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Research Article

Electricity Access, Electricity Consumption, and Economic Performance in Sierra Leone: Evidence from an ARDL Bounds and Error-Correction Framework (2000–2024)

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Abstract

Electricity access is key to Sierra Leone's development strategy, yet persistent reliability, affordability, and utility-finance constraints raise concern that more connections may not lead to productive electricity use. This study examines whether electricity access and electricity consumption are associated with economic performance in Sierra Leone, and distinguishing between long-run equilibrium effects and short-run adjustment dynamics. Using annual time-series data for 2000–2024, the paper estimates an Autoregressive Distributed Lag (ARDL) model, applies the bounds test for cointegration, and derives an unrestricted error-correction model (UECM). The bounds test confirms a stable long-run relationship among GDP per capita, electricity access, electricity consumption, investment, trade openness, and inflation (F-statistic = 5.07). Long-run estimates show that electricity access has a positive elasticity (0.0718), while electricity consumption per capita is economically negligible (-0.0008). Investment is strongly positive (0.2195). The error-correction term is negative (-0.393), implying that about 39% of disequilibrium is corrected within one year. The findings suggest that Sierra Leone's growth payoff from electrification depends less on expanding connections alone and more on improving reliability, reducing losses, strengthening sector governance, and promoting productive electricity use.

Keywords: Electricity access; electricity consumption; economic growth; error-correction model; Sierra Leone; power sector reliability.

1. Introduction

Electricity is a foundational input in modern production and household welfare. It enables mechanization, supports firm productivity, and raises the returns to investment in physical and human capital. When electricity supply is scarce or unreliable, firms face higher operating costs, production delays, equipment damage, and weaker incentives to expand; households also experience welfare losses that reduce study time and constrain microenterprise activity [1, 2]. These constraints are central to Sierra Leone's development debate because recent improvements in electrification have not always led to dependable service, and the cost of sustaining supply has become increasingly salient [2].

Recent published research reinforces the centrality of electricity to economic performance in African economies, and also showing that the relationship is more nuanced than simple connection counts suggest. Using East African Community data, Mutumba, Mubiinzi, and Amwonya [4] find evidence consistent with the growth hypothesis, with causality running from electricity consumption to economic growth. In a related contribution, Nsabimana et al. [5] showed that access to reliable electricity is a necessary condition for development and that resource constraints, more than resource utilization alone, are a major barrier to achieving reliable electricity access. Also, recent ARDL-based evidence also suggests that electricity availability and electricity access can have different economic effects, which further supports the need to distinguish between connection and effective service delivery in applied work on energy and growth [3].

Over the years, Sierra Leone has recorded gradual progress in electricity access, but the baseline remains low and spatial inequality is pronounced. World Development Indicators estimated that 35.5% of Sierra Leone's population had access to electricity in 2023 [8]. At that same time, widely cited policy reporting indicated that only about 30% of the population has electricity access overall, most unfortunately, that percentage falls to below 5% in rural areas, which highlights a large rural–urban gap that raises concerns for inclusive growth [6]. For a country seeking to expand food sufficiency, a diversified economy, rural services, and small-scale enterprise, this access gap is a social concern and a productivity constraint [6, 2]. Even within the urban areas, service quality is uneven, this reinforces differences in firm performance and household welfare [7, 2].

Recent studies also stress the case for treating electricity inequality as a development issue rather than a purely technical infrastructure concern. Gamette, Odhiambo, and Asongu [9] showed that although access to electricity expanded across sub-Saharan Africa between 2000 and 2022, the gains were disproportionately concentrated in urban areas and among higher-income groups. Zhao and Wu [10] likewise found that a wider urban–rural electricity gap significantly depresses human development, with stronger adverse effects in low-income countries. Complementing this, Dianda, Tou, and Zidouemba [11] found that more inclusive institutional arrangements improve rural electrification and reduce urban–rural electricity inequality in sub-Saharan Africa. These findings are very relevant to Sierra Leone, where low national access coexists with severe rural deprivation and uneven service quality.

The challenge, therefore, lies in both connection rates and the quality and reliability of electricity service. Enterprise-based evidence showed that disruptions are widespread: 66% of firms are reported to experience electrical outages in Sierra Leone in the most recent reported indicator year [12]. This is in alignment with qualitative accounts from businesses and households: that uncertainty about power availability affects production schedules and investment decisions and often pushes firms toward costly self-generation as a risk-management strategy [12, 13].

