. It has been found by Dong et al. (2022) that the role of Inclusive Financial Development (IFD) in the reduction of EP is mostly due to improvements in the provision of energy services in China between 2004 and 2017. Zhao et al. (2023) found that FI reduces EP in Korea. Between 2004 and 2019, a similar study was carried out in emerging economies, Brazil, China, India, Indonesia, Mexico, and Russia using the augmented autoregressive distributed lags model where Khan et al. (2023) showed that FI impacts EP. FI has been found to be a major factor for reducing EP in China as per Wang et al. (2023a, b). Dogan et al. (2021) found that FI is a major factor for reducing EP in Turkey. According to Asongu and Njangang (2022), household head age moderates the negative relationship between FI and EP in Ghana. Nguyen and Nasir (2021) revealed that rising income disparity exacerbates EP. Khan and Majeed (2023) evaluated the impact of financial sector growth on emerging nations' levels

of energy from 1990 to 2020 and found evidence to support the beneficial contribution that financial sector growth has made to reducing energy poverty in the sampled economies. Based on this, the following hypotheses can be derived:

H1: Financial inclusion has a significant negative effect on energy poverty in SSA countries.

Financial Inclusion, Institutional Quality and Energy Poverty

While the empirical evidence reviewed above establishes that FI can lower EP, and that IQ separately shapes poverty and inequality outcomes, the theoretical basis for why IQ should moderate the FI-EP relationship rather than simply exert an independent effect alongside it has not been made explicit in the literature. This study draws on institutional theory (North, 1993) and the law-and-finance view of financial development (Porta et al., 1998) to build this argument. North's (1993) institutional theory holds that institutions function as the "rules of the game," reducing transaction costs and uncertainty in economic exchange. Applied to the FI-EP relationship, this implies that financial inclusion access to savings, credit, and insurance does not automatically translate into reduced energy poverty; it does so only to the extent that the institutional environment allows financial resources to be reliably converted into productive, energy-related investment. Three mechanisms link IQ to this conversion process: First, contract enforcement and property rights. Strong property rights and enforceable contracts (Van et al., 2022) determine whether credit extended to households and small enterprises can actually be used to acquire energy-related assets solar home systems, efficient cookstoves, grid connections since lenders are more willing to finance such purchases, and borrowers more willing to invest, when collateral is secure and contracts are enforceable. Where institutions are weak, the same unit of financial inclusion carries higher default and expropriation risk, so it is less likely to be channelled into durable energy investments.

Second, regulatory quality and resource allocation. Financial inclusion alleviates EP partly by enabling economic growth and diversification into profitable sectors, as outlined in the growth channel identified by Koomson and Danquah (2021). However, the effectiveness of such growth in terms of achieving affordable and reliable energy access relies on the framework of regulations that apply to tariff settings, licensing of off-grid providers and subsidy programs in the energy market. As demonstrated by Aracil et al. (2022), IQ enhances the poverty alleviating impact of FI, especially in the poorest countries, and the same applies to the energy market, where well-functioning institutions and good regulations ensure that financial resources collected via FI are supported by the well-functioning supply side of clean energy (Cummins & Gillanders, 2020). Third, lower rates of leakage and corruption. As explained by Nsiah and Tweneboah (2024), institutions act as the vehicle for directing financial benefits towards households. With the presence of corruption and inefficiency (Farooq et al., 2022), there would be higher chances of misdirecting the funding in terms of both public and private investments related

to infrastructure of subsidies for energy, and therefore reducing the relationship between FI and energy production. In summary, this means that IQ does not only have a parallel and additive effect on EP similar to FI, but it also affects how FI could help in reducing energy poverty. The research findings are consistent with the above studies conducted by Van et al. (2022) and Aracil et al. (2022) where the asymmetric and income-based moderating effect of IQ was found. This further elaborates the findings by Ullah et al. (2021) regarding the influence of interaction between FI and IQ on energy poverty in SSA. Based on this, the following hypotheses can be derived:

H2 Institutional quality has a significant negative direct effect on energy poverty in SSA countries.

H3 Institutional quality positively moderates the relationship between financial inclusion and energy poverty, such that the energy-poverty-reducing effect of financial inclusion is stronger in SSA countries with higher institutional quality.

H4 The moderating effect of institutional quality on the FI-EP relationship varies across SSA sub-regions (West Africa, East Africa, and Southern Africa), reflecting heterogeneity in institutional and financial-sector development.

Data and Methodology

Data

The data used in the study were taken from the World Bank database from 2011 to 2020. The sample period was chosen to cover most of the SSA countries with available data within the stipulated period. A total of 24 SSA countries (Benin, Botswana, Burkina Faso, Cameroon, Côte d'Ivoire, Eswatini, Ghana, Guinea-Bissau, Kenya, Lesotho, Malawi, Mali, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Togo, Uganda, Zambia and Zimbabwe) were used in this study and were deemed energy poor. Refer to Table 1 for specific variable descriptions.

In line with the existing literature, the study also resorted to an aggregate proxy of IQ from Kaufmann et al. (2010). Similarly, FI was also measured as an index using the six dimensions of FI as per existing studies (see, e.g., Churchill et al., 2020; Churchill & Marisetty, 2020; Koomson & Danquah, 2021). Here, two dimensions of FI were categorised into supply-side and demand-side. On the one hand, the supply-side factors include policies, providing bank branches, the number of ATM outlets, and the number of authorised mobile money agents that make the medium available for executing financial transactions. On the other hand, the demand-side financial inclusion factors involve the consumption of financial services, which may be measured by the volume and amount of bank transactions (e.g., deposits and loans) and the number and value of mobile phone money transactions within a country. The formula for calculating the EP for the sampled SSA countries was given as:

$$EPindex = \sum_{i=1}^n w_i U_i \quad (1)$$

Table 1 Operationalisation of variables used in the study

Variable	Symbol	Formula/Source of data	Studies
Dependent Variable			
Energy Poverty Index	EPI	Entropy Weight Method	(Nguyen et al., 2021; Nguyen & Su, 2021)
Commercial bank branches per 100,000 adults	CBB	World Bank Database	(Dogan et al., 2021)
ATMs per 1,000 km ²	ATM1	World Bank Database	(Koomson & Danquah, 2021)
ATMs per 100,000 adults	ATM2	World Bank Database	(Koomson & Danquah, 2021)
Registered mobile money agent outlets per 100,000 adults	RMM	World Bank Database	(Koomson & Danquah, 2021)
Mobile money transactions per 100,000 adults	MMT1	World Bank Database	(Koomson & Danquah, 2021)
Value of mobile money transactions (during the reference year) (% of GDP)	MMT2	World Bank Database	(Koomson & Danquah, 2021)
Control Variables			
Gross Domestic Product	GDP	World Bank Database	(Omar & Inaba, 2020)
Unemployment	UNEMP	World Bank Database	(Koomson & Danquah, 2021)
GDP per capita	GDPC	World Bank Database	(Khan et al., 2021)
Inflation	Inf	World Bank Database	(Khan et al., 2021)
Trade openness	TO	World Bank Database	(Khan et al., 2021)
Foreign direct investment	FDI	World Bank Database	(Khan et al., 2021)
Urbanisation	URBAN	World Bank Database	(Koomson et al., 2020)
Total Population	POP	World Bank Database	(Khan et al., 2021)
Moderating Variable			
Governance/Institutional quality	Gov	World Bank Database	(Ullah et al., 2021)

$EPindex$ is energy poverty index; U_i are the values of the energy poverty individual indicators at a particular period; w_i is the weight of each indicator to the EP index variation explained by all the variables by principal component analysis. Therefore, w_i in this study is the standardized variance of the principal component. EP index is generated as the linear combination of energy poverty individual variables to the standardized variance of principal component 1 (w_i) (Dimnwobi et al., 2022). Here, note that low values of the dimensions of EP variables in the study will lead to a low EP index (i.e., $w_i U_i$), indicating high EP. This means that relative to its counterparts, a country or sub-region underperforms in the EP parameters. That is, a low $w_i U_i$ signifies a high EP and vice versa. The energy poverty index (EPI) is used to quantify the extent of energy poverty in select African nations.

Construction of the Energy Poverty Index (EPI) Using the Entropy Weight Method

Unlike subjective weighting approaches, which rely on expert judgement and are therefore vulnerable to bias, the entropy weight method (EWM) is an objective weighting technique that derives indicator weights directly from the degree of variation (dispersion) present in the data itself (Dimnwobi et al., 2022). The underlying

logic is that an indicator which varies more sharply across countries and time carries more discriminating information and should therefore receive a larger weight in the composite index, while an indicator that is relatively uniform across the sample conveys less information and should be weighted less heavily. This study adopts the EWM, rather than a purely correlation-based technique such as principal component analysis (PCA), because EWM weights are derived independently of inter-indicator correlation structure, are less sensitive to sample-specific covariance patterns, and yield weights with a direct information-theoretic interpretation grounded in Shannon entropy (Shannon, 1948).

The EPI is constructed from six energy poverty indicators energy intensity level of primary energy, population with access to clean fuel and technology for cooking, population with access to electricity, rural population with access to electricity, urban population with access to electricity, and renewable energy consumption observed across $i = 1, 2, \dots, m$ countries and $t = 1, 2, \dots, n$ years. The construction proceeds in six steps.

Step 1: Data standardisation.

Because the indicators are measured in different units and scales, and because some are positively associated with energy access (e.g., population with access to electricity) while others are negatively associated with it (e.g., energy intensity of primary energy, where a higher value signals greater inefficiency and thus greater energy poverty), each indicator is first normalised to a common $[0, 1]$ scale using the appropriate direction-specific transformation:

For positive (benefit-type) indicators, where a higher raw value indicates lower energy poverty:

$$x_{ij}' = (x_{ij} - \min(x_j)) / (\max(x_j) - \min(x_j)) \quad (2)$$

For negative (cost-type) indicators, where a higher raw value indicates higher energy poverty:

$$x_{ij}' = (\max(x_j) - x_{ij}) / (\max(x_j) - \min(x_j)) \quad (3)$$

where x_{ij} is the raw value of indicator j for observation i , and $\min(x_j)$ and $\max(x_j)$ are the minimum and maximum values of indicator j across all observations. This step ensures that, after normalisation, a higher x'_{ij} consistently corresponds to better energy access (lower energy poverty) for every indicator, so the resulting index is directionally consistent.

Step 2: Compute the proportion (share) of each observation.

For each indicator j , the normalised value of observation i is converted into a proportion of the column total:

$$p_{ij} = x_{ij}' / \sum_i x_{ij}' = 1/m \quad (4)$$

subject to $\sum_i p_{ij} = 1$ for each j . Here, p_{ij} can be interpreted as the “weight” of observation i within the distribution of indicator j , and forms the basis for computing entropy in the next step.

Step 3: Compute the entropy of each indicator.

The Shannon entropy value of indicator j is calculated as:

$$e_j = -k_i = \frac{1}{m} \sum_{i=1}^m p_{ij} \ln(p_{ij}), \quad k = 1/\ln(m), \quad 0 \leq e_j \leq 1 \quad (5)$$

where k is a normalising constant that ensures $0 \leq e_j \leq 1$, and m is the number of observations. Where $p_{ij}=0$ for a given i , the convention $p_{ij} \ln(p_{ij})=0$ is adopted, consistent with the limiting behaviour of the function. A higher e_j indicates that observations are more evenly distributed across indicator j (i.e., the indicator carries less discriminating information), while a lower e_j indicates greater dispersion and therefore greater informational content.

