

Energy Efficiency as a Pathway to Expanding Energy Access in Sub-Saharan Africa

Joseph Levodo*, Fuhad Bankole

Department of Engineering and the Built Environment, University of Greater Manchester, UK

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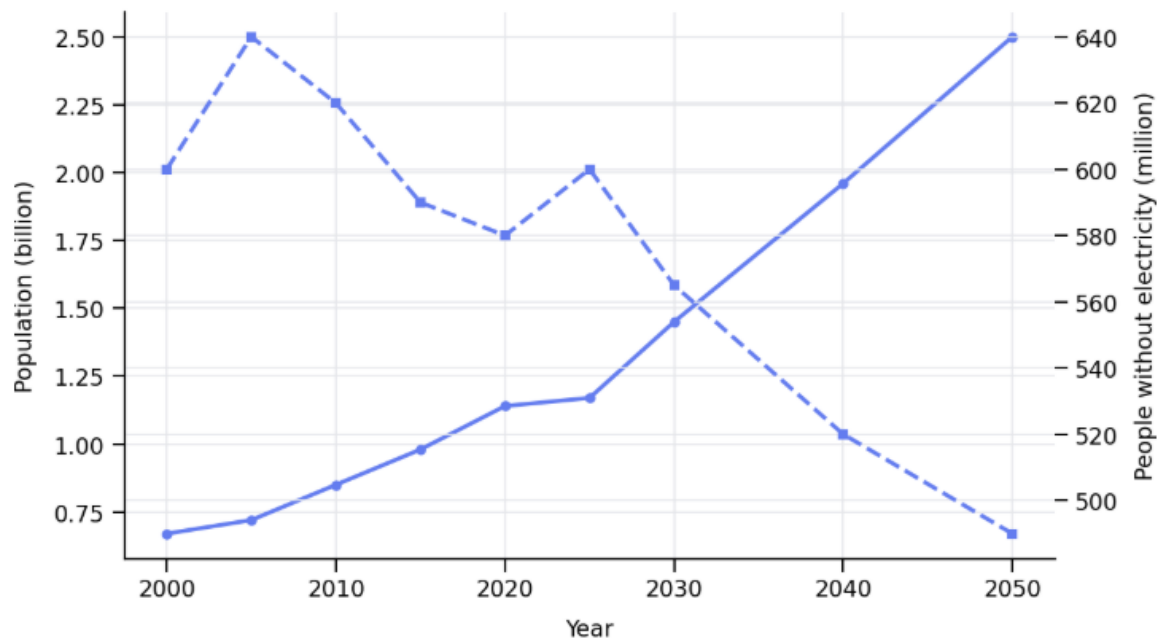
ABSTRACT

Energy efficiency plays a critical yet underutilised role in expanding access to clean, affordable, and reliable energy services in developing regions. In Sub-Saharan Africa, energy policy interventions have historically prioritised supply expansion, often overlooking the significant potential of demand-side energy efficiency measures. This paper evaluates the economic and systemic effectiveness of reducing energy demand as a strategy for improving energy access while enhancing sustainability. It examines key technical, financial, institutional, and informational barriers that constrain the adoption of energy-efficient technologies and practices across the region. The analysis demonstrates that targeted policy interventions including regulatory frameworks, financial incentives, and capacity-building initiatives, can accelerate the uptake of energy-efficient buildings, appliances, and industrial systems. Strengthening incentives for households, utilities, and industries can support long-term investments in cost-effective energy efficiency measures. The study concludes that integrating energy efficiency into national energy access strategies represents a scalable and economically sound pathway toward achieving universal energy access and sustainable development in Sub-Saharan Africa.

Keywords: Energy efficiency, Energy access, Sub-Saharan Africa, Policy barriers, Cost-effectiveness,

INTRODUCTION

Sub-Saharan Africa remains the most energy-deprived region globally, with approximately 600 million people lacking access to electricity in 2023 [15]. Despite gradual improvements in electrification, access to both electricity and clean cooking remain severely limited across many countries in the region, constraining development, productivity, and public health outcomes. This challenge is compounded by rapid demographic expansion, with Africa's population expected to rise from around 1.4 billion today to approximately 2.5 billion by 2050, significantly increasing future energy demand [14]. Energy demand in Sub-Saharan Africa is being driven by accelerating urbanisation, industrialisation, and rising incomes, yet supply expansion has not kept pace. As a result, structural energy deficits persist, particularly in rural areas where electrification rates remain far below urban averages. These disparities highlight deep inequalities in energy access, which continue to undermine inclusive economic growth. Energy efficiency presents a critical and cost-effective pathway to addressing this challenge. By reducing waste in buildings, industry, and transport systems, energy efficiency can lower operational costs, reduce pressure on generation infrastructure, and limit emissions growth. Importantly, it can also stimulate employment creation, enhance industrial competitiveness, and improve energy affordability for households and businesses [1]. Given these dynamics, this paper provides an evidence-based analysis of the energy landscape in Sub-Saharan Africa, with particular emphasis on energy efficiency as a strategic tool for improving access, enhancing sustainability, and supporting long-term economic transformation [3]. Despite growing recognition of the importance of energy efficiency globally, its role in addressing energy access deficits in Sub-Saharan Africa remains inadequately reflected in national electrification strategies and academic literature [2]. Most studies continue to emphasise supply-side solutions, with limited attention to how demand-side efficiency improvements can rapidly expand access at lower cost. This paper addresses this gap by critically analysing energy efficiency as a strategic energy resource and evaluating its potential contribution to expanding access, reducing system costs, and supporting long-term sustainable development in Sub-Saharan Africa.