A detailed monitoring from Freetown further revealed the scale and unevenness of reliability constraints. Using sensor-based monitoring across micro, small, and medium enterprises connected to multiple transformers, researchers recorded 6, 195 outage interruptions over nine months and found that enterprises in eastern Freetown experienced nearly seven times more outage hours than those in the west, equivalent to about 300 outage hours per month, or roughly 40% of the month without electricity [7, 14]. These patterns show how "access" can coexist with severe rationing and low effective electricity use, which is very critical for understanding why electrification does not always deliver a strong growth dividend [7, 2].

These service problems are closely connected to financial and operational weaknesses in the sector. Government support to electricity has become a recurring fiscal pressure. A fiscal risk assessment by Sierra Leone's Ministry of Finance reported that from 2018 to 2023 the Government provided over NLe 2 billion in subsidies to EDSA, including NLe 776 million in 2023 alone [15]. The same assessment emphasized that payment arrears and crisis interventions have contributed to supply instability and heightened uncertainty in power purchases, with more direct implications for reliability and economic activity [15].

From a macro-fiscal perspective, the World Bank reported that the government provided over US$100 million to support the sector during 2019–2022, and transferred US$38 million (0.6% of GDP) in subsidies in 2023 [2]. The same report noted that by August 2024, cumulative arrears to independent power producers and electricity imports had reached US$75.7 million. This is an illustration of how electricity sector weaknesses can transmit into broader fiscal stress and crowd out planned government priority spending [2].

The wider macroeconomic environment further reinforces why the electricity–growth relationship in Sierra Leone is likely to involve adjustment lags and short-run disruptions. Inflation has been exceptionally high in recent years; IMF reporting indicated end-of-period inflation of 52.2% in 2023 [16]. Under such volatility, affordability constraints, tariff adequacy, the real value of subsidies, and firms' ability to finance equipment can shift quickly. This makes it important to distinguish between long-run relationships and short-run fluctuations in how electricity access and use relate to income and economic performance [16, 2].

Furthermore, other recent findings increasingly suggests that the binding constraint is not connection alone, but the reliability and quality of electricity actually delivered to users. Osunmuyiwa and Wall [7] showed, using real-time monitoring of MSMEs in Freetown, that poor power quality and frequent outages materially constrain enterprise productivity and utility performance. Meriggi and Mével [13] similarly documented the substantial costs that unreliable grid electricity imposes on SMEs and argue that more dependable electricity provision is essential for productive activity. At a broader system level, Bakarr et al. [17] showed that

Sierra Leone's electricity transition is constrained by supply fragility, dependence on fossil-based generation, and the need for stronger regulatory and investment frameworks.

Though there is a growing literature on electricity and development, three crucial gaps remain. First, the empirical evidence on the electricity–growth nexus is still mixed across countries and methods, with recent studies showing that the strength and direction of the relationship depend heavily on context, institutions, and the nature of electricity use.
Also, much of the recent African literature has shifted toward questions of inequality, reliability, and electricity availability, showing that urban–rural disparities, weak institutions, and poor-quality supply can prevent electrification from leading to inclusive economic gains.

Finally, for Sierra Leone, recent evidence has drawn attention to severe reliability and power-quality problems and their consequences for firms, but this evidence is largely diagnostic and policy-oriented not macro-econometrically integrated. As a result, there is still limited country-specific evidence that separately estimates the roles of electricity access and electricity consumption in impacting economic performance, and distinguishing long-run relationships from short-run dynamics in a reliability-constrained setting. This study addresses that gap by estimating an ARDL bounds and error-correction framework for Sierra Leone over 2000–2024, and explicitly separate access from consumption and situating both within the country's broader macroeconomic and power-sector conditions.

The remainder of the paper is organized as follows. Section 2 reviews the relevant theoretical and empirical literature on electricity, electrification, and economic performance, with particular attention to the distinction between electricity access and electricity consumption. Section 3 presents the data, variable definitions, and empirical methodology, including the ARDL bounds-testing and error-correction framework. Section 4 reports and discusses the empirical findings, including the long-run estimates, short-run dynamics, and diagnostic and stability tests. Section 5 concludes by drawing out the main policy implications for Sierra Leone's electricity sector and broader economic development.

2. Literature Review

2.1. Theoretical foundations

Electricity is a central input in modern production systems because it supports mechanization, technology adoption, labor productivity, and the returns to both private and public investment. In that broad sense, the link between energy and economic performance is well grounded in the classical and infrastructure-augmented growth literature. Earlier foundational work shows that when energy is scarce, costly, or unreliable, it acts as a binding constraint on production and structural transformation. In this study, these theoretical insights are useful as a starting point, especially in a context such as Sierra Leone where electricity supply constraints affect households, firms, and the broader macroeconomy. The theoretical expectation, therefore, is that electricity can support long-run economic performance, but the magnitude of that effect depends on whether electricity is sufficiently available, reliable, and productively used.

