

Determinants of Clean Energy Access in Sub-Saharan Africa: Governance, Finance, and Digital Connectivity

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Abstract

Access to clean energy remains a critical challenge in Sub-Saharan Africa (SSA), where over 80% of households rely on solid biomass, exacerbating health risks and environmental degradation. Despite global commitments under SDG 7 and rising renewable energy shares, household-level adoption of clean energy technologies remains limited. This study examines the determinants of clean energy access across 12 SSA countries from 2000 to 2023 using panel data and advanced econometric techniques, with fixed effects (FE) as the primary specification, complemented by random effects (RE), generalised estimating equations (GEE), and mixed-effects Poisson models for robustness. The results show that institutional quality has the strongest positive effect on clean energy access ($\beta = 18.169$, $p < 0.001$), followed by financial inclusion ($\beta = 0.363$, $p < 0.001$) and energy infrastructure ($\beta = 0.162$, $p < 0.05$). At the same time, digital connectivity also contributes positively ($\beta = 0.058$, $p < 0.05$). Interaction analysis further shows that strong governance significantly amplifies the impact of financial inclusion on clean energy adoption. These findings highlight the importance of integrated development strategies that combine institutional reform, inclusive finance, and digital innovation to accelerate energy transitions. Policy implications include revising renewable energy metrics to distinguish modern energy sources from traditional biomass and prioritising governance-finance synergies to accelerate equitable energy transitions in SSA.

Keywords: Clean Energy, Sub-Saharan Africa, Governance, Financial Inclusion, Digital Connectivity, Panel Data, Econometrics; SDG.

Introduction

Access to affordable, reliable, and clean energy remains one of the most pressing developmental challenges in Sub-Saharan Africa (SSA). Despite global progress towards Sustainable Development Goal 7 (SDG 7), which seeks universal access to modern energy services, the region continues to experience severe disparities (World Bank Group, 2024). As of 2023, over 80% of households in many SSA countries still rely on solid biomass, wood, charcoal, and dung for cooking, exposing populations to harmful indoor air pollution and perpetuating poverty and environmental degradation (IEA, 2022; IEA et al., 2023; World Bank, 2024).

Paradoxically, renewable energy shares in total final energy consumption appear high across SSA, yet this metric is inflated by traditional biomass rather than modern and efficient technologies (Pachauri & Rao, 2013; Van der Kroon et al., 2013; IRENA, 2024). Consequently, reported progress in renewable energy expansion often fails to translate into meaningful improvements in household-level access to clean cooking solutions. This measurement bias obscures the persistence of energy poverty and complicates policy evaluation, as evidenced by the continued widespread reliance on traditional biomass despite reported renewable energy gains.

Existing literature identifies economic growth, urbanisation, and energy infrastructure as key drivers of energy access (Kaygusuz, 2012; Hsiao, 2014; IEA, 2025; World Bank, 2024). However, these factors alone have proven insufficient to achieve widespread access to clean energy. Structural constraints, including weak governance systems, limited financial inclusion, and underdeveloped digital infrastructure, continue to hinder progress across many SSA economies. Recent studies increasingly emphasise the role of digital connectivity in facilitating energy transitions through mobile money systems, pay-as-you-go (PAYGo) financing, and digital platforms that reduce transaction costs and improve affordability (Aker & Mbiti, 2010; Beck et al., 2018; Perros et al., 2024). At the same time, improvements in digital connectivity, particularly mobile penetration and mobile money platforms, have expanded access to clean energy services by lowering transaction costs and enhancing service delivery (GSMA, 2024; Nwaiwu, 2021). Governance effectiveness plays a complementary role by shaping the regulatory environment, strengthening policy implementation, and mobilising investment in clean energy infrastructure. Strong institutions enhance the effectiveness of financial inclusion and digital innovation by ensuring transparency, accountability and policy consistency, thereby creating an enabling environment for sustainable energy transition.

Building on the foregoing discussion, this study aims to examine the determinants of clean energy access in Sub-Saharan Africa with a particular focus on the roles of institutional quality, financial inclusion, and digital connectivity. Specifically, the study seeks to: (i) assess the impact of governance quality on clean energy access, (ii) evaluate the role of financial inclusion in facilitating household adoption of clean energy technologies, (iii) examine the contribution of digital connectivity to energy transitions, and (iv) analyse the interaction effects between governance and financial inclusion in shaping clean energy outcomes. Despite the roles of institutional quality, financial inclusion, and digital connectivity in shaping energy transitions, empirical evidence on their combined and interactive effects on clean energy adoption in SSA remains limited. Most existing studies examine these determinants in isolation or rely on aggregate renewable energy indicators, which often mask household-level realities and measurement biases. Furthermore, the continued reliance on aggregate renewable energy indicators, largely driven by traditional biomass, obscures the true extent of energy poverty and limits a comprehensive understanding of clean energy access dynamics at the household level. This study

addresses these gaps by analysing panel data for 12 SSA countries from 2000 to 2023 using robust econometric techniques, including fixed-effects, random-effects, and Poisson-based models. The study contributes to the literature in three key ways. First, it highlights how aggregate renewable energy indicators mask household-level energy poverty due to the dominance of traditional biomass. Second, it demonstrates the synergistic role of governance and financial inclusion in accelerating clean energy adoption. Third, it incorporates digital connectivity and human capital into a multidimensional framework, providing a more comprehensive understanding of the determinants of clean energy access in SSA.

The remainder of this paper is organised as follows: Section 2 presents the relevant literature review; Section 3 describes the data and methodology; Section 4 presents the empirical results and discussion; Section 5 concludes with policy implications and suggestions for future research.

Literature Review

Background

Energy access remains a critical determinant of socioeconomic development in Sub-Saharan Africa (SSA). Despite global initiatives such as SDG 7, which targets universal access to modern energy services by 2030, the region continues to experience severe energy poverty. Over 80% of households rely on solid biomass, wood, charcoal, and dung for cooking, contributing to indoor air pollution, health risks, and environmental degradation (IEA, 2022; Kaygusuz, 2012). While renewable energy shares appear high in SSA, this figure is largely driven by traditional biomass rather than modern technologies, creating a misleading impression of progress (Van der Kroon et al., 2013). This paradox underscores the need for nuanced metrics that distinguish modern renewables from traditional sources. Regional electricity interconnection networks, such as those shown in Figure 19, illustrate the role of power pools in shaping energy infrastructure across SSA.