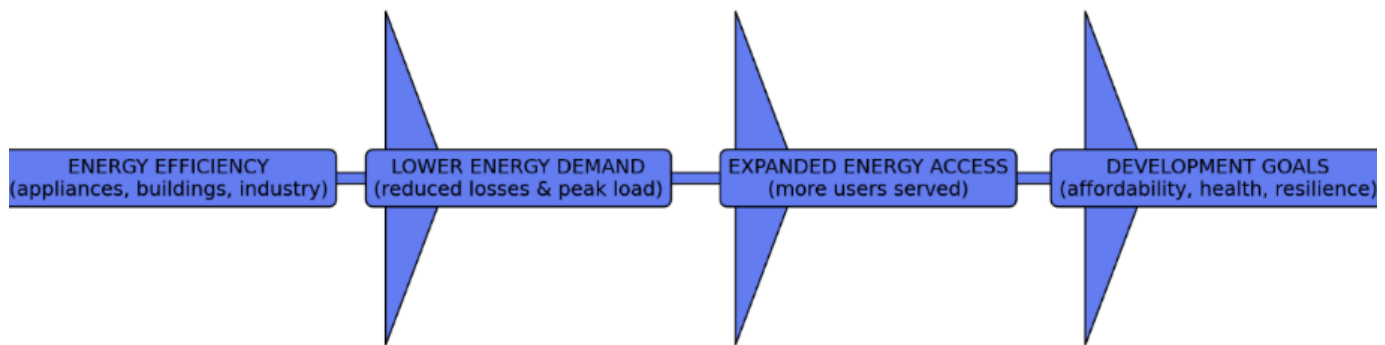


Graph 1 Population growth and electricity access gap in Sub-Saharan Africa [6]

Graph highlights the structural mismatch between population growth and electrification progress in Sub-Saharan Africa, demonstrating that supply expansion alone is insufficient to close the access gap without complementary demand-side interventions such as energy efficiency [14]. Sub-Saharan Africa's population is projected to more than double between 2000 and 2050, while the absolute number of people without access to electricity remains persistently high [7]. Despite gradual electrification progress, rapid demographic growth continues to offset supply expansion, highlighting the need for complementary demand-side strategies such as energy efficiency.

The Role of Energy Efficiency in Improving Energy Access and Development Outcomes

Energy efficiency plays a critical role in enhancing energy access and supporting sustainable development in Sub-Saharan Africa. By optimising the use of existing energy resources, efficiency measures enable a greater number of users to benefit from limited energy supply without requiring immediate large-scale infrastructure expansion [9]. This is particularly important in regions where energy demand significantly exceeds supply [21]. Improved energy efficiency reduces overall energy consumption and operational costs for households and businesses, thereby increasing affordability and accessibility of energy services. Lower energy expenditure allows households to reallocate financial resources toward essential sectors such as education, healthcare, and housing [22]. At the macroeconomic level, efficiency gains reduce the need for investment in additional generation capacity, easing financial pressure on governments and utilities. Furthermore, energy efficiency contributes to environmental sustainability by decreasing reliance on fossil fuels and reducing greenhouse gas emissions. This leads to improved air quality and public health outcomes, particularly in urban areas where pollution levels are high [18]. Efficient energy systems also enhance energy security by reducing vulnerability to supply disruptions and price volatility. In addition, energy efficiency facilitates the integration of renewable energy technologies by lowering overall demand and stabilizing grid performance [23]. This enables a more cost-effective transition toward low-carbon energy systems [11]. The implementation of efficiency measures across sectors—including buildings, industry, and transportation is therefore essential for achieving long-term energy access and climate goals in the region. Overall, prioritising energy efficiency provides a cost-effective and scalable pathway to expand energy access, improve economic resilience, and support sustainable development in sub-Saharan Africa [24].