1.1.2.2 Electricity access, electricity consumption, and the recent energy-growth literature

Recent empirical research continues to confirm that the electricity-growth nexus is important, but no longer treats it as a simple one-directional relationship. Mutumba, Mubiinzi, and Amwonya [4], using East African Community data, found evidence consistent with the growth hypothesis, with causality running from electricity consumption to economic growth. This supports the view that electricity is a productive input in African development. Similarly, newer work also shows that electricity access and electricity availability can generate different economic effects. Asaleye, Garidzirai, and Ncanywa [3], for example, show that access and availability have distinct short-run and long-run implications for economic participation, implying that the economic value of electrification depends on being connected, and also on whether electricity is reliably delivered.

2.3 Reliability, affordability, and why access does not always lead to development gains

A major shift in the recent literature is the move away from counting electricity connections alone. Recent evidence increasingly shows that the developmental effects of electricity depend on service quality, affordability, and the capacity of users to convert electricity into productive outcomes. Nsabimana et al. [5] argued that improving access to reliable electricity is a necessary condition for development, but that performance gaps are driven by resource constraints. MacGinley et al. [31], in a systematic review of 92 studies, find that although most reported effects of electricity access on human development are positive, a substantial minority are neutral or negative, with the most common barriers being poor service quantity, poor quality, and affordability constraints.

2.4 Electricity inequality, institutions, and Sub-Saharan Africa

Recent African findings have also widened the literature beyond the narrow question of whether electricity matters for growth, toward the deeper issue of who benefits from electrification and under what institutional conditions. Gamette, Odhiambo, and Asongu [9] show that improvements in electricity access across sub-Saharan Africa have been uneven, with urban areas benefiting more than rural ones and the richest groups enjoying better access than the poorest. Zhao and Wu [10] similarly showed that wider urban-rural electricity gaps significantly reduce human development, with stronger effects in low-income countries. Dianda, Tou, and Zidouemba [11] add an institutional dimension by showing that more equitable political power distribution improves rural electrification and narrows the urban-rural electricity gap. More recently, Dagal [18] argued that Africa's electrification challenge are affected less by technology alone than by governance, financing, and spatial inequality, and service quality continues to limit the real value of new connections.

2.5 Focus on Sierra Leone: electricity and growth

Sierra Leone clearly illustrates the complex relationship between electricity and economic performance. National and international policy diagnostics have repeatedly identified limited electricity access and weak reliability as constraints on private-sector development and long-run growth [15, 19]. World Bank Firm-level data also support this view: Enterprise Survey indicators for Sierra Leone showed high shares of firms experiencing outages in reported survey years [20]. These constraints affect investment decisions through higher operating costs, downtime, and the need for expensive coping strategies such as self-generation.

More recent monitoring evidence further unveils the importance of reliability. In Freetown, micro-data collected through transformer-level monitoring across micro, small and medium enterprises recorded 6, 195 outage interruptions over nine months, and showed that businesses in eastern Freetown experienced nearly seven times more outage hours than those in western Freetown, averaging about 300 outage hours per month, which is equivalent to being without electricity for roughly 40% of the month [7]. These findings support the argument that the growth payoff of electrification depends on whether access led to usable, and reliable energy services for households and firms [7]. Empirical research focused specifically on Sierra Leone is relatively limited, partly due to data gaps and structural breaks, but existing work generally supports a long-run link between electricity use and output. Together, these studies motivate a careful approach that distinguishes long-run relationships from short-run adjustment and separates access from consumption, since these channels can behave differently when reliability and affordability constraints are binding [21].

Furthermore, In recent years, Sierra Leone has pursued multiple initiatives to expand access and strengthen the sector, and also confronted the commercial and fiscal constraints that shape reliability outcomes. The Ministry of Finance documented persistent sector losses and subsidy pressures, that highlights how weak collections, system losses, and non-payment undermine maintenance and investment, and can perpetuate reliability problems [15].

For a closer look at Sierra Leone's current status, As of November 2025, EDSA reported a total customer base of 361, 571. This amount is dominated by 325, 253 residential customers, 29, 139 commercial customers, 4, 497 institutions, and 1, 388 large customers. This demand structure implies that improvements in electricity affect household welfare and the operations of the commercial and large-user segments that drive value addition and employment.

On the supply side, grid electricity in major load centers relies on a mixed portfolio that includes Karpowership (25–45 MW) for Freetown [22], EGTC thermal (10–70 MW) that is used to serve Freetown and selected provincial towns. Also, Bumbuna hydropower (6–50 MW) which is reliable mostly during the rainy season, is used to serve Bumbuna, Makeni, Magburaka, Freetown. There are also solar contributions from Planet Solar (36–40 MW) and Serengeti (1–5 MW) [22].