Step 4: Compute the degree of diversification (redundancy) of each indicator.

The degree of diversification, d_j , measures the discriminating power of indicator j and is defined as the complement of its entropy:

$$d_j = 1 - e_j \quad (6)$$

Indicators with a higher d_j contribute more useful variation to distinguishing countries' energy poverty levels and should therefore be assigned proportionally greater weight.

Step 5: Compute the entropy-based weight of each indicator.

The weight of indicator j , w_j , is obtained by normalising its degree of diversification against the sum of diversification degrees across all n indicators:

$$w_j = d_j / \sum_{j=1}^n d_j, \quad \sum_{j=1}^n w_j = 1 \quad (7)$$

This step converts each indicator's diversification degree into an objective weight that reflects its relative contribution to overall variation in the dataset, entirely free of subjective judgement.

Step 6: Compute the composite Energy Poverty Index.

The final EPI for each country-year observation is calculated as the weighted sum of the normalised indicator values:

$$EPI_{it} = \sum_{j=1}^n w_j x'_{ijt} \quad (8)$$

where EPI_{it} denotes the composite energy poverty index score for country i in year t , x'_{ijt} is the normalised value of indicator j for country i in year t , and w_j is the entropy-derived weight of indicator j obtained in Step 5.

Because the underlying indicators were standardised so that higher values consistently reflect better energy access, the resulting EPI is increasing in energy access: a higher EPI_{it} signifies lower energy poverty (i.e., a country performs relatively well on the underlying energy access dimensions), while a lower EPI_{it} signifies higher energy poverty, reflecting relative underperformance on the energy access parameters compared to its counterparts in the sample. This composite EPI is used throughout the study to quantify the extent of energy poverty across the selected African nations.

Table 2 shows the variables used in the construction of EP. The six dimensions of the EPI have been denoted as EP1 to EP6 (Table 2).

Model Specification

The study's estimated energy poverty models were specified following the systems dynamic GMM estimation technique proposed by Arellano and Bond (1998) and re-engineered by Roodman (2009a, 2009b). This estimator is used to cater for the endogeneity problem that arises from the inclusion of the lag-dependent variables, which represent an auto-regressive behaviour. This estimation technique has been propagated in recent literature (Agyei et al., 2020, 2021) and commended for dynamic panel models. Separate models were specified for the direct relationships and the moderating effects as follows.

$$EPI_{it} = \alpha + \beta_1 L.EPI_{it} + \beta_2 SFI_{it} + \beta_3 IQ_{it} + \sum_{i=1}^8 \beta_i Controls_{it} + \epsilon_{it} \quad (9)$$

$$EPI_{it} = \alpha + \omega_1 L.EPI_{it} + \omega_2 DFI_{it} + \omega_3 IQ_{it} + \sum_{i=1}^8 \omega_i Controls_{it} + \epsilon_{it} \quad (10)$$

The variables in Eqs. (2) and (3) are defined as follows. The cross-section and time dimensions are denoted by “*i*” and “*t*”, respectively. α is the regression intercept; β and ω signify regression coefficients; ϵ represents the noise or disturbance term; $L.EPI$ denotes the lag of energy poverty, signifying that the model is dynamic; SFI represents supply-side financial inclusion while DFI is demand-side financial inclusion; and IQ is institutional quality. The control variables are as defined in Table 2.

Table 2 Operationalisation of variables for energy poverty index

Indicators	Notation	Source	Reference
Percentage of the population with access to clean fuel and technology for cooking	EP1	World Bank data	(Nguyen et al., 2021; Nguyen & Su, 2021)
Percentage of the population with access to electricity	EP2		(Nguyen & Su, 2021)
Percentage of rural population with access to electricity	EP3		(Nguyen & Su, 2021)
Percentage of urban population with access to electricity	EP4		(Nguyen & Su, 2021)
The energy intensity level of primary energy (MJ/\$2017, GDP(PPP))	EP5		(Wang et al., 2021)
Renewable energy consumption (% of total final energy consumption)	EP6		(Zhao et al., 2023; Mensah & Abdul-Mumuni, 2023)

The models involving the interaction term(s) were specified in Eqs. (11) and (12) as follows:

$$EPI = \alpha + \phi_1 L.EPI_{it} + \phi_2 SFI_{it} + \phi_3 IQ_{it} + \phi_4 SFI \times IQ_{it} + \sum_{i=1}^8 \phi_i Controls_{it} + \epsilon_{it} \quad (11)$$

$$EPI = \alpha + \varphi_1 L.EPI_{it} + \varphi_2 DFI_{it} + \varphi_3 IQ_{it} + \varphi_4 DFI \times IQ_{it} + \sum_{i=1}^8 \varphi_i Controls_{it} + \epsilon_{it} \quad (12)$$

Here also, the cross-section and time dimensions are denoted by “ i ” and “ t ”, respectively. α is the regression intercept; ϕ and φ signify regression coefficients; ϵ represents the noise or disturbance term; $L.EPI$ denotes the lag of energy poverty, signifying that the model is dynamic; SFI represents supply-side financial inclusion while DFI is demand-side financial inclusion; IQ is institutional quality; $SFI \times IQ$ is the interaction term between supply-side financial inclusion and institutional quality; $DFI \times IQ$ is the interaction term between demand-side financial inclusion and institutional quality.

Presentation and Discussion of Results

Descriptive Statistics and Correlation Analysis

Table 3 shows summary statistics as calculated based on data from 24 SSA countries spanning the years 2011 to 2020.

The correlation matrix presented in Table 4 reveals several significant correlations.

Diagnostic Tests

This study assessed the statistical properties of the data to ascertain which estimation technique would be appropriate in the analysis framework. Three separate tests were explored: Pearson’s cross-sectional dependence (CD) test, White’s test for heteroscedasticity, and the Wooldridge test for autocorrelation. Table 5 displays the diagnostic test results for the data used in the regression model. Pearson’s CD test indicates that data are associated among the panel groups. The p -value of White’s test is less than the significance level, thus rejecting the H_0 . Therefore, the presence of heteroskedasticity could be envisaged. Using the Wooldridge test, the study revealed the issue of first-order autocorrelation. So, traditional methods like OLS cannot be employed because the data failed to support the cross-sectional independence and will provide unpredictable results. To overcome these limitations, this research used the two-step GMM approach Table 5.

Results on the Relationship between FI and EP

The study analysed the relationship between financial inclusion and energy poverty in two basic models that explain the direct relationship between financial inclusion

Table 3 Descriptive statistics

Variable	<i>N</i>	Mean	Std. Dev.	Minimum	Maximum	Shapiro-Wilk <i>W</i>	Shapiro-Wilk <i>p</i>
EPI	240	0.1695839	0.1453098	0.0317244	0.8254451	0.54376	<0.001
SFI	240	0.1819986	0.1593208	0.002157	0.8974164	0.81716	<0.001
DFI	240	0.1825624	0.1521236	0.0145947	0.6774592	0.85122	<0.001
CBB	250	5.28	2.91	1.09	15.4	0.901	<0.001
ATM1	250	4.71	5.71	0.06	22.6	0.723	<0.001
ATM2	250	13.6	17.2	0.91	72.8	0.649	<0.001
RMM	250	225	247	0	911	0.832	<0.001
MMT1	250	248	250	0	931	0.848	<0.001
MMT2	250	14.4	21.1	-0.34	139	0.717	<0.001
Unemployment	240	8.371167	7.969491	0.32	29.22	0.76381	<0.001
GDP(%)	240	4.102667	3.461673	-8.73	16.67	0.94661	<0.001
FDI	240	3.686864	5.397719	-2.544539	39.4562	0.58165	<0.001
Inflation	240	8.604138	39.39064	-3.233389	557.2018	0.13065	<0.001
Urbanisation	240	38.4829	14.4026	15.672	70.877	0.96491	<0.001
IQ	240	-0.4902572	0.48562	-1.482813	0.7209747	0.97738	<0.001
Population	240	2.50e+07	3.62e+07	1,072,029	2.06e+08	0.53808	<0.001
GDPPC	240	1786.13	1704.121	362.1316	7027.045	0.72112	<0.001
TO	230	66.92912	26.89681	16.35219	149.8899	0.92942	<0.001

Source: Estimations Based on Data Retrieved from WDI (2023)

and energy poverty in SSA. Using the 2-step GMM estimator, the results were presented in Table 6 in two models, Model 1 and Model 2. Both models have satisfactory statistical properties, as indicated by the *p*-values of the AR (1), AR (2), Sargan, and Hansen tests and the significance of the Wald statistics. The models include 22 instruments and are based on a sample of 207 observations from 23 countries. In Model 1, the main independent variable is the supply-side financial inclusion while the main independent variable in Model 2 is the demand-side financial inclusion. Models 3 and 4 control for year effect to capture the effect of covid-19. In both models, the various control variables are maintained. Following existing studies (Agyei et al., 2020, 2021; Asiamah et al., 2022), the results are summarised in Table 6 alongside estimation diagnostics (mainly, the Hansen and Sargan statistics) for the 2-step GMM technique. Standard errors, rather than *t*-statistics, are reported in parentheses below each coefficient because the estimations employ (panel-corrected/clustered/heteroskedasticity-and-autocorrelation-consistent) standard errors to correct for cross-sectional dependence and heteroskedasticity across SSA countries. Reporting standard errors allows readers to directly observe the precision of each estimate and construct confidence intervals, consistent with standard practice in panel data studies using [FE/GMM/PCSE] estimators. Statistical significance is indicated using conventional asterisks (**p*<0.10, ***p*<0.05, ****p*<0.01).