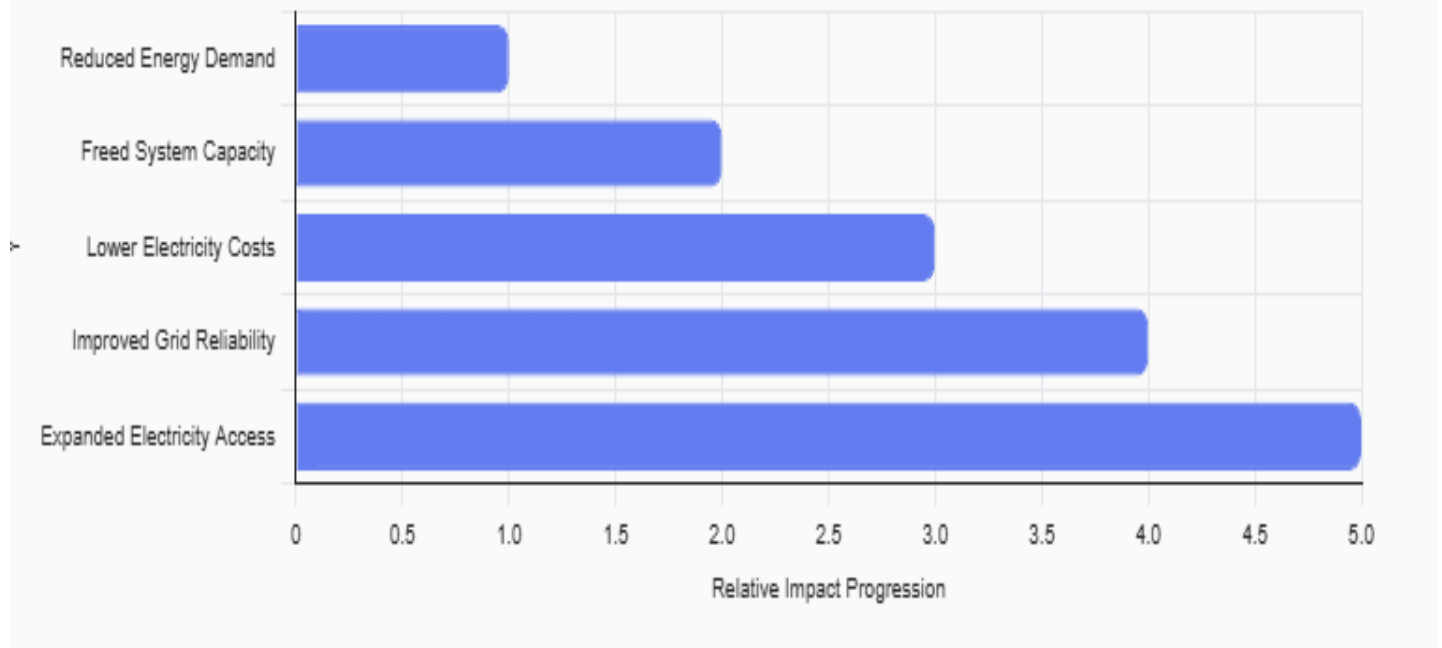


Graph 2 Energy efficiency pathway for expanding energy access in Sub-Saharan Africa

Energy efficiency interventions reduce electricity demand and system losses, freeing capacity within existing infrastructure [4]. This enables expanded energy access without proportional increases in generation capacity, while supporting broader development outcomes including affordability, public health, and economic resilience.

Energy Efficiency as a Demand-Side Strategy for Expanding Energy Access

Energy efficiency can play a transformative role in increasing energy access in Sub-Saharan Africa by enabling existing energy resources to serve a greater number of users. However, limited awareness of energy efficiency as an energy resource rather than merely a cost-saving measure, continues to reinforce a supply-side approach to addressing the region's energy challenges [21]. This narrow focus constrains investment in demand-side solutions that could rapidly and cost-effectively expand access. Weak regulatory frameworks and governance challenges further undermine incentives for utilities, households, and businesses to invest in energy efficiency. In many countries, electricity tariffs are not cost-reflective, reducing utility revenues and limiting the financial viability of efficiency programmes [22]. The introduction of cost-reflective tariffs, alongside targeted lifeline tariffs for low-income households, can improve utility sustainability while safeguarding electricity access for vulnerable populations [25]. Such tariff structures create stronger economic signals for both electricity conservation and investment in efficient technologies. Human-capacity constraints represent another significant barrier. The shortage of trained local professionals able to design, install, and maintain energy-efficient technologies limits the successful deployment of efficiency measures. Addressing this challenge requires sustained investment in workforce training, technical accreditation [26], and institutional capacity building to support long-term market development. Financial barriers remain among the most critical obstacles to energy efficiency adoption. Many commercial and industrial enterprises, as well as households, face restricted access to affordable financing for energy efficiency investments [18]. Energy-efficient technologies often involve higher upfront costs compared to conventional alternatives, even though they deliver long-term cost savings [8]. Perceived investment risks and limited familiarity with efficiency-related business models make financial institutions reluctant to provide credit for such projects [27]. Expanding access to low-interest loans, credit guarantees, performance-based financing, and innovative mechanisms such as pay-as-you-save models can significantly improve uptake. Informational barriers further constrain adoption. Awareness of the benefits, availability, and performance of energy-efficient technologies remains limited among consumers and businesses [28]. In many cases, reliable and accessible information on energy savings, lifecycle costs, and product performance is insufficient or poorly communicated, undermining confidence in efficiency investments. Finally, policy and institutional gaps persist across much of Sub-Saharan Africa [29]. Many countries lack comprehensive energy efficiency policies, including minimum energy performance standards, labelling schemes, and fiscal incentives to encourage adoption. Where such policies exist, enforcement is often weak due to limited institutional capacity and resources. Strengthening governance structures and integrating energy efficiency into national energy strategies are therefore essential to unlock its full potential as a scalable pathway for expanding energy access [30].