Moreover, the average available power rose from 42.74 in 2018 to 58.76 in 2024, and the average utilized power increased from 38.62 in 2018 to 56.51 in 2024 [22]. In 2024, utilization was about 96% [22]. This percentage means that shocks to supply or network performance can quickly turn into rationing and interruptions. The visualizations in figure 1 summarize both the generation capacity and the rate of utilization, as reported by EDSA.

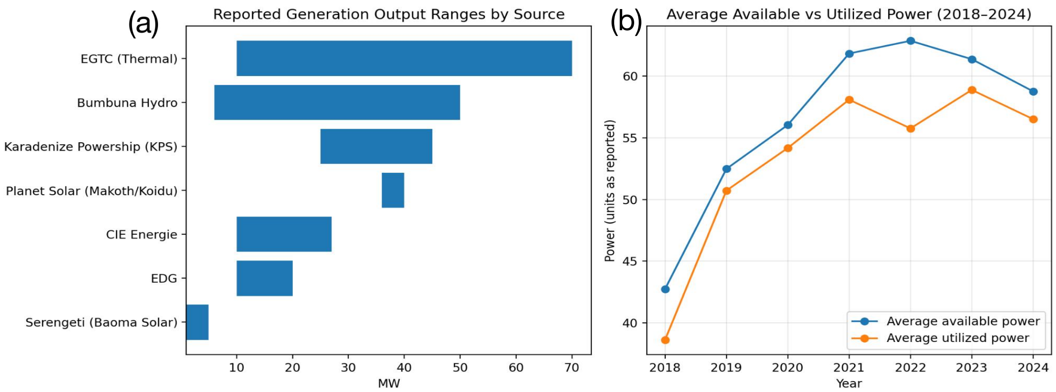

Figure 1. Sierra Leone grid power indicators: (a) reported generation output ranges by source; (b) average available and utilized grid power, 2018–2024

Several prior studies reported that reliability is as important as access itself. As such, reliability indicators, as reported by EDSA, show that long-run gains have not been fully sustained. SAIDI fell from 101.24 hours in 2017 to 15.14 hours in 2023, but increased to 18.48 hours in 2024 [22]. SAIFI declined from 35.36 in 2017, to around 24.04 to 24.17 in 2023 and 2024 respectively [22]. A key concern is restoration time: CAIDI, which rose from 0.63 hours in 2023 to 9.63 hours in 2024 [22]. This is implying that outages became much longer on average. Operational disruption is still large, total interruptions increased from 7, 178 in 2023 to 11, 908 in 2024, and average customers affected also rose from 222, 199 in 2023 to 230, 770 in 2024 [22]. These patterns help explain why access can coexist with weak growth dividends, as unreliable supply puts severe challenges on productive electricity use and raises coping costs for firms and households. Figure 2 below visualizes these indicators for better understanding.

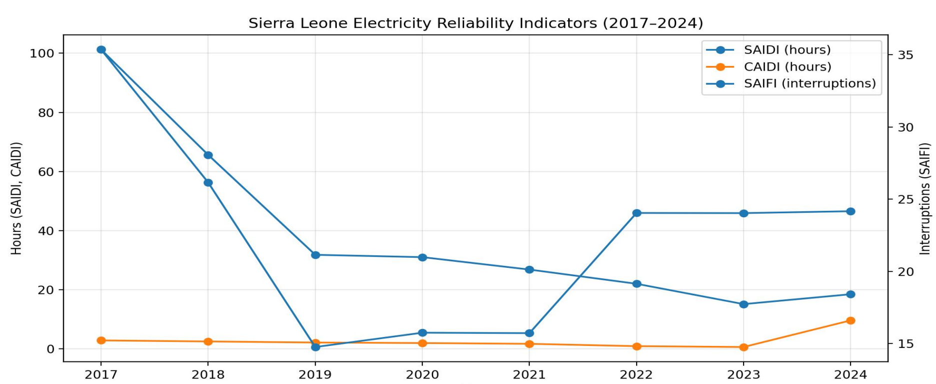

Figure 2. Electricity reliability indicators in Sierra Leone, including SAIDI, SAIFI, CAIDI, interruptions, and customers affected.

The sector's commercial and financial position also explains these reliability constraints. EDSA reported collections of NLe 1, 464, 653, 000 in 2024 and NLe 945, 543, 000 from January–August 2025, with an average monthly collection of NLe 118, 193, 000 over that period [22]. However, the arrears and losses are significant: MDAs and individual government officials reportedly owed NLe 552.05 million (which is about US$23 million) as of August 2025 [22]. System losses increased from 41.65% in 2022 to 49.92% in 2023, and 54.36% in 2024 [22]. High losses and weak payment discipline reduce cashflow for maintenance and investment. This in turn seriously undermines reliability and impedes the growth benefits of electrification. Figure 3 below visualizes the data explained above.