The study's first model is specified to examine the correlation between FI and EPI. From the estimates, the indication is a significant positive correlation between SFI and EPI ($\beta = 0.0981$, $p < 0.001$). It suggests that SFI improvement leads to more EP mitigation. Apart from IQ, unemployment, GDP per capita, FDI, inflation, urbanisation, TO and population no other variables in Model 1 have any statistically

Table 4 Correlation matrix

	EPI	SFI	DFI	IQ	UNEMP	GDPC	FDI	Inf	URBAN	TO	POP
EPI	1										
SFI	0.1329	1									
DFI	0.0479	0.1964	1								
IQ	0.1884	0.4372	-0.1759	1							
UNEMP	0.0958	0.3247	-0.255	0.5095	1						
GDPC	0.1867	0.4521	0.0577	0.5408	0.7233	1					
FDI	-0.0643	-0.1947	-0.1937	-0.0102	-0.1932	-0.3233	1				
Inf	0.0122	-0.0448	0.0292	-0.123	-0.0228	0.0208	-0.0278	1			
URBAN	0.233	0.0597	-0.0791	0.3472	0.3248	0.6125	-0.1359	-0.0431	1		
TO	-0.0539	-0.124	-0.394	0.3123	0.5103	0.1146	0.32	-0.0287	0.041	1	
POP	0.081	0.098	0.5655	-0.2299	-0.4752	-0.1082	0.0904	0.0336	0.0765	-0.5866	1

Source: Estimations Based on Data Retrieved from WDI (2023)

Table 5 Diagnostic tests

Test	Pesaran CD Test	White's test	Wooldridge test
Purpose	cross-sectional dependence	Heteroskedasticity	autocorrelation in panel data
Hypothesis	No cross-sectional dependence	Heteroskedasticity not present	No first-order autocorrelation ($\rho=0$)
<i>p</i> -Value	0.000	0.0139803	0.0000
Decision	Reject	Reject	Reject
Result	There exists cross-sectional dependence.	Heteroskedasticity is present	Presence of First order auto-correlation

Source: Estimations Based on Data Retrieved from WDI (2023)

significant impact on EPI. Secondly, Model 2 was intended to estimate the influence of DFI on EPI using additional variables. It turned out that there is a significant positive relationship between DFI and EPI ($\beta=0.0613$, $p<0.01$). This suggests that an improvement in DFI is associated with higher levels of EP alleviation. No other variables in Model 2, including IQ, unemployment, GDP per capita, FDI, inflation, urbanisation, TO, and population, show statistically significant associations with the EPI. Controlling for year effect in Models 3 and 4, SFI has a significant positive effect on the energy poverty alleviation index at a 1% significance level but DFI has no significant effect on EP alleviation. In Model 3 where the main independent variable is the supply-side financial inclusion, covid-19 is associated with higher levels of EP alleviation but the effect is insignificant under Model 4 where the main independent variable is the demand-side financial inclusion. The study findings highlight the significant positive impact of SFI and DFI on EP in SSA. These findings reinforce the crucial link between FI and EP alleviation through two main channels Table 6.

Moderation Effect

The study further analysed how the interaction between FI and IQ influences EP alleviation in SSA. The results from the 2-step GMM estimator were presented in two models, Model 5 and Model 6, in Table 7. Here also, both models have satisfactory statistical properties, as indicated by the *p*-values of the AR (1), AR (2), Sargan, and Hansen tests in addition to the Wald statistics. From Model 5, the main independent variable is SFI. Hence, the moderating effect is defined as the interaction between SFI and IQ. The main independent variable in Model 6 is DFI. So, the moderating effect in this model is defined as the interaction between DFI and IQ. In both models, the various control variables are maintained. Similar to existing literature (Agyei et al., 2020, 2021; Asiamah et al., 2022), the findings have been presented in Table 7 with the estimation diagnostics (Hansen and Sargan statistics) for the 2-step GMM model.

The IQ variable in Model 5 exhibits a statistically significant positive impact on EPI ($\beta=0.0738$, $p<0.001$). Thus, the higher level of the institutional quality corresponds to the higher level of EP. None of the variables included in Model 5, except

Table 6 GMM Regression results for direct relationships

Variables	Model 1	Model 2	Model 3	Model 4
	EPI	EPI	EPI	EPI
L.EPI	0.874*** (0.0554)	0.949*** (0.0849)	0.72364*** (0.13970)	0.99004*** (0.22029)
SFI	0.0981*** (0.0341)		0.00877*** (0.00334)	
DFI		0.0613** (0.0279)		0.00354 (0.00408)
IQ	-0.00474 (0.0216)	0.00134 (0.0128)	0.01381 (0.01367)	0.00693 (0.01389)
Unemployment	-0.00103** (0.000477)	-0.000826 (0.00140)	-0.00007 (0.00061)	-0.00003 (0.00077)
GDPPC	0.0109 (0.0148)	-0.00841 (0.0135)	0.05184* (0.02881)	0.01822 (0.02445)
FDI	0.000302 (0.000582)	2.80e-05 (0.000406)	-0.00068*** (0.00021)	-0.00072*** (0.00018)
Inflation	4.64e-05* (2.68e-05)	3.54e-05** (1.50e-05)	-0.00025 (0.00145)	-0.00067 (0.00110)
Urbanisation	0.000721* (0.000382)	0.00127 (0.000935)	0.00152 (0.00143)	-0.00052 (0.00147)
TO	0.000268** (0.000103)	0.000195* (9.98e-05)	0.00503 (0.01077)	-0.00844 (0.01572)
Population	0.0116* (0.00596)	0.000465 (0.0162)	-0.12259** (0.04813)	-0.07403 (0.05418)
Covid-19			0.03103*** (0.00924)	0.00110 (0.00338)
Constant	-0.305 (0.183)	-0.00387 (0.303)	1.58318** (0.71411)	1.11744 (0.78101)
Wald	13258.00***	74526.11***	19207.17***	51879.52***
Control for time effect	No	No	Yes	Yes
<i>p</i> -value of AR(1)	0.001	0.001	0.003	0.003
<i>p</i> -value of AR(2)	0.233	0.355	0.502	0.395
<i>p</i> -value of Sargan	0.433	0.216	0.724	0.388
<i>p</i> -value of Hansen	0.446	0.293	0.233	0.298
Instrument count	22	22	23	21
Observations	207	207	207	207
Number of countries	23	23	23	23

(Notes: This table presents the dynamic panel estimation results based on the two-step system GMM. EPI is energy poverty index; SFI denotes the supply-side financial inclusion (i.e., availability of infrastructure); DFI is demand-side financial inclusion (i.e., consumption/usage of financial services); FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDPPC is GDP per capita; and TO is trade openness. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$)

Source: Estimations Based on Data Retrieved from the WDI (2023)

Table 7 GMM regression results for the moderating effect

Variables	Model 5	Model 6	Model 7	Model 8
	EPI	EPI	EPI	EPI
L.EPI	0.879*** (0.0747)	0.979*** (0.0869)	0.92827*** (0.09227)	0.95990*** (0.07868)
SFI	0.0189 (0.0466)		0.00350 (0.00318)	
DFI		0.0968* (0.0501)		0.00482** (0.00245)
IQ	0.0738*** (0.0174)	-0.0226 (0.0293)	0.01285 (0.01773)	0.01491 (0.01854)
SFI × IQ	0.171** (0.0722)		-0.00096 (0.00423)	
DFI × IQ		0.110 (0.115)		-0.00187 (0.00502)
Unemployment	0.000573 (0.000875)	-0.000924 (0.00143)	0.00021 (0.00054)	0.00008 (0.00058)
GDPPC	-0.0482*** (0.0110)	-0.00347 (0.0149)	0.03126* (0.01653)	0.01736 (0.01551)
FDI	-0.00138*** (0.000371)	0.000193 (0.000474)	-0.00068*** (0.00017)	-0.00074*** (0.00017)
Inflation	2.11e-05 (5.12e-05)	3.03e-05* (1.53e-05)	-0.00062 (0.00091)	-0.00038 (0.00106)
Urbanisation	0.00146* (0.000729)	0.00124 (0.000964)	-0.00019 (0.00135)	-0.00055 (0.00142)
TO	0.000192* (0.000109)	0.000271* (0.000143)	-0.01157 (0.01275)	-0.01152 (0.01096)
Population	0.0129 (0.0197)	0.00128 (0.0162)	-0.06307* (0.03603)	-0.05258 (0.03842)
Covid-19			0.00184 (0.00215)	0.00167 (0.00232)
Constant	0.109 (0.316)	-0.0689 (0.318)	0.84402 (0.55100)	0.78046 (0.57656)
Wald	544.38***	88063.63***	90748.28***	352705.80***
Control for time effect	No	No	Yes	Yes
<i>p</i> -value of AR(1)	0.004	0.001	0.000	0.002
<i>p</i> -value of AR(2)	0.396	0.344	0.406	0.352
<i>p</i> -value of Sargan	0.449	0.156	0.941	0.601
<i>p</i> -value of Hansen	0.449	0.253	0.904	0.860
Instrument count	22	22	21	21
Observations	207	207	207	207
Number of countries	23	23	23	23

This table presents the dynamic panel estimation results based on the two-step system GMM. EPI is energy poverty index; SFI denotes the supply-side financial inclusion (i.e., availability of infrastructure); DFI is demand-side financial inclusion (i.e., consumption/usage of financial services); FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDPPC is GDP per capita; TO is trade openness; “SFI × IQ” is the interaction between supply-side financial inclusion and institutional quality; and “DFI × IQ” is the interaction between demand-side financial inclusion and institutional quality. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$)

Source: Estimations Based on Data Retrieved from the WDI (2023)

for IQ, SFI, DFI, unemployment, GDP per capita (GDPPC), FDI, inflation, urbanization, TO, and population has a significant association with EPI. Model 6 deals with the estimation of EPI with a number of additional variables. Lagged Energy Poverty Index (L.EPI) retains a statistically significant and positive impact on EPI ($\beta=0.979$, $p<0.001$). That is, there is high persistence in the phenomenon of energy poverty. Among the variables in Model 6, only DFI exhibits a statistically significant positive impact on EPI ($\beta=0.0968$, $p<0.05$).

It is worth noting that the interaction ($SFI \times IQ$) also shows a significant positive effect on the EPI ($\beta=0.171$, $p<0.01$). This indicates that the combined impact of SFI and IQ amplifies the association with EP. Meanwhile, no other variables in Model 6, including IQ, unemployment, GDP per capita (GDPPC), foreign direct investment (FDI), inflation, urbanisation, trade openness (TO), and population, show statistically significant associations with EPI. Here, the variables of interest are the interaction terms. Controlling for year effects to capture the Covid-19 period, there is no significant moderating effect of financial inclusion and institutional quality on EPI (see Models 7 and 8) Table 7.

Robust Analysis

A robust analysis is performed to examine the effect of financial inclusion on the individual indicators of the energy poverty index while controlling for the year effect as shown in appendices A1: Table 8 and A2: Table 9. The paper further interacted with the individual dimensions of governance and financial inclusion and examined the effect on the energy poverty index as shown in appendices B1 and B2. In Appendix A1: Table 8, supply-side financial inclusion (SFI) has a significant positive effect on access to clean fuel and technology at a 5% significance level (see Model 9). The effect of supply-side financial inclusion on the other indicators of energy poverty (thus, access to electricity, urban population access to electricity, rural population access to electricity, renewable energy and energy intensity) is not significant. The demand-side financial inclusion has a significant positive effect on access to clean fuel and technology and access to electricity at a 10% significance level (see Appendix A2: Table 9, Models 15 and 16). Demand-side financial inclusion (DFI) showed no significant effect on urban population access to electricity, rural population access to electricity, renewable energy and energy intensity (see Models 17–20). The moderating effect of SFI and individual governance indicators is not significant on the energy poverty alleviation index (see Appendix B1: Table 10, Models 21–26). Similarly, the moderating effect of DFI and individual governance indicators is not significant on the energy poverty alleviation index (see Appendix B2: Table 11, Models 27–32). These results are consistent with the results under Table 7 (see Models 7 and 8) where institutional quality has no significant effect on energy poverty when year effects are controlled for.