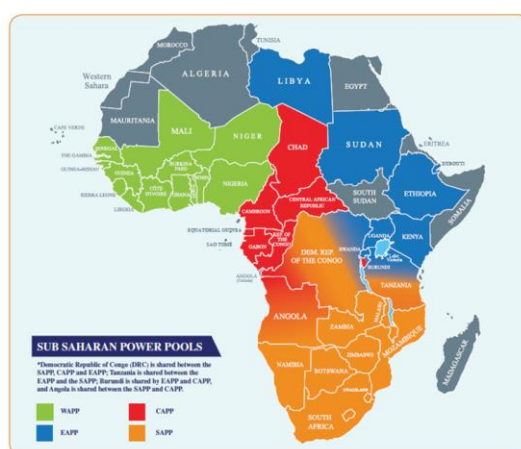


Figure 19: Sub-Saharan African Power Pools

Source: Liedemann (2019)

Energy Access and the Clean Cooking Challenge in SSA

Access to modern energy services remains highly uneven across Sub-Saharan Africa (SSA), where a large share of households continues to rely on solid biomass, principally wood, charcoal, and dung, for cooking. This reliance entrenches energy poverty, exacerbates health risks due to indoor air pollution, and contributes to environmental degradation (IEA et al., 2023; IEA, 2025). Despite global momentum around SDG 7, the region is off track. The number of people without access to clean energy in SSA has continued to rise, reaching nearly 960 million in 2023 (IEA, 2025; IEA, 2024). Although global progress since 2010 has reduced the number of people without access to modern energy by nearly 600 million, this improvement has not extended to Sub-Saharan Africa, where affordability challenges, infrastructure gaps, and weak policy implementation remain major constraints (IEA et al., 2023; IEA, 2025). The scale of the human capital and health burden is substantial. Household air pollution from traditional fuels contributes to millions of premature deaths globally, with particularly severe impacts among women and children in SSA (IEA, 2025; World Bank, 2024). Figure 20 highlights the continued reliance on biomass-based cooking methods, reinforcing the measurement bias discussed above.



Figure 20. Traditional cooking practices in SSA

Source: University of Liverpool, CLEAN-Air Africa (2024)

The Biomass Paradox and Measurement Issues

A core paradox in the SSA energy transition is the conflation of “renewable energy” with traditional biomass in official statistics. High shares of renewable energy in total final energy consumption often reflect traditional biomass rather than modern clean energy technologies, thereby masking energy poverty at the household level (Van der Kroon, Brouwer, & Van Beukering, 2013). Recent guidance urges explicit differentiation between

modern renewables (e.g., renewable-based electricity for e-cooking, biogas, bioethanol, efficient modern solid biomass) and traditional biomass in both policy design and empirical measurement (IRENA, 2024; IEA et al., 2023). Africa holds nearly 60% of the world's most favourable solar resources, yet its installed photovoltaic (PV) capacity and household-level access remain far below this vast potential (WMO, 2024; Dechamps, 2023). If metrics are not refined, policy evaluations may overstate progress and fail to adequately address the clean cooking gap (IRENA, 2024; IEA, 2025).

Financial Inclusion and Clean Energy Adoption

Access to finance is a critical enabler of clean energy adoption because it influences affordability, investment, and risk-sharing. Mechanisms such as microfinance, domestic credit, and pay-as-you-go (PAYGo) models help overcome high upfront costs by allowing incremental payments and leveraging digital platforms (Beck et al., 2018; Perros et al., 2024). These innovations have expanded access to modern fuels and appliances, particularly among low-income households. Recent evidence shows that PAYGo LPG systems improve access for urban poor communities, but face challenges related to unit economics and underinvestment, highlighting the need for supportive policies and blended financing solutions (Perros et al., 2024). However, macroeconomic instability, such as inflation, foreign exchange volatility, and supply chain disruptions, can erode affordability and slow scale-up (IEA et al., 2023).

The literature also points to complex interactions between credit and governance. While many studies find that strong institutions complement financial development to boost clean energy adoption, others report contexts where governance constraints limit the effectiveness of credit expansion (Acheampong, 2023; Shahbaz et al., 2022). This underscores the heterogeneity of outcomes across Sub-Saharan Africa and the importance of integrated strategies that combine financial innovation with institutional reform (Kwakwa, 2024).

Governance and Institutional Quality

Institutional quality, policy credibility, regulatory strength, and administrative effectiveness consistently emerge as a cornerstone of successful clean energy transitions (North, 1990; Acemoglu & Robinson, 2012). In SSA, panel evidence shows that governance quality influences environmental and energy outcomes through mechanisms such as tax effort, regulatory implementation, and investment mobilisation (Enusah et al., 2024; Bercu et al., 2019). Recent dynamic panel studies reveal threshold effects where, beyond certain ecological footprints, stronger institutions and governance work together to reduce environmental impacts, highlighting the non-linear benefits of governance reforms (Acheampong et al., 2021; Kwakwa, 2023). Complementary studies find that institutional quality and financial development jointly increase access to clean fuels, with heterogeneous effects across the distribution (Kwakwa, 2023; Shahbaz et al., 2022). These findings

reinforce the view that effective institutions magnify the returns to finance and infrastructure in clean cooking transitions, making governance reform a critical component of strategies aimed at achieving SDG 7 in Sub-Saharan Africa.

Digital Connectivity and Technology Diffusion

Digital connectivity, through mobile penetration, data networks, and fintech, has become a key enabler of clean energy adoption in Sub-Saharan Africa. Digitally enabled PAYGo platforms for solar and LPG, remote monitoring, and mobile-based tariff payments reduce transaction costs, smooth cash flow, and extend services to low-income consumers (Aker & Mbiti, 2010; Nwaiwu, 2021). The GSMA Mobile Economy Sub-Saharan Africa 2024 report highlights rapid growth in mobile money and 4G connectivity, which strengthens the viability of PAYGo business models and significantly expands the potential customer base (GSMA, 2024; Beck et al., 2018). At the same time, recent studies emphasise that PAYGo's benefits must be balanced with fair data practices, consumer protection, and inclusive business models, pointing to the importance of regulation and standards (Perros et al., 2024). Digital dividends, however, depend on complementary infrastructure and governance capacity. Interoperability, contract enforcement, and consumer safeguards amplify the impact of digital connectivity on clean cooking adoption, ensuring that technology diffusion translates into equitable and sustainable energy access (GSMA, 2024; Nwaiwu, 2021).