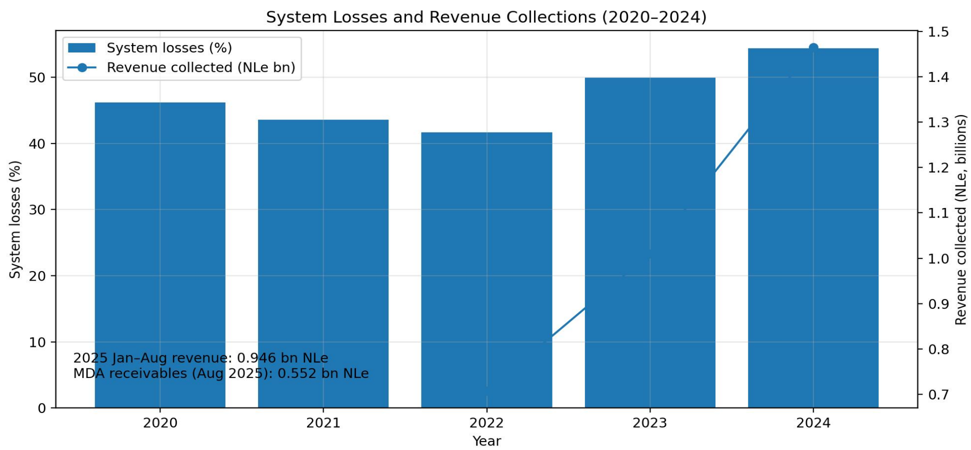

Figure 3. EDSA commercial and operational performance indicators, including collections, arrears, and system losses.

However, Sierra Leone's US$480 million Millennium Challenge Corporation compact, signed on 27 September 2024, is a major near-term chance to turn electricity access into real productivity gains. It targets the three bottlenecks that usually weaken the electricity–growth link: fragile networks, high losses and poor reliability, and weak institutions.

The compact is built around three projects. The Transmission Backbone Project focuses on expanding and modernizing the transmission system, strengthening system operations, facilitating regional power trade and the integration of new generation. The Distribution and Access Project aim to upgrade an overloaded distribution network, reduce losses, improve reliability and also supporting new and regularized connections; it includes both a main and backup dispatch center to improve operational control. The Power Sector Reform Project is designed to strengthen sector sustainability by improving regulation, planning capacity, cost-of-service management, and the conditions needed for private investment in generation and financing. From a growth perspective, this structure fits well with the needs of the Nation's electricity. It is about adding connections; it is about making electricity reliable and creating the institutional and investment conditions that can position electrification to drive higher output.

Furthermore, even though electricity is seen as essential for development, the existing research does not still show a clear link between common electricity metrics and economic performance (GDP or GDP per capita).

The major gap is the access - growth disconnect: which, in essence, means that connection rates can increase with immediate or long-term gains, or without measurable gains in output. The evidence is also mixed on whether electricity consumption is a stronger driver of growth, since higher consumption may mean more productive activity.

3. Research Methodology

3.1. Analytical framework and model specification

This study examines the relationship between electricity access, electricity consumption, and economic performance in Sierra Leone using annual time-series data for 2000–2024. The empirical framework is motivated by infrastructure-augmented growth theory, which treats energy services and productive infrastructure as factors that enhance productivity, lower transaction costs, and support long-run income growth. In this context, economic performance is proxied by real GDP per capita, and electricity access and electricity consumption are treated as conceptually distinct dimensions of electrification. The model also includes investment, trade openness, and inflation as standard macroeconomic controls to avoid attributing broader macroeconomic movements to electricity variables alone.

The long-run empirical relationship is specified as:

$$GDPPC_t = f(EA_t, EC_t, INV_t, OPN_t, INF_t)$$

where is real GDP per capita, is electricity access, is electric power consumption per capita, is gross capital formation, is trade openness, and is inflation. Because the variables are expressed in natural logarithms, the estimated long-run coefficients can be interpreted as elasticities.

3.2. Definition and measurement of variables

Real GDP per capita is measured as GDP divided by midyear population in constant 2015 US dollars. Electricity access is measured as the percentage of the population with access to electricity, electric power consumption per capita measures electricity production net of own use and transmission-related losses, divided by midyear population. Gross capital formation captures additions to fixed assets and inventories as a share of GDP. Trade openness is measured as the sum of exports and imports of goods and services relative to GDP. Inflation is measured by the annual percentage change in the consumer price index. These indicators are sourced primarily from the World Bank's World Development Indicators (Table 1).