Heterogeneity Analysis

The study further performed heterogeneity analysis. The study first performed a regional analysis using the Driscoll-Kraay regression and further used the method of moment quantile regression (MMQR) on the full sample while controlling for country and year effects. Middle Africa was omitted because it had only one country. The MMQR is robust to heterogeneity, endogeneity and non-normality while the Driscoll-Kraay regression is more robust to cross-sectional dependence, high-order autocorrelation and heteroscedasticity. From the Driscoll-Kraay regression in Appendix C1: Table 12, there is a significant positive effect of supply-side and demand-side financial inclusion on energy poverty (EP) alleviation of East and South African countries (see Models 34, 35, 37 and 38). However, supply-side and demand-side financial inclusion showed no significant effect on energy poverty alleviation for the West African region. Using the full sample under the method of moment quantile regression (MMQR) for the heterogeneity analysis, supply-side financial inclusion has a significant positive effect on EP across all the quantiles except quantiles 1 and 2 (see Appendix D1: Table 14). Demand-side financial inclusion has a significant positive effect on EP at higher quantiles (see quantile 5 to quantile 9, Appendix D2: Table 15).

For the interactions, there is a significant positive interactive effect of supply-side financial inclusion and institutional quality (IQ) on energy poverty in West Africa (see Appendix C2: Table 13, Model 39) but the effect is negative for the South African region (see Appendix C2: Table 13, Model 41). Similarly, there is a significant negative interactive effect of demand-side and IQ on EP for East and South African regions (see Appendix C2: Table 13, Models 43 and 44). Results from MMQR showed that SFI and IQ have no significant interactive effect on EP at lower quantiles, thus, from quantile 1 to quantile 6 but the interactive effect is positive and significant on EP at higher quantiles from quantile 7 to quantile 9 (see Appendix D3: Table 16). The findings from these interactions, evidencing the moderating effect of IQ on the relationship between SFI and EP in SSA, have important implications to be noted. That is, the presence of IQ plays a crucial role in enhancing the relationship between SFI and EP in SSA especially at higher quantiles. Finally, the interactive effect of DI and IQ on EP is negative at lower quantiles, thus, from quantile 1 to quantile 3 (see Appendix D4: Table 17).

Discussions of Empirical Findings

The availability of well-developed financial infrastructure on the supply side simplifies financial transactions and provides easy access to a wide range of financial services for individuals facing poverty. This, in turn, stimulates energy consumption by making it more convenient for households to obtain new energy connec-

tions and manage their energy bills effectively, a channel that is consistent with micro-evidence from Ghana (Koomson & Danquah, 2021) and aggregate evidence from low- and middle-income economies (Nguyen et al., 2021). Moreover, the link runs both ways: beyond easing transactions, FI also raises household income, enabling investment in clean fuels and grid connection charges, thereby accelerating progress on SDG 7. Bayar et al. (2021) further observe that a developed financial sector lets households hedge against energy-price volatility, smoothing investment in energy-efficient assets, precisely the mechanism through which both the demand-side (DFI) and supply-side (SFI) dimensions of FI in this study translate into measurable EPI gains.

In line with the second strand of findings, the results underscore the transformative potential of FI in reducing poverty, enhancing welfare, and driving economic development. Churchill and Marisetty (2020) and Koomson et al. (2020) found strong poverty reduction effects of FI on income and consumption that mirror the positive effects of SFI and DFI on welfare found herein. By enabling individuals to make investments, maintain their consumption levels and resist financial shocks, FI is key in improving earning potential (Demirgüç-Kunt et al., 2017). More precisely, the findings show that more branches of commercial banks, ATM outlets, and mobile money transactions are linked with better access to clean energy resources and technology. In terms of finance, advances in DFI determinants, such as more commercial bank transactions and mobile money transaction numbers and values, similarly help gain this access. As compared to previous studies conducted in one country or panel (Dogan et al. 2021; Said and Acheampong 2023; Koomson and Danquah 2021; Wang et al. 2023a, b; Maket 2024), the current findings add to the existing consensus about FI reducing energy poverty while broadening it to SSA. What differentiates the current contribution, however, is the explicit regional decomposition of these effects.

The significant role played by institutional quality (IQ) in enhancing the effect of SFI on energy poverty alleviation is only significant at higher quantiles of energy poverty. The qualitative direction aligns with Cummins and Gillanders (2020), who show that regulatory and governance quality improves the targeting of clean-energy subsidies and the credibility of electrification contracts, and with Maket (2024), who finds that institutional quality is the channel through which FI acts on energy poverty in a single-region SSA panel. The novelty here is that, when IQ is interacted with FI, the moderating effect is itself heterogeneous across SSA sub-regions rather than uniformly positive an asymmetry that single-region analyses cannot detect.

The discussion also illuminates the dynamics between other control variables and the EPI in SSA. Economic growth alleviates energy poverty: growth flows into household earnings, which enable the purchase of electricity and clean fuels and, more broadly, into public finance for grid extension corroborating Filippidis et al. (2021); Wang et al. (2023a, b), who document a positive growth-EP link through the energy-environmental Kuznets curve and FI channels. Population and FDI behave differently. Population growth raises electricity demand faster than supply expands, intensifying outages and reducing household access. FDI inflows, in this sample,

are negatively associated with access to electricity and rural access, consistent with Swart and Noije (2024), but in tension with Aluko et al. (2023), who report a positive direct effect of FDI on electricity access using IV-GMM and emphasize the moderating role of governance, and with Khan and Tariq (2021) and Nguea et al. (2022), who find FDI to be positive once country heterogeneity is accounted for. The divergence suggests that, in our sample, FDI is more likely entering via privatization-led tariff increases and crowding-out of small local providers than via new generation capacity, an interpretation Aluko et al. (2023) flag as a binding constraint under weak governance. Finally, the positive effect of trade openness on access to clean fuel and technology is consistent with Yan et al. (2023), who show that openness expands the import of clean-energy appliances, intensifies competition, and yields scale economies in distribution.

The regional decomposition (Appendix C1: Table 12) sharpens the discussion considerably. The estimate that SFI ($\beta = 0.05104$, $p < 0.01$) and DFI ($\beta = 0.01956$, $p < 0.05$) alleviate energy poverty in East Africa, and that both are also positive and significant in Southern Africa (SFI $\beta = 0.02214$, $p < 0.01$; DFI $\beta = 0.00544$, $p < 0.01$) while neither is significant in West Africa is consistent with the maturity gradient of financial infrastructure across SSA: Kenya-led East Africa has deep mobile-money penetration, and Southern Africa has comparatively high banking density, whereas West Africa's mobile-money and formal credit markets remain thinner and more uneven. The literature converges on this maturity-dependence result: Said and Acheampong (2023) find large effects of FI on EPI across 23 SSA countries but caution that the effect is uneven within the pool; Wang et al. (2023a, b) document heterogeneity in FI-EP coefficients across developing economies; and Koomson and Danquah's (2021) Ghana single-country estimates are sizeable but country-specific. The present regional decomposition adds two comparative insights. First, in West Africa IQ is negative and significant ($\beta = -0.052$ to -0.055 , $p < 0.01$) while insignificant in East and Southern Africa, suggesting that weak governance itself is a more binding constraint on energy-poverty outcomes than the availability of financial services per se. Second, the moderating effects (Appendix C2: Table 13) show that in West Africa the $IQ \times SFI$ interaction is positive and weakly significant ($\beta = 0.01159$, $p < 0.1$), implying that better institutions are a precondition rather than a complement for SFI to deliver energy-poverty gains aligned with the institutional-conduit argument of Aracil et al. (2022; Nsiah and Tweneboah (2024), who find that institutional quality is a hurdle that must be cleared before FI can reduce poverty in Africa.

By contrast, in Southern Africa, both interaction terms are negative and significant ($SFI \times IQ$: $\beta = -0.02850$, $p < 0.01$; $DFI \times IQ$: $\beta = -0.02579$, $p < 0.01$), and in East Africa, $DFI \times IQ$ is negative and significant ($\beta = -0.08359$, $p < 0.05$) while $SFI \times IQ$ is insignificant. The direction is consistent with a diminishing-marginal-returns reading: in sub-regions where institutions are already comparatively strong and FI is operationally mature, the marginal energy-poverty benefit of further IQ gains, transmitted through FI, falls as the system approaches its potential. Maket's (2024) single-region SSA estimate cannot capture this asymmetry, and recent work on African poverty reduction (e.g., Nsiah & Tweneboah, 2024) consistently shows that

the FI-institution interaction is moderated by the underlying institutional baseline. Together, these comparisons indicate that the moderating role of IQ in the FI-EP nexus is not uniform: in shallow financial systems and weak-institution settings, IQ functions as a genuine amplifier, even a prerequisite, consistent with Aracil et al. (2022); in deeper systems, FI and IQ act more as substitutes, with FI delivering strong energy-poverty gains largely on its own. This implies that any FI-energy poverty intervention calibrated at SSA-average parameters would mis-specify policy for individual sub-regions and underscores the need for differentiated, context-specific policy design.

Conclusion, Implications and Recommendations

Conclusions

Based on the empirical analysis, three conclusions emerge. First, energy poverty remains persistent across SSA, with substantial sub-regional heterogeneity in both levels and FI responses, in line with Said and Acheampong (2023) and Maket (2024). Second, both SFI and DFI show significant positive associations with the EPI particularly on access to electricity and access to clean fuel and technology establishing FI as a robust channel for alleviating energy poverty in SSA, an outcome corroborated by Koomson and Danquah (2021); Dogan et al. (2021); Wang et al. 2023a, b; Koomson et al. (2020). Third, and more precisely, the FI-EP relationship is not uniform across sub-regions: in West Africa, where financial systems are shallow and institutions weak, IQ functions as a prerequisite amplifier of SFI (Aracil et al. 2022; Nsiah and Tweneboah 2024), whereas in East and Southern Africa, where FI is comparatively mature, FI and IQ act more as substitutes, extending the single-region inference of Maket (2024).

Policy implications

Policy recommendations should be tailored to each SSA sub-region's stage of financial and institutional development:

- i. The first policy implication of the findings that policy makers have to be concerned about expanding supply-side FI for the energy sector. SSA-wide, regulators should deepen energy-sector financial infrastructure microfinance, credit lines, mobile banking for both producers and consumers and offer low-cost products (microinsurance, basic accounts). This is consistent with Bayar et al. (2021), Demirgüç-Kunt et al. (2017), and Said and Acheampong (2023).
- ii. Additionally, the results also suggest that there must be a prioritisation of institutional reform in West Africa. In West Africa, where neither SFI nor DFI reduces EP on its own but $SFI \times IQ$ is positive and weakly significant, the binding constraint is governance. Strengthening the legal and regulatory framework is a

precondition for FI to translate into clean-energy outcomes (Aracil et al. 2022; Cummins and Gillanders 2020).

- iii. Moreso, there must be a shift in geographical areas like East and Southern Africa. Where FI is already strong, additional FI gains yield energy-poverty relief on their own, so the marginal IQ investment can be redirected from the FI channel toward other complementary objectives, e.g., fine-tuning clean-fuel subsidy design and trade-facilitation reforms to sustain the gains from trade openness (Yan et al., 2023).
- iv. Finally, there must be effort to ensure appropriate integration of energy and development policies that can stand the test of time. SSA-wide, energy access strategies should be aligned with poverty-reduction, education, health, and trade policies, recognising the trade-clean-energy nexus and the infrastructure benefits of economic growth documented by Filippidis et al. (2021) and Wang et al. (2023a, b).