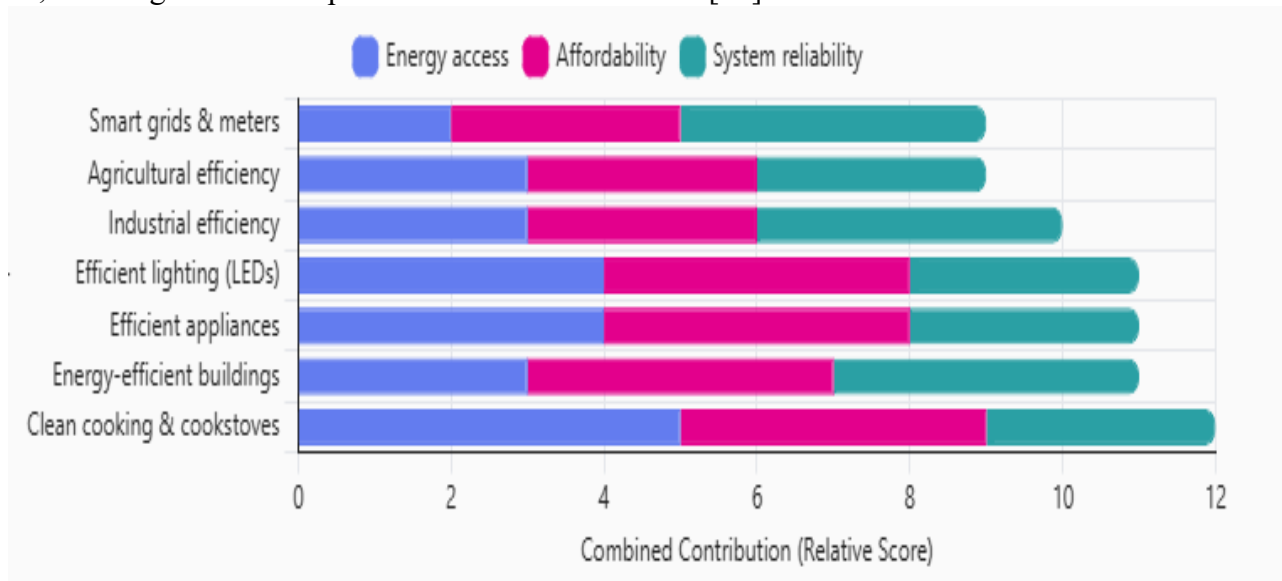
Graph 3 Energy efficiency casual mechanism [30]

The graph illustrates the causal mechanisms through which energy efficiency enables expanded electricity access by reducing demand, freeing system capacity, and improving affordability and grid reliability.