Table 1. Variable definitions, measurements, and expected signs.

Variable	Symbol	Measurement	Expected sign
Real GDP per capita	(GDPPC)	GDP per capita (constant 2015 US$)	Dependent variable
Electricity access	(EA)	Access to electricity (% of population)	(+)
Electricity consumption	(EC)	Electric power consumption (kWh per capita)	(+)
Investment	(INV)	Gross capital formation (% of GDP)	(+)
Trade openness	(OPN)	Trade (% of GDP)	(+/-)
Inflation	(INF)	Inflation, consumer prices (annual %)	(-)

3.3. Estimation Strategy

Given the short annual sample and the possibility that the regressors are integrated of different orders, the study employs the Autoregressive Distributed Lag (ARDL) bounds-testing approach to cointegration and its Unrestricted Error Correction Model (UECM) representation. The study employs the Autoregressive Distributed Lag (ARDL) bounds-testing approach because it is appropriate when the variables are integrated of order $I(0)$ and/or $I(1)$, provided that none is $I(2)$, and it is also well suited to small-sample time-series analysis [26].

The general ARDL $(p, q_1, q_2, q_3, q_4, q_5)$ specification is written as:

$$\ln GDPPC_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \ln GDPPC_{t-i} + \sum_{j=0}^{q_1} \delta_j \ln EA_{t-j} + \sum_{k=0}^{q_2} \phi_k \ln EC_{t-k} + \sum_{l=0}^{q_3} \gamma_l \ln INV_{t-l} + \sum_{m=0}^{q_4} \theta_m \ln OPN_{t-m} + \sum_{n=0}^{q_5} \psi_n \ln INF_{t-n} + u_t$$

To ensure the suitability of this framework, the study first applies the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit-root tests. The ADF test is used to assess whether each series contains a unit root [23], and the PP test provides a non-parametric correction for serial correlation and heteroskedasticity in the error process [27]. The ARDL bounds test is then used to examine whether a long-run level relationship exists among the variables.

The bounds-testing equation is estimated in UECM form:

$$\begin{aligned}\Delta\ln GDPPC_t = \alpha_0 &+ \sum_{i=1}^{p-1}\alpha_i^*\Delta\ln GDPPC_{t-i} + \sum_{j=0}^{q_1-1}\delta_j^*\Delta\ln EA_{t-j} + \sum_{k=0}^{q_2-1}\phi_k^*\Delta\ln EC_{t-k} + \sum_{l=0}^{q_3-1}\gamma_l^*\Delta\ln INV_{t-l}\\ &+ \sum_{m=0}^{q_4-1}\theta_m^*\Delta\ln OPN_{t-m} + \sum_{n=0}^{q_5-1}\psi_n^*\Delta\ln INF_{t-n} + \lambda_1\ln GDPPC_{t-1} + \lambda_2\ln EA_{t-1} + \lambda_3\ln EC_{t-1}\\ &+ \lambda_4\ln INV_{t-1} + \lambda_5\ln OPN_{t-1} + \lambda_6\ln INF_{t-1} + \mu_t\end{aligned}$$

The null hypothesis of no cointegration is tested as: $H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = 0$

If cointegration is confirmed, the short-run dynamics are interpreted through the error-correction model: $\Delta\ln GDPPC_t = \eta_0 + \sum\eta_i\Delta X_{t-i} + \rho ECT_{t-1} + \nu_t$

where is the lagged error-correction term derived from the estimated long-run equation, and measures the speed at which the system returns to equilibrium after a shock. A negative and statistically significant coefficient on indicates convergence toward the long-run equilibrium.

3.4. Lag-length selection

Lag length is selected carefully because the sample contains only 25 annual observations. To avoid overfitting and unstable dynamic specifications, the study begins with information-criterion-based lag selection, using the Akaike Information Criterion under conservative maximum lag limits. The final specification is then chosen on the basis of parsimony and dynamic stability. In the present study, the stable model retained for estimation is ARDL(1, 1, 1, 1, 1, 1).

3.5. Diagnostic and stability tests

To assess the adequacy of the estimated model, the study applies standard post-estimation diagnostic tests. Residual normality is evaluated using the Jarque–Bera test, heteroskedasticity is examined using the Breusch–Pagan test, and serial correlation is tested using the Breusch–Godfrey LM test, which is appropriate in dynamic regressions that include lagged dependent variables. Parameter stability is further examined using the CUSUM and CUSUMSQ tests, which are based on recursive residuals and are designed to detect gradual parameter drift and more abrupt structural instability over time [24].