Human Capital and Urbanisation

Human capital, measured through educational attainment and skill development, plays a critical role in clean energy adoption by shaping awareness, maintenance capabilities, and behavioural change (Acheampong et al., 2021; Khan et al., 2020). Evidence from the World Bank links reliance on traditional solid fuels to adverse human capital outcomes, including higher growth impairment risk in the Sahel even after controlling for socioeconomic status, reinforcing the urgency of clean cooking interventions (World Bank, 2024; IEA, 2025). Urbanisation can facilitate access to clean energy through population density, market depth, and proximity to infrastructure. However, transitions in urban areas are highly heterogeneous. For example, Das et al. (2024) find that willingness to pay for LPG in Nairobi is nearly twice that in Dar es Salaam, while charcoal lock-in among low-income households implies the need for differentiated policy tools. More broadly, recent urban analyses argue that clean cooking is pivotal to sustainable city planning and emissions reduction, urging integration into municipal policy, procurement, and financing frameworks (CCA & ICLEI Africa, 2023).

Research Gap

Despite the growing literature on energy access and renewable energy in SSA, few studies jointly examine governance effectiveness, financial inclusion, digital connectivity, human

capital, and infrastructure as interacting determinants of household adoption of clean energy. Most existing analyses emphasise single factors or rely on aggregate renewable energy shares, which are often inflated by traditional biomass and therefore obscure household-level realities and measurement bias (Irena, 2024; IEA et al., 2023). Recent policy and financing momentum, including the USD 2.2 billion commitments announced at the 2024 Summit on Clean Cooking, highlights an opportunity to evaluate synergies across institutions, finance, and digital ecosystems (IEA, 2024; Forbes, 2024). This study addresses these gaps by adopting a multidimensional, interaction-aware framework and applying robust panel econometric techniques across 12 SSA countries (2000-2023) to assess the direct and conditional effects of institutional, financial, digital, and socio-economic variables on clean energy access.

Based on these identified gaps, the following hypotheses are developed to guide the empirical analysis.

H1: Institutional quality positively affects clean energy access.

H2: Financial inclusion positively influences clean energy access.

H3: Digital connectivity positively affects clean energy access.

H4: Energy infrastructure positively influences clean energy access.

H5: Urbanisation influences clean energy access.

H6: Institutional quality strengthens the effect of financial inclusion on clean energy access.

H7: The interaction between energy infrastructure and urbanisation influences clean energy access.

Conceptual Framework

Figure 21: Conceptual framework presents the conceptual framework underpinning this study.

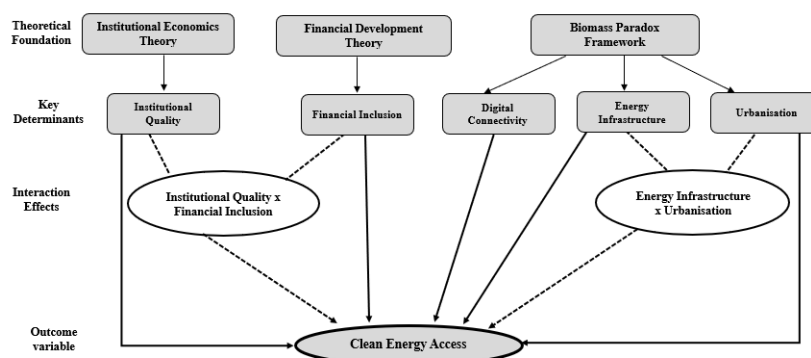


Figure 21: Conceptual framework

The framework integrates institutional economics theory, financial development theory, and the biomass paradox framework to explain the determinants of clean energy access in Sub-Saharan Africa. It identifies institutional quality, financial inclusion, digital connectivity, energy infrastructure, and urbanisation as key determinants of clean energy

access. The framework further incorporates interaction effects between institutional quality and financial inclusion, and between energy infrastructure and urbanisation. These interactions recognise that the effectiveness of financial systems may depend on the quality of institutions, while the benefits of energy infrastructure may vary according to the level of urbanisation. Overall, the conceptual framework provides a structured representation of the relationships examined in this study and establishes the link between the theoretical foundations, research hypotheses, and empirical model.

Methodology

Study Design, Sample, and Period

This study employs a balanced panel dataset covering 12 Sub-Saharan African (SSA) countries, Botswana, Ethiopia, The Gambia, Ghana, Kenya, Lesotho, Liberia, Mauritius, Nigeria, Sierra Leone, South Africa, and Uganda, over the period 2000-2023 (288 country-year observations). The unit of analysis is the country-year. The selection of countries was based primarily on the availability of balanced and consistent data for clean energy access and the key explanatory variables across the study period. While the sample does not cover all SSA countries, it captures substantial variation in institutional quality, financial inclusion, infrastructure development, and digital connectivity across the region. In addition, the inclusion of relatively more economically developed countries such as South Africa, Botswana, and Mauritius broadens the range of institutional, financial, infrastructural, and energy access conditions represented in the sample. This variation enables the analysis to capture heterogeneous energy transition pathways and governance conditions across Sub-Saharan Africa, an important consideration in cross-country panel analysis (Baltagi, 2008; Hsiao, 2014).

Data Sources and Variables

Secondary data were drawn from the World Bank's World Development Indicators (WDI) and Worldwide Governance Indicators (WGI). The dependent variable is clean energy access, which refers to the percentage of the population using clean fuels and technologies for cooking (SDG 7 indicator). Key explanatory variables are institutional quality, financial inclusion, digital connectivity, and energy infrastructure. The control variables are economic performance, price stability, urbanisation, human capital, human development, and land use structure. Continuous variables were log-transformed where appropriate to address skewness and facilitate the interpretation of elasticities. Variable definition and summary statistics are detailed in Table 1. Descriptive statistics (Table 1) reveal substantial variation across countries and years: Clean energy access averages 24.26% (0-99%), while energy transition averages 56.61%, largely driven by traditional biomass. Digital connectivity shows rapid growth, and institutional quality and financial inclusion exhibit wide disparities, underscoring heterogeneity across SSA economies.