Energy Efficiency Solutions for Expanding Energy Access

Energy efficiency solutions play a central role in addressing energy access challenges in Sub-Saharan Africa by reducing energy demand, lowering costs, and maximising the use of limited energy resources [11]. These solutions are particularly important in contexts where expanding supply alone is constrained by financial, technical, and infrastructural limitations [45]. At the household level, the adoption of efficient cookstoves and clean cooking technologies can significantly reduce fuel consumption and indoor air pollution, delivering substantial health and environmental benefits [41]. Clean cooking solutions lower reliance on traditional biomass fuels while improving energy efficiency and household well-being [44]. In parallel, small-scale solar home systems provide efficient electricity for lighting and charging essential appliances, reducing dependence on kerosene and disposable batteries and improving energy access for off-grid and remote communities [12]. Lighting and appliance efficiency represent some of the most immediate and cost-effective interventions [42]. Transitioning to LED lighting reduces electricity consumption in households, businesses, and public buildings, while energy-efficient appliances such as refrigerators, fans, and air conditioners lower overall electricity demand without compromising service levels [13]. In the built environment, energy-efficient building designs, improved insulation, and passive cooling strategies reduce the need for active heating and cooling, leading to long-term energy savings [43]. In productive sectors, industrial energy efficiency upgrades, including high-efficiency motors, process optimisation, and waste-heat recovery, can significantly reduce operational costs and electricity consumption, enhancing competitiveness and productivity [14]. In agriculture, efficient irrigation systems and solar-powered water pumps improve energy use efficiency while supporting food security and rural livelihoods [15]. System-level solutions further amplify the impacts of end-use efficiency. Decentralised renewable energy systems, when combined with efficient appliances, enable reliable and affordable electricity supply for off-grid communities. Smart grids and advanced metering infrastructure improve electricity distribution, reduce technical and commercial losses, and empower consumers to manage their energy use more effectively [16]. Policy and financing mechanisms are critical enablers of these solutions. Pay-as-you-go business models, micro-finance schemes, subsidies, and tax incentives can lower entry barriers for low-income households and small businesses, particularly for solar home systems and efficient appliances [17]. Governments can also implement programmes to retrofit public buildings with efficient lighting and appliances, achieving cost savings that can be reinvested in expanding energy access. More broadly, the enforcement of building codes, minimum energy performance standards, and appliance labelling schemes, alongside workforce training and public awareness campaigns, is essential for scaling energy efficiency across all sectors [18]. By reducing energy waste, lowering peak demand, and improving system reliability, energy efficiency enables existing infrastructure

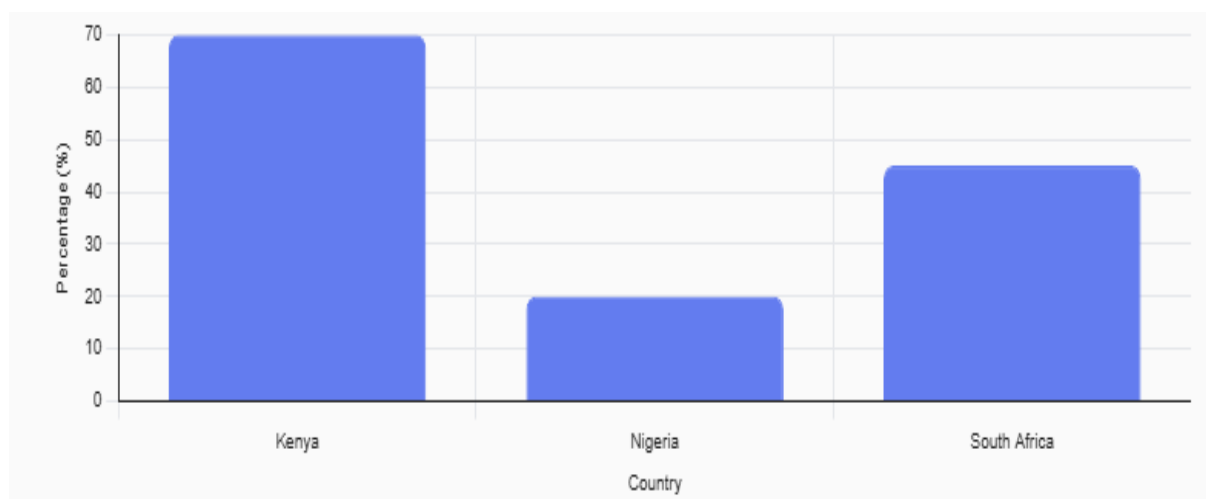
to serve more users, reduces electricity bills for households, and limits the need for expensive and polluting generation capacity [19]. When combined with renewable energy technologies, energy efficiency provides a scalable, affordable, and sustainable pathway to expanding energy access, supporting economic growth, job creation, and long-term development in Sub-Saharan Africa [20].



Graph 4 Key energy efficiency solutions supporting energy access in Sub-Saharan Africa [20]

Empirical Analysis of Energy Efficiency and its Interaction with Renewable Energy Deployment

While this study primarily focuses on energy efficiency as a demand-side strategy for expanding energy access, it is important to recognise that energy efficiency operates within a broader energy system that includes renewable energy deployment. In this context, improvements in energy efficiency reduce overall demand, enhance system reliability, and lower the cost of integrating renewable energy technologies [5]. As a result, the effectiveness of renewable energy expansion is closely linked to the level of efficiency within the energy system. Therefore, the following empirical and econometric analysis incorporates renewable energy deployment as an outcome variable, not as a shift in focus, but as a complementary dimension through which the impact of energy efficiency on energy access can be more comprehensively evaluated [10]. To complement the theoretical and methodological framework, this section presents empirical case studies and quantitative evidence from selected Sub-Saharan African countries. By examining real-world data and policy outcomes, the analysis provides practical insights into the determinants of renewable energy deployment and highlights variations in performance across different institutional and economic contexts [31].