Practice implications

For implementing agencies and practitioners:

- i. There should be a prioritisation of differentiated product design in Sub-Saharan Africa. Financial service providers should adapt offerings to sub-regional maturity: in West Africa, pair financial products with consumer-protection and financial-literacy guarantees that IQ infrastructure supports, while in East and Southern Africa the priority is scaling up transaction volume and breadth, since FI alone produces strong EP gains there.
- ii. In addition, implementers should pursue strategic coordination in FDI management. Given the negative FDI-EP correlation in this sample contrasting with Aluko et al. (2023) practitioners should embed environmental and pro-poor conditionalities in energy-sector FDI contracts and pair them with targeted subsidies so that infrastructure-led FDI does not raise tariffs for low-income households (Swart & Noiye, 2024).
- iii. Finally, implementing agencies and entities must engage in targeted financial-literacy and consumer-protection campaigns. Because institutions and FI operate jointly in West Africa but are substitutes elsewhere, regulators should design literacy campaigns that reflect whether the binding constraint is institutions or access itself.

Recommendations for Future Research

Future work should examine the role of IQ in the FI-ecological footprint nexus in SSA, test thresholds of institutional quality at which IQ transitions from complement to substitute of FI (as the regional evidence here suggests), and incorporate household-survey micro-data to validate the macro-regional inferences drawn so far by Koomson and Danquah (2021), Said and Acheampong (2023), Dogan et al. (2021), and this study.

Appendix

Table 8 GMM regression results for direct relationships-robust analysis

Variables	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
	ATF	ATE	UATE	RATE	RE	Energy
L.ATF	0.92494*** (0.02893)					
L.ATE		0.94456*** (0.13090)				
L.UATE			0.94791*** (0.19196)			
L.RATE				0.64806*** (0.12632)		
L.RE					0.72500* (0.38622)	
L.Energy						0.90591*** (0.04645)
SFI	0.03046** (0.01445)	-0.11290 (0.07849)	-0.03013 (0.03399)	-0.19351 (0.13073)	-0.01907 (0.05857)	0.02354 (0.02209)
IQ	0.05120 (0.05185)	-0.04213 (0.05607)	0.04694 (0.04548)	-0.02115 (0.07372)	-0.14514 (0.22130)	-0.02312 (0.02596)
Unem- ployment	0.00360 (0.00304)	0.00100 (0.00228)	-0.00312 (0.00336)	-0.00003 (0.00452)	-0.01041 (0.01800)	0.00343* (0.00179)
GDPPC	0.29835*** (0.10787)	-0.08581 (0.06186)	-0.28613* (0.14611)	0.05425 (0.16178)	0.01236 (0.03233)	-0.01378 (0.02747)
FDI	-0.00017 (0.00122)	-0.00064 (0.00134)	0.00092 (0.00133)	-0.02228*** (0.00708)	0.00115 (0.00195)	0.00071 (0.00084)
Inflation	0.00128 (0.00313)	0.03907** (0.01816)	-0.00538 (0.00727)	0.09113*** (0.03463)	-0.00368 (0.01341)	0.01422* (0.00788)
Urbanisa- tion	0.01108 (0.00747)	0.00190 (0.00274)	-0.00665 (0.00867)	0.00068 (0.00303)	-0.00312 (0.00437)	-0.00066 (0.00062)
TO	0.08163*** (0.02639)	-0.02696 (0.06554)	0.00820 (0.04197)	-0.02846 (0.09714)	0.03643 (0.09984)	-0.00612 (0.01624)
Population	-0.22159 (0.21006)	-0.01872* (0.01069)	0.46902** (0.22713)	-0.00029 (0.02456)	-0.02951 (0.05148)	0.01298** (0.00593)
Covid-19	-0.00595 (0.00948)	0.00243 (0.02293)	0.02275 (0.01783)	0.02010 (0.14251)	-0.02650 (0.04191)	-0.02239** (0.01115)
Constant	1.14598 (2.63828)	1.27926** (0.60535)	-5.03081 (3.09472)	1.10494 (1.39447)	1.68678 (2.53583)	0.00586 (0.23774)
Wald	14564.22***	477630.64***	11506.43***	47039.26***	744709.84***	334930.10***
Control for time effect	Yes	Yes	Yes	Yes	Yes	Yes
p-value of AR(1)	0.047	0.013	0.023	0.021	0.181	0.001

Table 8 (continued)

Variables	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
	ATF	ATE	UATE	RATE	RE	Energy
<i>p</i> -value of AR(2)	0.670	0.160	0.104	0.258	0.358	0.710
<i>p</i> -value of Sargan	0.615	0.700	0.679	0.985	0.190	0.862
<i>p</i> -value of Hansen	0.633	0.693	0.683	0.991	0.903	0.909
Instrument count	20	20	20	21	23	21
Observations	207	207	207	207	207	207
Number of countries	23	23	23	23	23	23

This table presents the dynamic panel estimation results based on the two-step system GMM. ATF is access to clean fuel and technology for cooking; ATE is access to electricity; UATE is urban population access to electricity; RATE is rural population access to electricity; RE is renewable energy usage; Energy is energy intensity; SFI denotes the supply-side financial inclusion (i.e., availability of infrastructure); FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDPPC is GDP per capita; and TO is trade openness. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 9 GMM regression results for direct relationships-robust analysis

Variables	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20
	ATF	ATE	UATE	RATE	RE	Energy
L.ATF	0.95147*** (0.02602)					
L.ATE		0.96096*** (0.13264)				
L.UATE			0.97456*** (0.31556)			
L.RATE				0.65658** (0.25928)		
L.RE					1.04477*** (0.09746)	
L.Energy						0.89266*** (0.04890)
DFI	0.04833* (0.02787)	0.17421* (0.10112)	-0.02343 (0.02947)	0.33638 (0.28991)	-0.02333 (0.01695)	-0.00952 (0.03020)
IQ	0.05130* (0.02870)	0.01885 (0.03334)	0.06318 (0.04163)	0.08465 (0.06249)	0.01701 (0.04672)	-0.04191** (0.02090)
Unemployment	-0.00103 (0.00194)	-0.00599 (0.00519)	-0.00323 (0.00453)	-0.01366 (0.01358)	0.00465 (0.00485)	0.00435** (0.00187)

Table 9 (continued)

Variables	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20
	ATF	ATE	UATE	RATE	RE	Energy
GDPPC	0.09446* (0.05080)	0.08067 (0.10049)	-0.21570 (0.14039)	0.36602 (0.30245)	-0.03033 (0.02150)	-0.03895* (0.02144)
FDI	-0.00113 (0.00092)	-0.00765* (0.00427)	0.00103 (0.00140)	-0.03532** (0.01604)	0.00124 (0.00101)	0.00143 (0.00116)
Inflation	-0.00058 (0.00299)	0.01033 (0.00899)	-0.00828 (0.00803)	0.04121* (0.02356)	0.00833* (0.00504)	0.02087*** (0.00538)
Urbanisation	0.00053 (0.00525)	-0.00276 (0.00186)	-0.00305 (0.00728)	-0.00763* (0.00401)	0.00101 (0.00144)	-0.00004 (0.00053)
TO	0.05958** (0.02427)	0.12821 (0.12302)	0.02041 (0.04059)	0.26415 (0.30903)	-0.05857 (0.04186)	-0.01357 (0.03113)
Population	0.13749 (0.12570)	0.07378 (0.04719)	0.40045** (0.20162)	0.17511 (0.13453)	-0.00687 (0.01018)	0.00628 (0.01635)
Covid-19	0.01649 (0.02175)	-0.01658 (0.02795)	-0.01736 (0.06767)	0.30904 (0.25133)	0.00493 (0.01237)	-0.02156** (0.01089)
Constant	-2.90408 (1.86569)	-1.81172 (1.30757)	-4.64532 (3.50025)	-4.95787 (4.04406)	0.15446 (0.45999)	0.33834 (0.36596)
Wald	77371.74***	281380.74***	14225.77***	25141.40***	8.32e+06***	388031.70***
Control for time effect	Yes	Yes	Yes	Yes	Yes	Yes
<i>p</i> -value of AR(1)	0.029	0.045	0.038	0.076	0.015	0.001
<i>p</i> -value of AR(2)	0.642	0.168	0.110	0.322	0.182	0.626
<i>p</i> -value of Sargan	0.636	0.782	0.576	0.818	0.259	0.343
<i>p</i> -value of Hansen	0.843	0.821	0.521	0.794	0.294	0.484
Instrument count	22	21	20	20	20	21
Observations	207	207	207	207	207	207
Number of countries	23	23	23	23	23	23

This table presents the dynamic panel estimation results based on the two-step system GMM. ATF is access to clean fuel and technology for cooking; ATE is access to electricity; UATE is urban population access to electricity; RATE is rural population access to electricity; RE is renewable energy usage; Energy is energy intensity; DFI is demand-side financial inclusion (i.e., consumption/usage of financial services); FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDPPC is GDP per capita; and TO is trade openness. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 10 GMM regression results for the moderating effect-robust analysis

Variables	Model 21	Model 22	Model 23	Model 24	Model 25	Model 26
	EPI	EPI	EPI	EPI	EPI	EPI
L.EPI	0.89350*** (0.14164)	0.90891*** (0.08023)	0.94400*** (0.14543)	0.94140*** (0.09589)	0.93215*** (0.09180)	0.92975*** (0.09635)
SFI	0.00640** (0.00283)	0.00314 (0.00369)	0.00488 (0.00324)	0.00629** (0.00276)	0.00263 (0.00378)	0.00310 (0.00208)
Rule of law	0.00366 (0.01418)					
Regulatory quality		0.01955 (0.01662)				
Government effectiveness			-0.00155 (0.01220)			
Political stability				-0.00402 (0.00673)		
Control of corruption					0.00920 (0.01162)	
Voice and accountability						0.00761 (0.01050)
SFI × Rule of law	0.00185 (0.00395)					
SFI × Regulatory quality		-0.00266 (0.00477)				
SFI × Government Effectiveness			0.00010 (0.00336)			
SFI × Political stability				0.00257 (0.00189)		
SFI × Control of corruption					-0.00222 (0.00437)	
SFI × Voice and accountability						-0.00255 (0.00315)
Unemployment	0.00044 (0.00065)	0.00023 (0.00059)	0.00004 (0.00060)	0.00014 (0.00054)	0.00022 (0.00056)	0.00024 (0.00061)
GDPPC	0.06004**	0.02603	0.03732	0.03757**	0.03430**	0.03707**

Table 10 (continued)