Table 1: Descriptive Statistics

Variables	Definition	Obs	Mean	Std. Dev.	Min	Max
Clean energy access	Access to clean fuels and technologies for cooking (% of population)	288	24.259	32.312	0	99
Energy transition	Renewable energy consumption (% of total final energy consumption)	288	56.614	32.159	0	95.6
Digital connectivity	Mobile cellular subscriptions (per 100 people)	288	62.269	50.478	0	179.027
Economic performance	GDP per capita growth (annual %)	288	2.171	4.58	-30.699	23.941
Price stability	Inflation, GDP deflator (annual %)	288	10.372	14.861	-6.682	168.053
Urbanisation level	Urban population (% of total population)	288	41.423	15.995	14.74	72.867
Energy infrastructure	Access to electricity (% of population)	288	45.637	28.993	0	100
Human development	Life expectancy at birth, total (years)	288	59.172	7.094	43.182	74.515
Human capital	Educational attainment, at least completed upper secondary, population 25+, total (%) (cumulative)	288	8.406	15.234	0	51.117
Land use structure	Agricultural land (% of land area)	288	54.406	18.026	14.193	80.888
Institutional quality	Government Effectiveness: Estimate	288	-0.428	0.653	-1.792	1.15
Financial inclusion	Domestic credit to private sector (% of GDP)	288	27.446	34.607	0	142.422

Source: Author's estimation

Baseline Empirical Specification

We estimate a two-way panel model with country and year effects to capture unobserved heterogeneity and global shocks:

$$y_{it} = \alpha + \beta'X_{it} + \gamma_1(EL_{it} \times UL_{it}) + \gamma_2(IQ_{it} \times FI_{it}) + \mu_i + \lambda_t + \varepsilon_{it}.$$

where y_{it} is clean energy access, X_{it} is the vector of covariates, and interaction terms test conditional effects of “energy infrastructure–urbanisation level” and “institutional quality–financial inclusion”. For log-specifications, y_{it} remains in levels (share, %), while regressors enter as $\ln(\cdot)$ were noted to stabilise variance and ease elasticity interpretation.

Model choice: Model selection follows standard panel data procedures. Both Fixed Effects (FE) and Random Effects (RE) models were estimated, and the Hausman test was used to determine the preferred specification. The results of the Hausman test indicated that the FE was appropriate, as key explanatory variables, particularly institutional quality and financial inclusion, were likely correlated with unobserved country-specific effects (Baltagi, 2008; Hsiao, 2014). Although FE is theoretically preferred due to correlation with country-specific effects, RE results are reported for comparison and to retain time-invariant variables. FE remains the primary specification, while RE serves as a robustness check. This dual specification is consistent with econometric standards; thus, when unobserved effects correlate with regressors, FE is the consistent choice, as indicated by the Hausman test, while RE models allow inclusion of time-invariant covariates that FE would omit (Hausman, 1978; Williams, 2018). Further details on robustness checks and alternative estimators are provided in Section 36.

Addressing Panel Data Challenges

Panel data analysis often faces issues such as cross-sectional dependence, slope heterogeneity, non-stationarity, and long-run relationships. To ensure robust estimation, we applied a series of diagnostic tests and corrective measures as outlined below.

Cross-Sectional Dependence

We first tested for cross-sectional dependence using Pesaran’s CD test (Pesaran, 2006). The test statistic is given by:

$$CSD = \frac{2T}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \sigma_{ij}^t$$

where N is the number of cross-sections, T is the time dimension, and σ_{ij}^t represents the pairwise correlation of residuals. Where dependence was detected, we applied the Common Correlated Effects Mean Group (CCE-MG) estimator to mitigate bias.

Slope Homogeneity

Slope homogeneity was assessed using the Pesaran-Yamagata test (Pesaran & Yamagata, 2008). The test statistics are:

$$\Delta_{SHT} = \frac{\tilde{s}K}{2K}$$

$$\Delta_{ASHT} = \frac{N(T - K - 1)(\tilde{s} - K)}{2K(T + 1)}$$

where $\tilde{s}$ denotes the sum of squared deviations, K is the number of regressors, and N, T represent cross-sectional and time dimensions. Significant values indicate heterogeneous slopes across countries.

Panel Unit Root Tests

To check stationarity, we employed second-generation unit root tests: Cross-Sectionally Augmented Dickey-Fuller (CADF) and CIPS (Pesaran, 2007):

$$\text{CADF: } \Delta\chi_{it} = \beta\chi_{it-1} + \delta_i T + \sum_{j=1}^p \gamma_{ij} \Delta\chi_{it-j} + \varepsilon_{it}$$

$$\text{CIPS: } CIPS = \frac{1}{N} \sum_{i=1}^N \phi_i(N, T)$$

These tests account for cross-sectional dependence and provide robust stationarity checks.

Panel Cointegration

Finally, long-run relationships were confirmed using the Westerlund cointegration test (Westerlund, 2007), expressed as:

$$G_r = \frac{1}{N} \sum_{i=1}^N \frac{\eta_i}{SE(\eta_i)}$$

$$G_a = \frac{1}{N} \sum_{i=1}^N T \eta_i \left(1 - \sum_{j=1}^k \eta_{ij} \right)$$

$$P_r = \frac{\eta_i}{SE(\eta_i)}, P_a = T \eta_i$$

where η_i represents the speed of adjustment toward equilibrium. Significant group and panel statistics validate the presence of cointegration among variables.

Robustness and Alternative Estimators

Given that the dependent variable, clean energy access, is expressed as a percentage (bounded between 0 and 100), the analysis complements linear panel models with alternative estimators that better handle non-negative and bounded outcomes. Specifically, the study employs *Generalised Estimating Equations (GEE)* under a Poisson log link and *Poisson Pseudo-Maximum Likelihood (PPML)* estimators, which are widely used for fractional or skewed data due to their robustness to heteroskedasticity and distributional assumptions.

Although Poisson models are traditionally applied to count data, PPML provides consistent estimates for any non-negative dependent variable under correct mean specification and is

robust to various forms of heteroskedasticity (Santos Silva & Tenreiro, 2006). To account for serial correlation within panels, an AR (1) working correlation structure is adopted in the GEE framework (Liang & Zeger, 1986). Additionally, mixed-effects Poisson models with random intercepts are estimated to capture unobserved country-specific heterogeneity under a multiplicative mean function.

The Poisson log link function is specified as:

$$E[y_{it} | X_{it}] = \exp(\alpha + \beta'X_{it} + \gamma_1 \cdot \text{int}_1 + \gamma_2 \cdot \text{int}_2 + \mu_i + \lambda_t)$$

where y_{it} is clean energy access, X_{it} is the vector of covariates, and μ_i and λ_t represent country and year effects, respectively.