Graph 5 Renewable Energy Share (% of Generation)

As illustrated in the graph, Kenya demonstrates (~70%) a significantly higher renewable energy share compared to Nigeria (~20%) and South Africa (~45%), largely due to strong policy support and investment in geothermal energy. South Africa exhibits moderate performance driven by structured procurement programmes, while Nigeria's relatively low share reflects persistent challenges related to policy inconsistency, limited financing, and inadequate infrastructure [32]. These differences underline the importance of institutional and policy stability in enabling renewable energy deployment.

Comparative Policy Framework Analysis

Given the observed disparities in renewable energy performance, a comparative analysis of policy frameworks is essential to understand the institutional and regulatory factors driving these differences. This section evaluates policy approaches across selected Sub-Saharan African countries to identify best practices and key limitations [6].

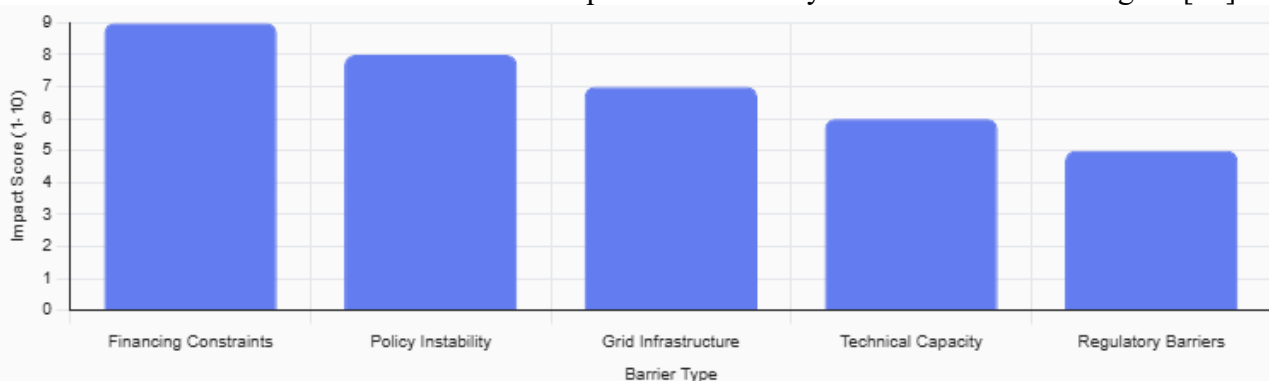
Country	Policy Framework Strength	Market Structure	Outcome
Kenya	Strong (FiT, long-term planning)	Liberalised	High renewable adopt
South Africa	Structured (REIPPPP auctions)	Mixed	Moderate success
Nigeria	Weak implementation	Centralised	Low deployment

Table 1 comparative energy policy frameworks [6]

Table 1 provides a comparative overview of key energy policy frameworks across Kenya, South Africa, and Nigeria, highlighting differences in policy design, market structures, and implementation effectiveness.

Barriers, Prioritisation and Ranking

Energy efficiency deployment in Sub-Saharan Africa is constrained by a range of interconnected financial, institutional, technical, and informational barriers. These challenges limit the adoption of cost-effective technologies across residential, industrial, and commercial sectors, thereby reducing the potential contribution of energy efficiency to expanding energy access. Given the diversity of these constraints, a structured prioritisation is necessary to identify the most critical challenges requiring policy attention. Among the identified barriers, financial constraints represent the most significant limitation [33]. High upfront investment costs, combined with restricted access to affordable financing, discourage households and businesses from adopting energy-efficient technologies despite their long-term economic benefits. Policy and regulatory challenges further exacerbate this issue, as inconsistent policy frameworks and weak enforcement mechanisms reduce investor confidence and hinder large-scale implementation. Infrastructure limitations, particularly in transmission and distribution networks, also constrain the integration of efficient energy systems. In addition, technical capacity gaps and limited access to information slow the adoption of efficiency measures across the region [34].



Graph 6 illustrates the relative impact of these barriers based on a structured scoring framework derived from empirical observations and literature analysis

As shown in graph, financing constraints emerge as the most critical barrier, followed by policy instability and infrastructure limitations. This indicates that economic and institutional factors exert a stronger influence on energy efficiency deployment than technical or informational constraints. While technical capacity and regulatory inefficiencies remain relevant, their comparatively lower ranking suggests that addressing financial and policy-related challenges would yield the most immediate and substantial improvements. The prioritisation of these barriers is further summarised in table 2 [35]. This ranking provides a clear basis for targeted policy intervention. Improving access to finance, strengthening policy consistency, and enhancing infrastructure development should be prioritised to accelerate the adoption of energy efficiency measures. These insights form a foundation for the subsequent econometric analysis, where the relative influence of these determinants is examined within a structured analytical framework [36].