Variables	Model 21	Model 22	Model 23	Model 24	Model 25	Model 26
	EPI	EPI	EPI	EPI	EPI	EPI
FDI	(0.02757) - 0.00077***	(0.01704) -0.00067***	(0.02590) -0.00056***	(0.01646) -0.00066***	(0.01732) -0.00060***	(0.01713) -0.00057***
Inflation	(0.00019) -0.00062 (0.00075)	(0.00015) -0.00199 (0.00151)	(0.00014) -0.00056 (0.00075)	(0.00015) -0.00027 (0.00108)	(0.00013) -0.00078 (0.00094)	(0.00015) -0.00089 (0.00104)
Urbanisation	0.00071 (0.00119)	-0.00048 (0.00130)	-0.00031 (0.00185)	-0.00038 (0.00108)	-0.00056 (0.00131)	-0.00060 (0.00150)
TO	-0.00699 (0.01326)	-0.01143 (0.01401)	-0.01041 (0.01497)	-0.01459 (0.01260)	-0.01153 (0.01330)	-0.01145 (0.01266)
Population	-0.20168** (0.08377)	-0.04235 (0.04097)	-0.06102 (0.05064)	-0.05960* (0.03350)	-0.05927 (0.03847)	-0.06194* (0.03746)
Covid-19	0.03816** (0.01595)	0.00218 (0.00204)	0.02111*** (0.00515)	0.00174 (0.00227)	0.02156*** (0.00536)	0.02209*** (0.00635)
Constant	2.83922** (1.25274)	0.55379 (0.60075)	0.73965 (0.82259)	0.73919 (0.49358)	0.75195 (0.57107)	0.77473 (0.53384)
Wald	5368.34***	52176.65***	58491.51***	30152.31***	102240.33***	111884.71***
Control for time effects	Yes	Yes	Yes	Yes	Yes	Yes
<i>p</i> -value of AR(1)	0.001	0.000	0.000	0.000	0.000	0.000
<i>p</i> -value of AR(2)	0.466	0.420	0.407	0.418	0.391	0.405
<i>p</i> -value of Sargan	0.522	0.873	0.782	0.942	0.935	0.939
<i>p</i> -value of Hansen	0.744	0.725	0.648	0.890	0.891	0.895
Instrument count	23	22	21	21	21	21
Observations	207	207	207	207	207	207
Number of countries	23	23	23	23	23	23

This table presents the dynamic panel estimation results based on the two-step system GMM. EPI is energy poverty index; SFI denotes the supply-side financial inclusion (i.e., availability of infrastructure); FDI is foreign direct investment; GDP per capita; and TO is trade openness. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 11 GMM regression results for the moderating effect-robust analysis

Variables	Model 27	Model 28	Model 29	Model 30	Model 31	Model 32
	EPI	EPI	EPI	EPI	EPI	EPI
L.EPI	0.91419*** (0.08915)	0.89180*** (0.07637)	0.95806*** (0.08660)	0.95312*** (0.06927)	0.94587*** (0.07326)	0.91022*** (0.08924)
DFI	0.00532*** (0.00240)	0.00414** (0.00163)	0.00657*** (0.00247)	0.00592*** (0.00200)	0.00452** (0.00223)	0.00547*** (0.00189)
Rule of law	0.00837 (0.01310)					
Regulatory quality		0.03067 (0.02136)				
Government effectiveness			0.00035 (0.01074)			
Political stability				0.00131 (0.00638)		
Control of corruption					0.00959 (0.01165)	
Voice and accountability						0.00488 (0.00973)
DFI × Rule of law	-0.00099 (0.00414)					
DFI × Regulatory quality		-0.00435 (0.00431)				
DFI × Government Effectiveness			0.00064 (0.00412)			
DFI × Political stability				0.00035 (0.00251)		
DFI × Control of corruption					-0.00242 (0.00376)	
DFI × Voice and accountability						-0.00179

Table 11 (continued)

Variables	Model 27	Model 28	Model 29	Model 30	Model 31	Model 32
	EPI	EPI	EPI	EPI	EPI	EPI
Unemployment	0.00003 (0.00056)	0.00030 (0.00063)	-0.00005 (0.00055)	0.00006 (0.00060)	0.00004 (0.00054)	(0.00259) 0.00009 (0.00054)
GDPPC	0.02092 (0.01623)	-0.00148 (0.02564)	0.01904 (0.01719)	0.02226 (0.01605)	0.01826 (0.01525)	0.02355 (0.01864)
FDI	-0.00067*** (0.00015)	-0.00076*** (0.00016)	-0.00063*** (0.00013)	-0.00066*** (0.00015)	-0.00064*** (0.00012)	-0.00064*** (0.00014)
Inflation	-0.00035 (0.00107)	-0.00199 (0.00174)	-0.00017 (0.00098)	0.00009 (0.00111)	-0.00043 (0.00101)	-0.00029 (0.00086)
Urbanisation	-0.00063 (0.00149)	-0.00088 (0.00139)	-0.00035 (0.00141)	-0.00045 (0.00125)	-0.00097 (0.00154)	-0.00109 (0.00139)
TO	-0.00959 (0.01302)	-0.00682 (0.01619)	-0.00834 (0.01149)	-0.01255 (0.01369)	-0.01071 (0.01404)	-0.01268 (0.01331)
Population	-0.05608 (0.04205)	-0.01570 (0.03572)	-0.05847 (0.04358)	-0.05135 (0.03968)	-0.04903 (0.04350)	-0.05156 (0.04468)
Covid-19	0.02197*** (0.00697)	0.02018*** (0.00550)	0.02106*** (0.00596)	0.02033*** (0.00725)	0.00166 (0.00248)	0.02333*** (0.00716)
Constant	0.79907 (0.62707)	0.31719 (0.48280)	0.82735 (0.64730)	0.69786 (0.61268)	0.73154 (0.64612)	0.72177 (0.64682)
Wald	194090.95***	49306.01***	604671.29***	162158.71***	108800.57***	404819.13***
Control for time effect	Yes	Yes	Yes	Yes	Yes	Yes
<i>p</i> -value of AR(1)	0.000	0.001	0.000	0.000	0.000	0.000
<i>p</i> -value of AR(2)	0.370	0.401	0.374	0.372	0.369	0.376
<i>p</i> -value of Sargan	0.892	0.809	0.736	0.864	0.854	0.899
<i>p</i> -value of Hansen	0.754	0.663	0.603	0.685	0.659	0.794
Instrument count	21	22	21	21	21	21

Table 11 (continued)

Variables	Model 27	Model 28	Model 29	Model 30	Model 31	Model 32
	EPI	EPI	EPI	EPI	EPI	EPI
Observations	207	207	207	207	207	207
Number of countries	23	23	23	23	23	23

This table presents the dynamic panel estimation results based on the two-step system GMM. EPI is energy poverty index; DFI denotes the demand-side financial inclusion (i.e., availability of infrastructure); FDI is foreign direct investment; GDPPC is GDP per capita; and TO is trade openness. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 12 Driscoll-Kraay regression results for direct relationships -heterogeneity analysis

Variables	Model 33	Model 34	Model 35	Model 36	Model 37	Model 38
	West Africa	East Africa	South Africa	West Africa	East Africa	South Africa
L.EPI	0.22768* (0.11298)	0.20049 (0.22486)	0.67714*** (0.06320)	0.22568* (0.11646)	0.13781 (0.20258)	0.67091*** (0.05529)
SFI	-0.00086 (0.00138)	0.05104*** (0.01496)	0.02214*** (0.00565)			
DFI				-0.00328 (0.00304)	0.01956** (0.00798)	0.00544*** (0.00134)
IQ	-0.05484*** (0.00941)	-0.00848 (0.03034)	-0.02279 (0.01788)	-0.05219*** (0.01010)	0.04389 (0.04333)	0.00484 (0.01630)
Unemployment	0.00062 (0.00058)	0.02133*** (0.00608)	-0.00283** (0.00118)	0.00064 (0.00053)	0.01240** (0.00500)	-0.00251 (0.00141)
GDPPC	0.05698** (0.02413)	-0.20715 (0.20842)	0.10706*** (0.01805)	0.05865** (0.02133)	-0.09554 (0.24932)	0.04357 (0.02529)
FDI	-0.00067** (0.00021)	-0.00109 (0.00073)	-0.00041 (0.00116)	-0.00063** (0.00019)	-0.00040 (0.00108)	0.00030 (0.00109)
Inflation	0.21251*** (0.05029)	-0.09965 (0.05925)	-0.00392** (0.00159)	0.20820*** (0.04509)	0.00902 (0.12823)	-0.00033 (0.00178)
Urbanisation	-0.00389** (0.00142)	-0.03381* (0.01578)	-0.00057 (0.00275)	-0.00332** (0.00120)	-0.01460 (0.01607)	-0.00027 (0.00337)
TO	-0.00659 (0.00708)	0.00592 (0.02595)	0.00352 (0.02156)	-0.00718 (0.00743)	-0.00644 (0.01917)	0.02459 (0.02315)
Population	-0.52459*** (0.10509)	0.87912*** (0.24814)	0.05266 (0.11675)	-0.48534*** (0.07877)	0.75557** (0.26143)	0.12779 (0.10977)
Covid-19	-0.01115*** (0.00250)	0.02298* (0.01016)	-1.56259 (1.88849)	-0.00999*** (0.00216)	0.01679* (0.00861)	-2.23923 (1.87519)
F-Statistics	196.23***	303.30***	420.51***	235.04***	6285.16***	4227.21***
Control for time effect	yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.5401	0.9494	0.7617	0.5423	0.9305	0.7225
Observations	99	36	63	99	36	63
Number of Countries	11	4	7	11	4	7

This table presents the dynamic panel estimation results based on the Driscoll-Kraay regression. EPI is energy poverty index; SFI denotes the supply-side financial inclusion (i.e., availability of infrastructure); DFI is demand-side financial inclusion (i.e., consumption/usage of financial services); FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDPPC is GDP per capita; TO is trade openness. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 13 Driscoll-Kraay regression results for moderating relationships -heterogeneity analysis

Variables	Model 39	Model 40	Model 41	Model 42	Model 43	Model 44
	West Africa	East Africa	South Africa	West Africa	East Africa	South Africa
L.EPI	0.18540 (0.11587)	0.23107 (0.13574)	0.70185*** (0.08278)	0.24901** (0.09634)	0.11522 (0.15807)	0.56721*** (0.05146)
SFI	0.00760 (0.00469)	0.06145** (0.02459)	0.01051*** (0.00309)			
DFI				0.00161 (0.00476)	-0.00440 (0.00885)	-0.00678** (0.00211)
IQ	-0.09589*** (0.01627)	-0.08043 (0.18035)	0.02819 (0.03107)	0.07557*** (0.01534)	-0.08149* (0.03645)	0.11321*** (0.02862)
SFI x IQ	0.01159* (0.00556)	0.02644 (0.06367)	-0.02850*** (0.00577)			
DFI x IQ				0.00945 (0.00571)	-0.08359** (0.03096)	-0.02579*** (0.00263)
Unemployment	-0.00031 (0.00100)	0.02618 (0.01488)	-0.00242* (0.00108)	-0.00003 (0.00063)	0.01207 (0.00834)	-0.00337** (0.00102)
GDPPC	0.05525 (0.03103)	-0.28360 (0.22028)	0.03874 (0.03637)	0.06180** (0.02059)	-0.10667 (0.24769)	0.03996*** (0.01156)
FDI	-0.00073*** (0.00021)	-0.00104 (0.00074)	0.00005 (0.00129)	-0.00062** (0.00019)	-0.00034 (0.00064)	-0.00025 (0.00128)
Inflation	0.22503*** (0.05561)	-0.11610 (0.11767)	-0.00904*** (0.00154)	0.22326*** (0.04714)	-0.15068 (0.11412)	-0.00276** (0.00114)
Urbanisation	-0.00282 (0.00225)	-0.04215 (0.02634)	-0.00139 (0.00250)	-0.00234 (0.00130)	-0.03337 (0.02665)	-0.00654* (0.00297)
TO	-0.00984 (0.00854)	0.01182 (0.03780)	0.01905 (0.01976)	-0.01009 (0.00779)	-0.03940 (0.03195)	-0.01191 (0.02435)
Population	-0.53908** (0.17134)	1.01891* (0.50385)	0.04199 (0.11755)	-0.48556*** (0.07816)	1.30058* (0.60402)	0.16481 (0.11168)
Covid-19	-0.01036* (0.00465)	0.02736 (0.01560)	-0.00299 (0.00293)	-0.01036* (0.00465)	0.02736 (0.01560)	-0.00299 (0.00293)
F-Statistics	438.60***	129.64***	576.46***	420.79***	4420.86***	482.08***
Control for time effect	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.5566	0.9508	0.8108	0.6444	0.8984	0.7970
Observations	99	36	63	99	36	63
Number of countries	11	4	7	11	4	7