For the mixed-effects PPML model, random intercepts are assumed as:

$$u_i \sim N(0, \sigma_u^2)$$

These alternative estimators serve as robustness checks, ensuring that the main findings are not sensitive to model choice or error structure. Results from GEE and mixed-effects Poisson regressions confirm the significance and expected signs of key determinants, such as institutional quality, financial inclusion, and digital connectivity, reinforcing the reliability of the baseline estimates.

Econometric Specification and Estimation Strategy

The empirical analysis begins with a baseline panel model estimated under both fixed-effects (FE) and random-effects (RE) assumptions, with the Hausman test guiding the preferred specification. Robust standard errors clustered at the country level were applied to address heteroskedasticity and serial correlation. Recognising the bounded nature of the dependent variable (percentage of population with clean energy access), the study complements linear models with generalised estimating equations (GEE) under a Poisson log link and mixed-effects Poisson regressions, which allow for random intercepts and provide consistent estimates under heteroskedasticity. Interaction terms were incorporated to capture conditional relationships, specifically between energy infrastructure and urbanisation, and between institutional quality and financial inclusion, with marginal effects and predictive margins computed for interpretation.

Results and Discussion

Results

The analysis confirms that institutional quality, financial inclusion, digital connectivity, and energy infrastructure are the strongest determinants of clean energy access in Sub-Saharan Africa. These relationships remain robust across multiple estimation techniques, including Random Effects (RE), Generalised Estimating Equations (GEE), and Mixed-Effects Poisson regressions.

Correlation Analysis

As shown in Table 2, clean energy access is highly correlated with financial inclusion (0.82), institutional quality (0.79), and energy infrastructure (0.73), while negatively correlated with energy transition (−0.75). This pattern illustrates the “biomass paradox”: high renewable energy shares in SSA often reflect traditional biomass rather than modern clean technologies, masking true progress toward SDG 7 (IEA et al., 2022).

Table 2: Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) clean energy access	1.000											
(2) Energy transition	-0.753	1.000										
(3) Digital connectivity	0.531	-0.606	1.000									
(4) Economic performance	-0.032	0.062	-0.128	1.000								
(5) Price stability	-0.185	0.099	-0.198	-0.008	1.000							
(6) Urbanisation level	0.386	-0.546	0.540	-0.172	-0.039	1.000						
(7) Energy infrastructure	0.726	-0.766	0.682	-0.012	-0.101	0.509	1.000					
(8) Human development	0.541	-0.331	0.304	0.336	-0.384	-0.650	0.782	1.000				
(9) Human capital	0.491	-0.401	0.518	-0.048	-0.087	0.300	0.507	0.609	1.000			
(10) Land use structure	0.164	-0.272	0.220	-0.066	-0.052	0.064	0.255	-0.554	0.109	1.000		
(11) Institutional quality	0.793	-0.685	0.400	0.049	-0.047	0.262	0.659	0.653	0.347	0.139	1.000	
(12) Financial inclusion	0.818	-0.676	0.478	-0.058	-0.193	0.381	0.699	0.372	0.512	0.273	0.660	1.000

Source: Author’s estimation

Regression Results

As shown in

Table 3, the Fixed Effects (FE) estimates indicate that financial inclusion, energy infrastructure, and human capital positively influence clean energy access in Sub-Saharan Africa. Financial inclusion remains particularly important ($\beta = 0.224$, $p < 0.01$), suggesting that access to credit and inclusive financial systems significantly improves household adoption of clean energy technologies. Energy infrastructure also exhibits a positive effect ($\beta = 0.160$, $p < 0.10$), reinforcing the importance of electricity access in supporting clean energy transitions. Human capital demonstrates a positive and weakly significant relationship with clean energy access ($\beta = 0.092$, $p < 0.10$), implying that educational attainment may enhance awareness and adoption of modern energy technologies. Conversely, urbanisation level and human development exhibit negative effects under the FE specification, suggesting that rapid population growth and broader structural pressures may constrain clean energy adoption where infrastructure expansion remains insufficient. The FE results further show that institutional quality and digital connectivity lose statistical significance compared to the Random Effects (RE) estimates. This suggests that part of their influence may reflect cross-country heterogeneity rather than within-country changes over time. In contrast, the RE model reports strong positive and statistically significant effects for institutional quality ($\beta = 18.169$, $p < 0.01$), digital connectivity ($\beta = 0.058$, $p < 0.05$), and financial inclusion ($\beta = 0.363$, $p < 0.01$). These findings reinforce the importance of governance quality, mobile-enabled systems, and financial access in promoting clean energy transitions across SSA economies. While the FE model serves as the primary specification based on the Hausman-test-guided model selection procedure, the RE estimates remain broadly consistent in direction and are retained for robustness comparison. Overall, the results highlight the multidimensional nature of clean energy access, where institutional, financial, infrastructural, and socioeconomic factors interact to shape energy transition outcomes in Sub-Saharan Africa.

Table 3: Regression estimates - Determinants of clean energy Access

Variables	FE	RE
Energy transition	-0.086** (0.042)	-0.185*** (0.047)
Digital connectivity	0.001* (0.025)	0.058** (0.027)
Economic performance	-0.074* (0.130)	-0.150* (0.185)
Price stability	-0.005* (0.043)	-0.145** (0.058)
Urbanisation level	-0.733** (0.360)	-0.113* (0.071)
Energy infrastructure	0.160* (0.085)	0.162** (0.085)

Variables	FE	RE
	(0.087)	(0.067)
Human development	-0.470* (0.273)	-0.731*** (0.213)
Human capital	0.092* (0.048)	0.132* (0.068)
Land use structure	-0.298* (0.237)	-0.267*** (0.063)
Institutional quality	0.048* (2.715)	18.169*** (1.983)
Financial inclusion	0.224*** (0.084)	0.363*** (0.039)
R-squared	0.160	-
F-statistic	4.458	-
Prob > F	0.000	-
AIC	2114.648	-
BIC	2158.603	-
Overall R-squared	-	0.825
Wald Chi-square	-	1296.912
Prob > chiz	-	0.000
Observation	288	288

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, $p < 0.10$.

Source: Author's estimation

Slope Homogeneity Test

From **Table 4**, using the Pesaran & Yamagata (2008) test, the study rejects the null hypothesis of homogeneous slope coefficients across countries. Delta and adjusted statistics ($\Delta = 5.179$, $\Delta_{adj} = 7.442$) are significant at $p = 0.000$. This implies heterogeneous slopes and supports modeling choices that allow parameters to vary across SSA economies, reinforcing the need for robustness and interaction analyses that account for cross-country differences.