3.6. Data type and sources

The study used annual secondary macroeconomic time-series data for Sierra Leone covering 2000–2024. The core indicators are sourced from the World Bank's World Development Indicators (WDI). Electricity-sector information is complemented, where necessary, with data from national and sector institutions, including the Electricity Distribution and Supply Authority (EDSA), the Bank of Sierra Leone, and the Ministry of Finance, Sierra Leone, and other official publications.

4. Empirical Reults

4.1.1. Descriptive statistics and correlation analysis

All variables record positive mean values (Table 2). The mean of ln (GDP per capita) is the largest, which explains the scale of income relative to the other macroeconomic indicators used in the model. In terms of distributional shape, ln (GDP per capita), ln (electricity consumption), ln (investment), and ln (trade openness) are negatively skewed, which implies that observations are more concentrated above the mean with a longer left tail. By contrast, ln (electricity access) and ln (inflation) show slight positive skewness. Ln (investment) shows comparatively high kurtosis that is consistent with episodic spikes in capital formation during specific years of the sample.

Also, the correlation matrix indicates that ln (GDP per capita) is positively correlated with electricity access, electricity consumption, and investment (Table 3). This trend is consistent with infrastructure-augmented growth arguments that improved energy services and capital deepening support productivity and income over time [25]. Inflation is negatively correlated with ln (GDP per capita). This is also consistent with the standard view that macro-instability undermines real income growth and investment incentives.

Table 2. Results of descriptive statistics.

Statistic	Ln (GDPPC)	Ln (EA)	Ln (EC)	Ln (INV)	Ln (OPN)	Ln (INF)
Mean	6.839592	2.812118	2.655128	2.652555	3.648694	2.641413
Median	6.871689	2.821379	2.754297	2.730543	3.726208	2.598746
Maximum	7.044748	3.583519	3.490429	3.840429	4.052306	3.863733
Minimum	6.464645	2.04122	1.252763	0.092406	3.056668	1.534566
Std. Dev.	0.145956	0.444966	0.505983	0.66014	0.301384	0.668442
Skewness	-0.760299	0.083672	-1.03079	-2.211975	-0.820576	0.217192
Kurtosis	3.287477	2.018829	4.713278	12.535249	2.699191	2.099293

Source: Author's computation (2026), Note: GDPPC = GDP per capita; EA = electricity access; EC = electricity consumption per capita; INV = investment (gross capital formation); OPN = trade openness; INF = inflation. All variables are in natural logs as defined in the methodology.

Table 3. Correlation matrix.

Variable	Ln (GDPPC)	Ln (EA)	Ln (EC)	Ln (INV)	Ln (OPN)	Ln (INF)
ln(GDPPC)	1	0.838526	0.499274	0.55003	0.227351	-0.309792
ln(EA)	0.838526	1	0.654573	0.438509	0.173708	0.052997
ln(EC)	0.499274	0.654573	1	0.357021	0.436846	0.245948
ln(INV)	0.55003	0.438509	0.357021	1	-0.02691	-0.293359
ln(OPN)	0.227351	0.173708	0.436846	-0.02691	1	0.195643
ln(INF)	-0.309792	0.052997	0.245948	-0.293359	0.195643	1

Source: Author's computation (2026)

4.2. Stationarity test results

Although ARDL bounds testing can be applied when regressors are a mix of I(0) and I(1), it is essential to confirm that none of the variables is integrated of order two, I(2), because the bounds critical values are not valid in the presence of I(2) series [26]. Accordingly, the study applied the Augmented Dickey–Fuller (ADF) test [23] and the Phillips–Perron (PP) test [27] to each logged series in levels and first differences (Table 4). The test results show that the variables are non-stationary in levels but become stationary after first differencing, thus implying that they are integrated of order one, I(1), and none is I(2). This satisfies the core requirement for applying the ARDL bounds testing approach [26].

Table 4. Stationarity test results (ADF and PP).

Variable	ADF p (Level)	PP p (Level)	ADF p (1st Diff)	PP p (1st Diff)	Order of Integration
lnEA	0.942433	0.831404	0.000000	0.000000	I(1)
lnEC	0.562024	0.802845	0.009092	0.002807	I(1)
lnINV	0.309384	0.000000	0.004470	0.000000	I(1)
lnGDPPC	0.603175	0.681876	0.000680	0.000000	I(1)
lnINF	0.479013	0.599426	0.002701	0.005277	I(1)
lnOPN	0.062459	0.170960	0.000068	0.000000	I(1)

Source: Author's computation.