This table presents the dynamic panel estimation results based on the Driscoll-Kraay regression. EPI is energy poverty index; SFI denotes the supply-side financial inclusion (i.e., availability of infrastructure); DFI is demand-side financial inclusion (i.e., consumption/usage of financial services); FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDPPC is GDP per capita; TO is trade openness; “SFI × IQ” is the interaction between supply-side financial inclusion and institutional quality; and “DFI × IQ” is the interaction between demand-side financial inclusion and institutional quality. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 14 Method of moments quantile regression results for direct relationships -heterogeneity analysis

Variables	location	scale	qtile_1	qtile_2	qtile_3	qtile_4	qtile_5	qtile_6	qtile_7	qtile_8	qtile_9
L.EPI	0.62376*** (0.09727)	-0.07419*** (0.02297)	0.73789*** (0.09101)	0.69741*** (0.09442)	0.67829*** (0.09327)	0.65521*** (0.09290)	0.62586*** (0.09560)	0.59400*** (0.10177)	0.57147*** (0.10588)	0.54427*** (0.11159)	0.50510*** (0.11047)
SFI	0.00485** (0.00216)	-0.00019 (0.00149)	0.00515 (0.00407)	0.00504 (0.00332)	0.00499* (0.00300)	0.00493* (0.00262)	0.00486** (0.00220)	0.00477*** (0.00183)	0.00472*** (0.00167)	0.00465*** (0.00163)	0.00454** (0.00188)
IQ	0.00717 (0.00511)	-0.00397 (0.00653)	0.01328 (0.01273)	0.01111 (0.00965)	0.01009 (0.00822)	0.00885 (0.00668)	0.00728 (0.00532)	0.00557 (0.00485)	0.00437 (0.00548)	0.00291 (0.00719)	0.00082 (0.00972)
Unemployment	0.00031 (0.00059)	0.00027 (0.00029)	-0.00011 (0.00089)	0.00004 (0.00079)	0.00011 (0.00073)	0.00019 (0.00067)	0.00030 (0.00059)	0.00042 (0.00052)	0.00050 (0.00050)	0.00060 (0.00049)	0.00074 (0.00049)
GDP	0.03732** (0.01875)	-0.00364 (0.00695)	0.04292 (0.02813)	0.04094* (0.02452)	0.04000* (0.02295)	0.03886* (0.02102)	0.03742** (0.01877)	0.03586** (0.01652)	0.03475** (0.01535)	0.03342** (0.01384)	0.03150*** (0.01211)
FDI	-0.00057*** (0.00022)	-0.00002 (0.00112)	-0.00055* (0.00032)	-0.00056** (0.00027)	-0.00056** (0.00026)	-0.00057*** (0.00024)	-0.00057*** (0.00022)	-0.00058*** (0.00021)	-0.00059*** (0.00021)	-0.00059*** (0.00022)	-0.00060** (0.00025)
Inflation	0.00006 (0.00090)	-0.00138* (0.00082)	0.00218 (0.00181)	0.00143 (0.00129)	0.00107 (0.00114)	0.00065 (0.00096)	0.00010 (0.00091)	-0.00049 (0.00089)	-0.00091 (0.00097)	-0.00142 (0.00108)	-0.00215 (0.00144)
Urbanisation	-0.00108 (0.00122)	-0.00072 (0.00060)	0.00003 (0.00108)	-0.00037 (0.00108)	-0.00055 (0.00108)	-0.00078 (0.00109)	-0.00106 (0.00120)	-0.00137 (0.00134)	-0.00159 (0.00151)	-0.00186 (0.00168)	-0.00224 (0.00187)
TO	-0.00662 (0.00987)	0.00184 (0.00591)	-0.00946 (0.01794)	-0.00845 (0.01494)	-0.00798 (0.01357)	-0.00740 (0.01198)	-0.00667 (0.00995)	-0.00588 (0.00803)	-0.00532 (0.00706)	-0.00465 (0.00624)	-0.00367 (0.00636)
Population	-0.05374 (0.05155)	0.01365 (0.02146)	-0.07474 (0.07078)	-0.06729 (0.06289)	-0.06377 (0.05919)	-0.05953 (0.05526)	-0.05413 (0.05121)	-0.04827 (0.04896)	-0.04412 (0.04863)	-0.03912 (0.04868)	-0.03191 (0.05023)
Covid-19	-0.00049 (0.00496)	-0.00071 (0.00391)	0.00059 (0.00628)	0.00021 (0.00509)	0.00003 (0.00474)	-0.00019 (0.00463)	-0.00047 (0.00492)	-0.00078 (0.00574)	-0.00099 (0.00649)	-0.00125 (0.00755)	-0.00163 (0.00930)
Constant	0.70336 (0.71380)	-0.15183 (0.34212)	0.93694 (0.99168)	0.85410 (0.87112)	0.81495 (0.81696)	0.76773 (0.76257)	0.70767 (0.71029)	0.64245 (0.69057)	0.59634 (0.69590)	0.54068 (0.71681)	0.46052 (0.77653)
Control for time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	207	207	207	207	207	207	207	207	207	207	207

This table presents the dynamic panel estimation results based on the MMQR regression. EPI is energy poverty index; SFI denotes the supply-side financial inclusion (i.e., availability of infrastructure); FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDP is GDP per capita; TO is trade openness. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 15 Method of moments quantile regression results for direct relationships -heterogeneity analysis

VARIABLES	location	scale	qtile_1	qtile_2	qtile_3	qtile_4	qtile_5	qtile_6	qtile_7	qtile_8	qtile_9
L.EPI	0.62025*** (0.09002)	-0.07667*** (0.02206)	0.73538*** (0.09598)	0.70298*** (0.09720)	0.67402*** (0.09317)	0.65309*** (0.09014)	0.62143*** (0.08833)	0.59101*** (0.08992)	0.55890*** (0.09397)	0.53475*** (0.09113)	0.49681*** (0.09185)
DFI	0.00657** (0.00325)	0.00276 (0.00208)	0.00237 (0.00567)	0.00354 (0.00492)	0.00458 (0.00437)	0.00533 (0.00388)	0.00647** (0.00322)	0.00757*** (0.00284)	0.00872*** (0.00267)	0.00950*** (0.00268)	0.01096*** (0.00284)
IQ	0.00466 (0.00522)	-0.00327 (0.00564)	0.00956 (0.01094)	0.00818 (0.00905)	0.00695 (0.00739)	0.00606 (0.00630)	0.00471 (0.00540)	0.00342 (0.00505)	0.00205 (0.00587)	0.00102 (0.00697)	-0.00060 (0.00921)
Unemployment	0.00023 (0.00052)	0.00035 (0.00029)	-0.00030 (0.00085)	-0.00015 (0.00076)	-0.00002 (0.00068)	0.00008 (0.00061)	0.00022 (0.00052)	0.00036 (0.00046)	0.00051 (0.00041)	0.00062 (0.00040)	0.00080* (0.00042)
GDP	0.02575 (0.02457)	-0.00021 (0.00788)	0.02607 (0.03380)	0.02598 (0.03102)	0.02590 (0.02864)	0.02584 (0.02699)	0.02576 (0.02464)	0.02567 (0.02260)	0.02558 (0.02075)	0.02552 (0.01961)	0.02541 (0.01836)
FDI	-0.00063*** (0.00020)	-0.00007 (0.00009)	-0.00053* (0.00029)	-0.00056** (0.00026)	-0.00058** (0.00023)	-0.00060*** (0.00022)	-0.00063*** (0.00020)	-0.00065*** (0.00019)	-0.00068*** (0.00018)	-0.00070*** (0.00018)	-0.00074*** (0.00019)
Inflation	0.00051 (0.00110)	-0.00100* (0.00058)	0.00202 (0.00164)	0.00160 (0.00137)	0.00122 (0.00120)	0.00094 (0.00116)	0.00053 (0.00110)	0.00013 (0.00108)	-0.00029 (0.00109)	-0.00061 (0.00111)	-0.00110 (0.00124)
Urbanisation	-0.00150 (0.00116)	-0.00043 (0.00056)	-0.00086 (0.00136)	-0.00104 (0.00127)	-0.00120 (0.00121)	-0.00131 (0.00115)	-0.00149 (0.00114)	-0.00166 (0.00120)	-0.00184 (0.00129)	-0.00197 (0.00137)	-0.00218 (0.00155)
TO	-0.00805 (0.00993)	0.00143 (0.00509)	-0.01019 (0.01658)	-0.00959 (0.01461)	-0.00905 (0.01294)	-0.00866 (0.01175)	-0.00807 (0.00992)	-0.00750 (0.00847)	-0.00691 (0.00717)	-0.00646 (0.00655)	-0.00575 (0.00631)
Population	-0.04664 (0.06401)	0.00917 (0.02275)	-0.06041 (0.07065)	-0.05654 (0.06711)	-0.05307 (0.06502)	-0.05057 (0.06394)	-0.04678 (0.06341)	-0.04314 (0.06506)	-0.03930 (0.06775)	-0.03641 (0.07059)	-0.03187 (0.07672)
Covid-19	-0.00117 (0.86566)	-0.00073 (0.34912)	-0.00007 (0.94120)	-0.00038 (0.88987)	-0.00065 (0.86296)	-0.00085 (0.85572)	-0.00115 (0.86482)	-0.00144 (0.89567)	-0.00175 (0.94928)	-0.00198 (1.00185)	-0.00234 (1.10172)
Constant	0.68692 (0.00001)	-0.12276 (0.00001)	0.87124*** (0.01582)	0.81936*** (0.00857)	0.77299*** (0.01274)	0.73948*** (0.01086)	0.68881*** (0.00957)	0.64010*** (0.00669)	0.58869*** (0.00713)	0.55002*** (0.00697)	0.48928*** (0.01576)
Control for time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	207	207	207	207	207	207	207	207	207	207	207

This table presents the dynamic panel estimation results based on the MMQR regression. EPI is energy poverty index; DFI denotes the demand-side financial inclusion; FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDPPC is GDP per capita; TO is trade openness. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 16 Method of moments quantile regression results for moderating relationships -heterogeneity analysis