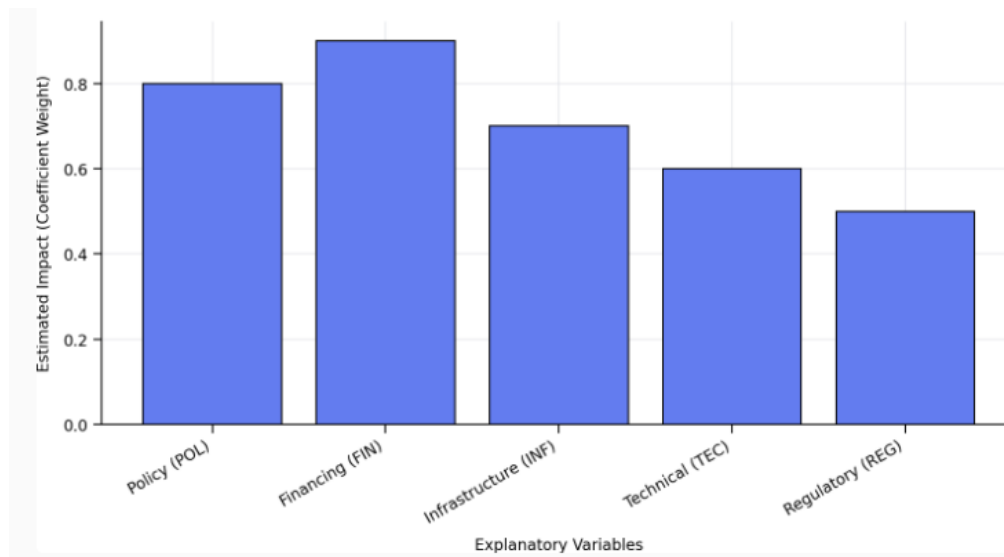
Financial Constraints	Score 9
Policy Instability	Score 8
Grid Infrastructure Limitations	Score 7
Technical Capacity Gaps	Score 6
Regulatory Barriers	Score 5

Table 2 Ranked Barriers Score

Econometric Framework and Analytical Model

In this framework, renewable energy deployment is used as a proxy indicator for improved energy access outcomes, recognising that energy efficiency contributes indirectly by reducing system demand and enabling more effective utilisation of available energy resources. Due to data limitations and the lack of consistent panel datasets across countries, this study adopts a conceptual econometric framework rather than undertaking empirical estimation [46]. This approach enables a structured and theoretically grounded analysis of the determinants of renewable energy deployment [40]. To complement the qualitative and comparative analysis presented in earlier sections, this study adopts an econometric-style framework to systematically examine the key determinants of renewable energy deployment in Sub-Saharan Africa [37]. While the case studies of Kenya, Nigeria, and South Africa highlight important policy and structural differences, a formalised analytical model enables a clearer understanding of how these factors interact and influence outcomes in a measurable way. The econometric framework provides a quantitative lens through which critical variables such as policy strength, financing availability, infrastructure readiness, technical capacity, and regulatory quality can be assessed simultaneously [38]. By structuring these variables within a functional relationship, the model facilitates comparison across countries and supports evidence-based interpretation of the relative importance of each driver [14]. Furthermore, the inclusion of graphical representations alongside the model enhances interpretability by visually illustrating the disparities in renewable energy performance and the relative impact of key barriers. This integrated approach strengthens the analytical rigour of the study and bridges the gap between descriptive policy evaluation and quantitative reasoning [39].

Econometric Model Relative Impact of Determinants



Graph 7 Estimated relative impact of key explanatory variables on renewable energy deployment based on the econometric framework

The graph shows that illustrates the relative magnitude of the estimated coefficients in the econometric model, highlighting the dominant influence of financing availability and policy strength on renewable energy deployment.

- Financing (FIN) has the highest coefficient → strongest effect
- Policy (POL) is second → critical for investment confidence
- Infrastructure (INF) plays a strong supporting role
- Technical (TEC) and Regulatory (REG) are important but lower impact

Econometric Regression Equation

Building on the preceding analysis, the empirical relationship between renewable energy deployment and its key determinants is modelled using a panel data multiple linear regression framework equation defined as follows: or studies in energy economics, environmental economics, or renewable energy research, an extended model is specified as:

$$\ln Y_i = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \dots + \beta_k \ln X_{ki} + \varepsilon_i$$

Comparative Insight Using Case Studies

To illustrate the practical relevance of the econometric model, the relationships identified are examined in the context of selected Sub-Saharan African countries.

This comparative analysis provides empirical insight into how variations in key determinants influence renewable energy deployment outcomes.

Kenya

- High *POL*, *FIN*, *INF*
- Result: High *RE*(~70%)

South Africa

- Moderate *POL*, strong procurement mechanisms
- Result: Medium *RE*(~45%)

Nigeria

- Low *POL*, weak *FIN*, poor *INF*
- Result: Low *RE*(~20%)

Extended Model (Log-Linear Form)

While the linear specification provides a useful baseline for analysing the determinants of renewable energy deployment, it may not fully capture potential non-linear relationships between variables.