Table 4: Pesaran-Yamagata Slope Homogeneity Test (Panel)

Statistic (Test)	Value	p-value	Decision (1-10%)	Interpretation
Δ (Delta)	5.179	0.000	Reject H_0	Slopes are heterogeneous across countries.
Δ_{adj} (Adjusted Delta)	7.442	0.000	Reject H_0	Slopes are heterogeneous across countries.

Δ and Δ_{adj} statistics with p-values

Source: Author's estimation

Panel Cointegration Assessment

The Westerlund-type panel cointegration results reported under the CCEMG framework show statistically significant group and panel statistics, indicating long-run relationships among the core variables. This validates the empirical strategy and justifies the interpretation of both short and long-run effects presented in the subsequent tables. Illustrative short and long-run coefficient patterns (presented in Table 5) show, for example, that digital connectivity is positively associated with clean energy access in the short run, while energy transition retains a negative association in both horizons, consistent with the biomass paradox and the enabling role of digital rails.

Table 5: Panel Cointegration Estimate

Variables	Short-term estimate	Long-term estimate
Energy transition	-0.002** (0.026)	-0.015** (0.049)
Digital connectivity	0.013*** (0.008)	-0.008*** (0.029)
Urbanisation level	-1.506* (1.447)	0.954 (1.728)
Energy infrastructure	0.039** (0.037)	-0.001*** (0.028)
Human development	-0.550* (0.291)	0.550* (0.378)
Human capital	0.004*** (0.004)	-0.010** (0.020)
Land use structure	0.043** (0.143)	0.209* (0.199)
Institutional quality	0.320* (0.484)	1.163* (0.487)
Financial inclusion	0.016*** (0.010)	-0.052** (0.075)
Wald Chi (g)	43.44	
Prob > chi2	0.000	
Observation	288	

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, $p < 0.10$.

Source: Author's estimation

Robustness Tests - GEE and Mixed-Effects GLM:

To address the bounded nature of the dependent variable and heteroskedasticity, the model was re-estimated using GEE (Poisson log link) and Mixed-Effects Poisson GLM. As shown in Table 6, results are consistent with the baseline: institutional quality remains highly significant ($\beta = 1.139$, $p < 0.001$), financial inclusion is positive and significant ($\beta =$

0.004, $p < 0.001$), and energy transition continues to exhibit a negative association ($\beta = -0.013$, $p < 0.001$). The GEE estimates similarly preserve expected signs and significance across key variables, confirming that the main findings are robust to alternative estimators and error structures.

Table 6: Robustness test (Determinant of Clean Energy)

Variables	GEE with Poisson log link	Mixed-Effects GLM Poisson
Energy transition	-0.007*** (0.000)	-0.013*** (0.001)
Digital connectivity	0.001*** (0.000)	0.002*** (0.000)
Economic performance	-0.008*** (0.001)	-0.022*** (0.003)
Price stability	-0.002** (0.000)	-0.017*** (0.002)
Urbanisation level	-0.001* (0.002)	-0.005*** (0.001)
Energy infrastructure	0.020*** (0.001)	0.017*** (0.001)
Human development	-0.025** (0.002)	-0.054*** (0.005)
Human capital	0.003** (0.000)	0.003*** (0.001)
Land use structure	-0.011*** (0.002)	-0.007*** (0.002)
Institutional quality	0.014* (0.024)	1.139*** (0.042)
Financial inclusion	0.006*** (0.000)	0.004*** (0.001)
Chi-square	964.44	6422.197
Akaike crit. (AIC)	-	2342.954
Prob > chi2	0.000	0.000
Observation	288	288
Year fixed effect	Yes	Yes
Country fixed effect	Yes	Yes

*Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, $p < 0.10$.*

Source: Author's estimation

Interaction Effects

As shown in Table 5, the interaction between institutional quality and financial inclusion is strongly positive ($\beta = 0.174$, $p < 0.001$), demonstrating that governance effectiveness magnifies the returns to credit expansion and inclusive finance in enabling household

adoption of clean technologies. The energy infrastructure $\times$ urbanisation interaction is negative but significant ($\beta = -0.005$, $p < 0.10$), suggesting that in highly urbanised contexts, electrification benefits may be attenuated, plausibly because urban expansion outpaces infrastructure delivery.

Table 5: Determinants of Clean Energy with interaction variables

Variables	Coef.
Energy transition	-0.177*** (0.046)
Digital connectivity	0.076*** (0.026)
Economic performance	-0.153 (0.183)
Price stability	-0.136** (0.056)
Urbanisation level	0.125 (0.142)
Energy infrastructure	0.314*** (0.115)
Human development	-0.753*** (0.208)
Human capital	0.143** (0.067)
Land use structure	-0.184*** (0.066)
Institutional quality	15.787*** (2.357)
Financial inclusion	0.334*** (0.043)
Energy infrastructure $\times$ Urbanisation level	-0.005* (0.003)
Financial inclusion $\times$ institutional quality	0.174*** (0.061)
Chi-square	1375.719
Prob > χ^2	0.000
Number of obs	288
Year FE	YES
Country FE	YES

*Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, $p < 0.10$.*

Source: Author's estimation

Predictive Margins

Predictive margins analysis quantifies how clean energy access responds to changes in moderating variables. As shown in Tables 8 and 9, when both urbanisation and electricity access are low (20%), predicted clean energy access is 13.5%. As electricity access rises to 80%, predicted access increases to 32-37%, with further gains as urbanisation improves. For governance-finance synergy, under weak governance (-0.5) and low credit (10% of GDP), predicted clean energy access is 17.3%. Under strong governance (+1.0) with high credit (100% of GDP), predicted access rises sharply to 71.1%, underscoring how institutional capacity and financial depth jointly drive inclusive energy transitions.

Table 6: Predictive Margins of Clean Energy Access by Urbanisation and Electricity Access

Urbanisation (%)	Energy infrastructure (%)	Predicted Clean Energy Access (%)
20	20	13.53
20	50	22.94
20	80	32.36
40	80	34.86
60	80	37.37

Source: Author's estimation

Table 7: Predictive Margins of Clean Energy Access by Institutional Quality and Financial Inclusion

Governance Effectiveness	Credit to Private Sector (% of GDP)	Predicted Clean Energy Access (%)
-0.5	10	17.30
-0.5	100	47.38
0.0	50	38.56
0.5	100	63.16
1.0	100	71.06

Predicted clean energy access (%) under different governance effectiveness and credit-to-GDP scenarios, demonstrating governance-finance synergy.