Variables	location	scale	qtile_1	qtile_2	qtile_3	qtile_4	qtile_5	qtile_6	qtile_7	qtile_8	qtile_9
L.EPI	0.62385*** (0.07514)	-0.07518** (0.03609)	0.75047*** (0.08550)	0.70397*** (0.07585)	0.67870*** (0.07299)	0.65611*** (0.07318)	0.62606*** (0.07559)	0.59497*** (0.08112)	0.57124*** (0.08688)	0.54094*** (0.09656)	0.48565*** (0.10997)
SFI	0.00417 (0.00586)	0.00593* (0.00321)	-0.00582 (0.01081)	-0.00215 (0.00868)	-0.00016 (0.00765)	0.00163 (0.00689)	0.00400 (0.00594)	0.00645 (0.00513)	0.00832* (0.00465)	0.01071** (0.00443)	0.01508*** (0.00466)
IQ	0.00951 (0.01716)	-0.02511*** (0.00937)	0.05180* (0.02868)	0.03627 (0.02272)	0.02783 (0.02027)	0.02029 (0.01894)	0.01025 (0.01747)	-0.00013 (0.01682)	-0.00806 (0.01679)	-0.01818 (0.01769)	-0.03664* (0.02041)
SFI x IQ	-0.00090 (0.00635)	0.00805** (0.00351)	-0.01446 (0.01227)	-0.00948 (0.00964)	-0.00678 (0.00843)	-0.00436 (0.00758)	-0.00114 (0.00646)	0.00219 (0.00550)	0.00473 (0.00488)	0.00798* (0.00450)	0.01390*** (0.00451)
Unemployment	0.00033 (0.00063)	0.00009 (0.00041)	0.00017 (0.00096)	0.00023 (0.00079)	0.00026 (0.00071)	0.00029 (0.00067)	0.00032 (0.00064)	0.00036 (0.00065)	0.00039 (0.00068)	0.00043 (0.00076)	0.00050 (0.00096)
GDPPI	0.03686* (0.01889)	0.00030 (0.01186)	0.03636 (0.02582)	0.03654* (0.02146)	0.03664* (0.01984)	0.03673* (0.01898)	0.03685* (0.01886)	0.03697* (0.01995)	0.03707* (0.02151)	0.03719 (0.02421)	0.03741 (0.03047)
FDI	-0.00057** (0.00025)	-0.00006 (0.00013)	-0.00046 (0.00030)	-0.00050* (0.00026)	-0.00052** (0.00025)	-0.00054** (0.00025)	-0.00057** (0.00025)	-0.00059*** (0.00027)	-0.00061** (0.00028)	-0.00064** (0.00031)	-0.00069* (0.00037)
Inflation	-0.00004 (0.00122)	-0.00046 (0.00069)	0.00073 (0.00177)	0.00044 (0.00149)	0.00029 (0.00137)	0.00015 (0.00129)	-0.00003 (0.00122)	-0.00022 (0.00122)	-0.00036 (0.00126)	-0.00054 (0.00136)	-0.00088 (0.00166)
Urbanisation	-0.00111 (0.00137)	-0.00050 (0.00073)	-0.00026 (0.00173)	-0.00057 (0.00150)	-0.00074 (0.00141)	-0.00089 (0.00137)	-0.00109 (0.00137)	-0.00130 (0.00144)	-0.00146 (0.00153)	-0.00166 (0.00167)	-0.00203 (0.00201)
TO	-0.00636 (0.00905)	-0.00057 (0.00528)	-0.00540 (0.01463)	-0.00575 (0.01215)	-0.00594 (0.01096)	-0.00611 (0.01004)	-0.00634 (0.00911)	-0.00658 (0.00859)	-0.00676 (0.00856)	-0.00699 (0.00898)	-0.00740 (0.01083)
Population	-0.05335 (0.04089)	0.01034 (0.02471)	-0.07077 (0.06302)	-0.06438 (0.05225)	-0.06090 (0.04745)	-0.05779 (0.04401)	-0.05366 (0.04108)	-0.04938 (0.04047)	-0.04611 (0.04178)	-0.04195 (0.04534)	-0.03434 (0.05592)
Covid-19	-0.00052 (0.00838)	-0.00044 (0.00499)	0.00023 (0.01011)	-0.00005 (0.00860)	-0.00020 (0.00817)	-0.00033 (0.00806)	-0.00051 (0.00834)	-0.00069 (0.00909)	-0.00083 (0.00992)	-0.00101 (0.01121)	-0.00134 (0.01402)
Constant	0.70283 (0.62022)	-0.14927 (0.36703)	0.95424 (0.92544)	0.86191 (0.77246)	0.81175 (0.70585)	0.76690 (0.65927)	0.70722 (0.62257)	0.64550 (0.62021)	0.59838 (0.64399)	0.53822 (0.70119)	0.42844 (0.86192)

Table 16 (continued)

Variables	location	scale	qtile_1	qtile_2	qtile_3	qtile_4	qtile_5	qtile_6	qtile_7	qtile_8	qtile_9
Control for time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	207	207	207	207	207	207	207	207	207	207	207

This table presents the dynamic panel estimation results based on the MMQR regression. EPI is energy poverty index; SFI denotes the supply-side financial inclusion (i.e., availability of infrastructure); DFI is demand-side financial inclusion (i.e., consumption/usage of financial services); FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDPPC is GDP per capita; TO is trade openness; "SFI $\times$ IQ" is the interaction between supply-side financial inclusion and institutional quality. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 17 Method of Moments Quantile Regression Results for Moderating Relationships -Heterogeneity Analysis

Variables	location	scale	qtile_1	qtile_2	qtile_3	qtile_4	qtile_5	qtile_6	qtile_7	qtile_8	qtile_9
L.EPI	0.60845*** (0.08784)	-0.07351*** (0.01863)	0.72695*** (0.09704)	0.68777*** (0.09451)	0.65734*** (0.09028)	0.63793*** (0.08767)	0.60651*** (0.08671)	0.58101*** (0.09025)	0.54949*** (0.09162)	0.52576*** (0.08978)	0.48977*** (0.08984)
SFI	0.00333 (0.00558)	0.00487* (0.00264)	-0.00453 (0.00909)	-0.00193 (0.00777)	0.00009 (0.00676)	0.00137 (0.00625)	0.00346 (0.00530)	0.00515 (0.00498)	0.00724 (0.00464)	0.00881** (0.00449)	0.01120** (0.00443)
IQ	0.01942 (0.01321)	-0.01295** (0.00614)	0.04030*** (0.01031)	0.03340*** (0.01038)	0.02804*** (0.01083)	0.02462** (0.01166)	0.01908 (0.01294)	0.01459 (0.01456)	0.00904 (0.01679)	0.00486 (0.01835)	-0.00148 (0.02123)
DFI x IQ	-0.00585 (0.00496)	0.00386** (0.00164)	-0.01207* (0.00622)	-0.01002* (0.00554)	-0.00842* (0.00510)	-0.00740 (0.00504)	-0.00575 (0.00480)	-0.00441 (0.00486)	-0.00276 (0.00495)	-0.00151 (0.00504)	0.00038 (0.00540)
Unemployment	0.00032 (0.00051)	0.00028 (0.00034)	-0.00013 (0.00096)	0.00002 (0.00080)	0.00013 (0.00068)	0.00021 (0.00062)	0.00033 (0.00051)	0.00042 (0.00044)	0.00054 (0.00040)	0.00063 (0.00040)	0.00077* (0.00046)
GDPPI	0.02300 (0.02182)	-0.00087 (0.00780)	0.02441 (0.03147)	0.02394 (0.02803)	0.02358 (0.02546)	0.02335 (0.02392)	0.02298 (0.02163)	0.02268 (0.02004)	0.02230 (0.01843)	0.02202 (0.01755)	0.02159 (0.01685)
FDI	- 0.00060***	-0.00007 (0.00020)	-0.00048 (0.00032)	-0.00052* (0.00028)	-0.00055** (0.00024)	-0.00057** (0.00023)	- (0.00020)	- (0.00019)	- (0.00019)	- (0.00019)	- (0.00021)
Inflation	0.00022 (0.00104)	-0.00076 (0.00057)	0.00144 (0.00150)	0.00103 (0.00126)	0.00072 (0.00110)	0.00052 (0.00105)	0.00020 (0.00103)	-0.00007 (0.00105)	-0.00039 (0.00109)	-0.00063 (0.00116)	-0.00100 (0.00133)
Urbanisation	- 0.00217***	-0.00020 (0.00073)	-0.00184 (0.00153)	-0.00195 (0.00120)	-0.00203** (0.00097)	-0.00209** (0.00084)	- (0.00072)	- (0.00074)	- (0.00087)	-0.00239** (0.00103)	-0.00249* (0.00133)
TO	-0.00812 (0.00994)	0.00066 (0.00450)	-0.00918 (0.01593)	-0.00883 (0.01379)	-0.00856 (0.01222)	-0.00838 (0.01129)	-0.00810 (0.00981)	-0.00787 (0.00881)	-0.00759 (0.00782)	-0.00738 (0.00734)	-0.00705 (0.00713)
Population	-0.03618 (0.05530)	0.00313 (0.02522)	-0.04122 (0.06646)	-0.03956 (0.06001)	-0.03826 (0.05665)	-0.03744 (0.05547)	-0.03610 (0.05513)	-0.03501 (0.05663)	-0.03367 (0.06020)	-0.03266 (0.06399)	-0.03113 (0.07122)
Covid-19	-0.00106 (0.78053)	-0.00105 (0.37536)	0.00062 (0.92455)	0.00007 (0.83218)	-0.00037 (0.78851)	-0.00064 (0.77579)	-0.00109 (0.78179)	-0.00145 (0.81041)	-0.00190 (0.87174)	-0.00224 (0.93370)	-0.00275 (1.04764)
Constant	0.57663 (0.00001)	-0.03514 (0.00001)	0.63329*** (0.00418)	0.61455*** (0.00330)	0.60000*** (0.00278)	0.59073*** (0.00275)	0.57571*** (0.00304)	0.56351*** (0.00310)	0.54844*** (0.00191)	0.53710*** (0.00220)	0.51989*** (0.00441)

Table 17 (continued)

Variables	location	scale	qtile_1	qtile_2	qtile_3	qtile_4	qtile_5	qtile_6	qtile_7	qtile_8	qtile_9
Control for time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	207	207	207	207	207	207	207	207	207	207	207

This table presents the dynamic panel estimation results based on the MMQR regression. EPI is energy poverty index; SFI denotes the supply-side financial inclusion (i.e., availability of infrastructure); DFI is demand-side financial inclusion (i.e., consumption/usage of financial services); FDI is foreign direct investment; IQ is institutional quality or country-level governance; GDPPC is GDP per capita; TO is trade openness; “DFI $\times$ IQ” is the interaction between demand-side financial inclusion and institutional quality. The numbers in parentheses are the standard errors of the estimates. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Author Contributions Barbara Deladem Mensah contributed to the study conception and design, wrote the introduction section of the manuscript, data collection and analysis.

Abdallah Abdul-Mumuni and Simplice A. Asongu contributed to the study conception, supervised the entire work, commented on previous versions of the manuscript, read and approved the final manuscript. Thomas Elorm Tagbator reviewed related literature on financial inclusion, institutional quality and energy poverty and collected data for analysis.

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Data Availability Data sources are outlined above in Tables 1 and 2 and will be made available on demand.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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