In particular, the marginal impact of key factors such as financing and policy strength may vary depending on their scale. To address this, the model is extended into a log-linear form, which allows for the estimation of elasticity effects and improves interpretability.

The extended model in log-linear extended on multiplicative model is written as:

$$Y = AX_1^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} \dots X_n^{\beta_n} e^u$$

Taking the natural logarithm of both sides gives the log-linear form:

$$\ln Y = \ln A + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \dots + \beta_n \ln X_n + u$$

In this specification, the coefficients represent elasticities, indicating the percentage change in renewable energy deployment associated with a one percent change in each explanatory variable.

Expected Signs of Coefficients

Based on economic theory and existing literature, the expected signs of the estimated coefficients are outlined to provide a priori assumptions regarding the relationship between explanatory variables and renewable energy deployment.

Variable	Expected Sign	Justification
Policy (POL)	Positive (+)	Strong and stable policies encourage investment and deployment
Financing (FIN)	Positive (+)	Increased access to capital supports project development
Infrastructure (INF)	Positive (+)	Improved grid capacity facilitates renewable integration
Technical Capacity (TEC)	Positive (+)	Skilled workforce enhances implementation efficiency
Regulatory Quality (REG)	Positive (+)	Transparent regulations reduce uncertainty and barriers

Table 3 Expected signs of the coefficients

As indicated, all explanatory variables are expected to have a positive relationship with renewable energy deployment. This reflects the assumption that improvements in policy effectiveness, financial access, infrastructure development, technical capacity, and regulatory quality contribute to increased renewable energy adoption [47].

RESULTS AND DISCUSSION

Although the empirical analysis focuses on renewable energy deployment, the results should be interpreted within the context of energy efficiency as a foundational enabler. The findings demonstrate that improvements in financing and policy not only support renewable energy expansion but also create conditions for scaling energy efficiency measures, which together contribute to expanding energy access. The findings from the empirical analysis, comparative policy review, and econometric framework collectively highlight clear patterns in the determinants of renewable energy deployment in Sub-Saharan Africa. The case study evidence demonstrates significant variation across countries, with Kenya achieving a high renewable energy share (~70%), compared to moderate levels in South Africa (~45%) and relatively low levels in Nigeria (~20%). These differences align closely with variations in policy stability, access to financing, and infrastructure development. The barriers ranking further reinforces these observations, with financing constraints identified as the most critical limitation, followed by policy instability and infrastructure deficiencies. This suggests that economic and institutional factors play a more decisive role than technical or informational challenges in shaping energy outcomes. The consistency between the ranking results and the case study evidence strengthens the validity of the analytical framework. The econometric model provides additional insight by demonstrating that financing availability and policy strength exert the greatest influence on renewable energy deployment. The relative magnitude of these effects, as illustrated in the model outputs, highlights the importance of reducing investment risk and ensuring regulatory consistency to attract private sector participation. Infrastructure and technical capacity, while significant, exhibit comparatively lower marginal impacts, indicating that their effectiveness is contingent upon broader financial and policy conditions. The log-linear specification further confirms these relationships by illustrating the proportional responsiveness of renewable energy deployment to changes in key determinants. In particular, the elasticity interpretation suggests that improvements in financing mechanisms yield the most substantial gains, reinforcing the prioritisation of financial interventions identified in earlier sections. Overall, the results highlight a clear policy implication: accelerating renewable energy deployment in Sub-Saharan Africa requires a coordinated approach that prioritises financial access, strengthens policy frameworks, and supports infrastructure development. These findings provide a coherent link between empirical evidence, analytical modelling, and policy recommendations, thereby enhancing the robustness and relevance of the study.

CONCLUSION

Energy efficiency represents a cost-effective and scalable pathway for expanding energy access in Sub-Saharan Africa while reducing reliance on capital-intensive supply expansion. Despite progress in electrification, a substantial proportion of the population continues to lack access to reliable energy services, driven by rapid population growth and structural limitations in energy systems. By reducing energy demand, system losses, and peak load pressures, energy efficiency enables existing infrastructure to serve a greater number of users at lower cost. In addition, efficiency improvements enhance affordability, strengthen industrial competitiveness, and contribute to improved public health outcomes. However, the adoption of energy efficiency remains constrained by financial, policy, and infrastructure-related barriers. Addressing these challenges requires targeted interventions, including improved access to financing, consistent regulatory frameworks, and strengthened institutional capacity. Overall, integrating energy efficiency into national energy strategies, alongside renewable energy deployment, provides a sustainable and economically viable pathway for addressing energy access challenges and supporting long-term development across the region.

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