Source: Author's estimation

Visual Trends

The trends depicted in Figures 4-7 complement the regression evidence. Figure 22 shows persistent disparities and slow progress in clean energy access from 2000 to 2023, consistent with the modest baseline averages and significant cross-country heterogeneity. Figure 23 illustrates that reported renewable energy gains are dominated by traditional biomass, aligning with the negative coefficient for the energy transition variable. Figure 24 shows rapid growth in mobile subscriptions per 100 people, supporting the positive effect of digital connectivity. Figure 25 highlights volatile GDP per capita growth across countries, explaining why growth alone is insufficient without supportive institutions and finance.

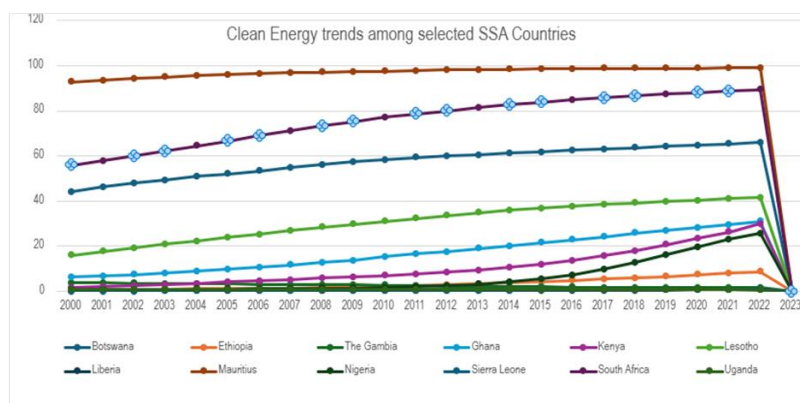


Figure 22: Clean Energy Access Trends in Sub-Saharan Africa (2000–2023).

Source: Author's computation using World Bank WDI (2000-2023).

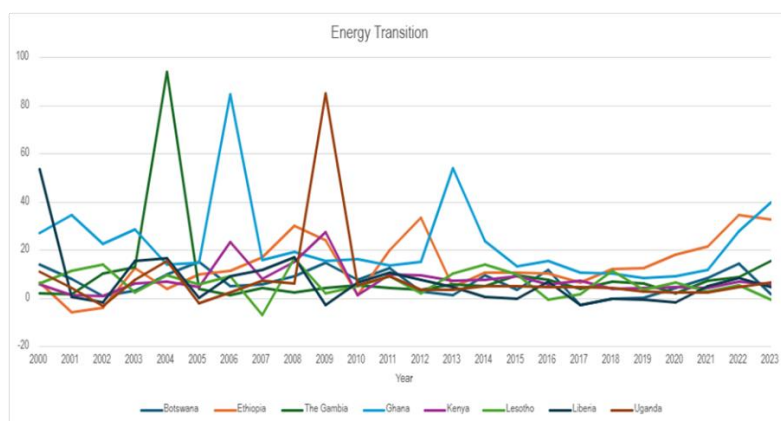


Figure 23: Energy Transition Trend in Sub-Saharan Africa (2000-2023).

Source: Author's own computation using WDI 2000-2023

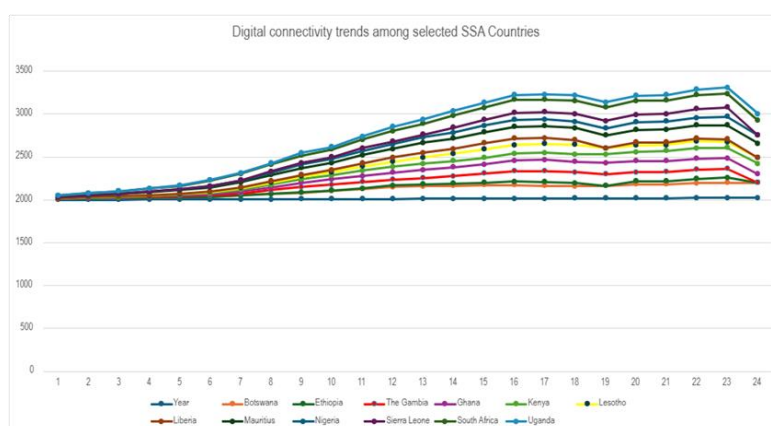


Figure 24: Digital Connectivity Trends in Sub-Saharan Africa (2000-2023).

Source: Author's own computation using WDI 2000-2023

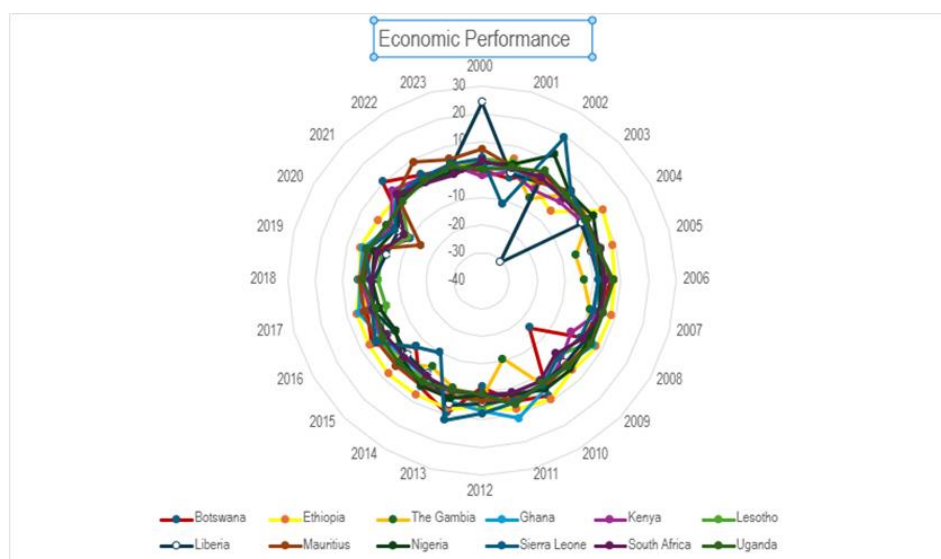


Figure 25: Economic Performance Trend in Sub-Saharan Africa (2000-2023).

Source: Author's own computation using WDI 2000-2023

Discussions

The results demonstrate that institutional quality, financial inclusion, digital connectivity, and energy infrastructure are the most significant determinants of clean energy access in Sub-Saharan Africa. The strong effect of governance aligns with prior research emphasising institutional quality as a cornerstone of successful energy transitions (Acheampong, 2023; North, 1990). Robust governance frameworks enhance policy credibility, regulatory enforcement, and investment mobilisation, which are critical for scaling clean energy solutions. This finding is consistent with the International Energy Agency's earlier observations on governance and regulatory reform in energy markets (IEA, 2010), which continue to be emphasised in more recent IEA reports on energy transitions and investment conditions in Africa (IEA, 2024; IEA, 2025).

Financial inclusion also plays a pivotal role, supporting evidence that microfinance and pay-as-you-go (PAYGo) models reduce affordability barriers and enable incremental payments for clean energy access technologies (Beck et al., 2018; Perros et al., 2024). The positive interaction between governance and financial inclusion suggests that institutional capacity amplifies the benefits of credit expansion, creating synergies that accelerate household adoption of modern energy solutions.

Digital connectivity's significance reflects the growing role of mobile-based payment systems and PAYGo platforms in expanding access to clean energy. GSMA (2024) highlights that mobile network expansion in SSA is strongly tied to energy access, with operators investing in renewable-powered infrastructure to maintain service in off-grid areas. This supports the empirical evidence that mobile penetration facilitates clean energy adoption by lowering transaction costs and enabling flexible payment options.

The negative coefficient for human development, measured by life expectancy, is also noteworthy and requires careful interpretation. Although improvements in life expectancy are generally associated with socioeconomic progress, this relationship may reflect broader structural pressures within many SSA economies. Higher life expectancy may coincide with rapid population growth and rising household energy demand that outpaces improvements in clean energy infrastructure and affordability. Consequently, households may continue to rely on traditional biomass despite improvements in health outcomes. This finding, therefore, likely reflects infrastructural and economic constraints rather than a direct adverse effect of human development on clean energy access.

An important finding emerging from the panel cointegration estimates is the reversal of coefficient signs between the short-run and long-run effects for digital connectivity, energy infrastructure, and financial inclusion. In the short run, these variables positively influence clean energy access by improving affordability, expanding infrastructure availability, and facilitating mobile-enabled payment mechanisms such as pay-as-you-go (PAYGo) systems. However, the negative long-run coefficients suggest that the benefits of digital and financial expansion may not be evenly sustained across Sub-Saharan Africa over time. Structural inequalities limited rural infrastructure penetration, weak institutional coordination, and persistent dependence on traditional biomass may reduce the long-term effectiveness of these factors. In many SSA economies, improvements in digital connectivity and financial systems are often concentrated in urban areas and among higher-income populations, limiting broader inclusion in clean energy transitions. These findings imply that technological and financial innovations alone are insufficient to guarantee sustained clean energy adoption without complementary governance reforms, targeted infrastructure investment, and inclusive policy implementation.

Conversely, the negative coefficient for energy transition confirms the "biomass paradox," where high renewable energy shares in SSA are driven by traditional biomass rather than modern technologies. This finding underscores the need for refined metrics that distinguish modern renewables from traditional sources, as recommended by IRENA (2024) and IEA (2023).

Policy Implications

Expanding renewable energy capacity alone is insufficient to achieve universal clean energy access. Progress depends on integrated strategies that strengthen governance, deepen financial systems, and invest in both physical and digital infrastructure. Inclusive financial mechanisms such as microcredit and PAYGo models, combined with governance reforms, can accelerate adoption and promote equity. Additionally, revising renewable energy indicators to exclude traditional biomass will improve policy targeting and monitoring. Digital infrastructure and mobile payment systems should be prioritised to complement physical electrification efforts, thereby enhancing affordability and accessibility for low-income households.

Conclusion

This study examined the determinants of clean energy access in Sub-Saharan Africa using panel data from 2000 to 2023. The analysis for the study draws on panel data for 12 Sub-Saharan African countries (2000-2023) from World Bank WDI and WGI sources, applying fixed-effects and robustness checks using GEE and mixed-effects Poisson models to ensure reliability. The findings reveal that progress toward SDG 7 depends not only on renewable energy expansion but on a combination of institutional quality, financial inclusion, digital connectivity, and energy infrastructure. While renewable energy shares appear high, they are often inflated by traditional biomass, underscoring the need for refined metrics that distinguish modern technologies. Results are robust across FE, RE, and Poisson-based estimators, reinforcing the reliability of findings.

Policy implications are clear, and the study suggests that expanding clean energy access requires integrated strategies that strengthen governance, deepen financial systems, and invest in both physical and digital infrastructure. Inclusive financial mechanisms such as microcredit and pay-as-you-go models, coupled with governance reforms, can accelerate adoption and ensure equity. Human capital development and awareness programs should complement these efforts to drive behavioural change.

Achieving universal clean energy access in Sub-Saharan Africa is not just a matter of technology, it also requires strong institutions and sustainable financing. And inclusive infrastructure development. Expanding clean energy access is essential for advancing SDG 7 and supporting long-term socioeconomic development across the continent.

Limitations and Future Research

This study is subject to several limitations. First, the analysis relies on national-level aggregate data, which may obscure intra-country disparities and informal energy use patterns. Household-level variations in income, gender roles, and cultural preferences are not captured, limiting the granularity of insights. Second, the econometric approach assumes exogeneity among key explanatory variables, yet governance quality, financial inclusion, and energy access may exhibit endogeneity, potentially biasing estimates. Although robustness checks using alternative estimators mitigate this concern, future research should consider dynamic panel models or instrumental variable techniques. Third, the study does not incorporate geospatial electrification data or micro-level behavioural factors, which are critical for understanding localised adoption dynamics. Finally, while the time frame (2000-2023) provides a long-term perspective, structural breaks such as policy reforms or global shocks may influence results in ways not fully addressed by the models. Future research should integrate household survey microdata and geospatial electrification measures to capture heterogeneity more accurately. Incorporating behavioural insights and cultural factors will help design targeted interventions. Advanced econometric approaches, including dynamic panels and causal inference techniques, can address endogeneity concerns. Additionally, exploring the role of emerging technologies and

climate resilience strategies will provide a more comprehensive understanding of pathways to universal clean energy access in Sub-Saharan Africa.

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