Note: ADF = Augmented Dickey–Fuller test; PP = Phillips–Perron test; p = p-value; 1st Diff = first difference; I(1) = integrated of order one, meaning the series becomes stationary after first differencing. ln denotes natural logarithm. EA = electricity access; EC = electricity consumption per capita; INV = investment, measured by gross capital formation as a percentage of GDP; GDPPC = GDP per capita; INF = inflation; and OPN = trade openness, measured as trade as a percentage of GDP

4.3. Lag length selection

With a small annual sample (25 observations), which is essentially because of the unavailability of more data for previous years, and several regressors, large lag orders can overfit the data and destabilize the estimated dynamics. An initial automatic lag selection based on AIC was attempted under conservative maximum lags (maximum AR lag = 2; maximum distributed lags = 2). However, the automatically selected specification did not satisfy the stability screen (Table 5). The analysis therefore adopted a parsimonious and stable model: ARDL (1, 1, 1, 1, 1, 1). This choice is consistent with good practice in short samples, where parsimony is crucial to preserve degrees of freedom and avoid unstable parameter estimates [26].

Table 5. Final lag structure used for estimation.

Variable	Lag Order Used
ln (GDP per capita)	1
ln (Electricity access)	1
ln (Electricity consumption per capita)	1
ln (Investment: GCF % of GDP)	1
ln (Trade openness: Trade % of GDP)	1
ln (Inflation)	1

Source: Author's computation.

4.4. Bounds test for cointegration analysis

The ARDL bounds test evaluated the null hypothesis of no cointegration (no long-run level relationship). The reported F-statistic is 5.070, with corresponding p-values indicating rejection of the null. In the bounds framework, this supports the existence of a stable long-run relationship among ln(GDP per capita) and the model regressors (Table 6).

Table 6. ARDL bounds test for cointegration result.

Test Statistic	Value	Null Hypothesis	Decision
F-statistic	5.07002	No cointegration	Reject null

Source: Author's computation.

4.5. Long run regression result

Because the model is estimated in log–log form, the long-run coefficients are interpreted as elasticities. The long-run estimates indicate that electricity access has a positive elasticity of approximately 0.07, implying that, holding other factors constant, higher access is associated with higher long-run income per capita. This is consistent with infrastructure-augmented growth evidence that improved infrastructure quantity and quality support long-run productivity and income [25].

In contrast, electricity consumption per capita has a near-zero long-run elasticity (that is slightly negative and economically negligible). In Sierra Leone's context, this pattern is plausible because measured consumption can rise without proportional productivity gains if electricity is unreliable or if additional electricity is absorbed largely by non-productive uses rather than by firm expansion and technology adoption. Another evidence on power-quality constraints in Freetown showed severe and spatially unequal outages that can suppress effective electricity use in businesses, even among connected users [7].

The estimates also show that investment (gross capital formation) has the strongest positive long-run association with income: a 1% increase in investment is associated with approximately 0.22% higher GDP per capita in the long run. This is in line with growth mechanisms in which sustained capital accumulation expands productive capacity and raises steady-state income [28]. Trade openness has a small negative long-run elasticity (Table 7). In small import-dependent economies, this sign can be a reflection of the trade structure (e.g., import dominance and leakage effects) rather than indicating that trade is intrinsically harmful. Finally, inflation shows a small positive long-run coefficient. This should be interpreted cautiously, since inflation in Sierra Leone has been volatile; such a coefficient may reflect cyclical co-movement during recovery periods rather than a causal growth benefit [16].

Table 7. ARDL/UECM long-run elasticities.

Variable	Long-run Elasticity	Economic Interpretation (Long Run)
lnEA	0.07181	Electrification expansion is growth-supporting (productivity and welfare channel).
lnEC	-0.000779	Effect is economically negligible; may reflect reliability/efficiency constraints.
lnINV	0.21951	Investment-driven capital deepening raises long-run income per capita.
lnOPN	-0.008573	Weak/negative effect consistent with import-heavy openness structure.
lnINF	0.078148	Caution: may reflect cyclical regimes or co-movement rather than inflation being growth-enhancing.

Source: Author's computation.

4.6. Short run error correction model (uecm) result

The error-correction term (ECT) is negative, indicating convergence back toward the long-run equilibrium after the occurrence of shocks (Table 8). The estimated adjustment coefficient is approximately −0.393, implying that about 39% of the previous year's disequilibrium is corrected within one year. This is the expected sign in an error-correction framework when a stable long-run relationship exists [26].

In the short run, the first-difference coefficients for electricity access, electricity consumption, investment, trade openness, and inflation are statistically weak in this annual sample. This is not unusual in macro time-series with limited observations, where year-to-year noise, policy lags, and measurement limitations can reduce statistical power and obscure short-term effects.

Table 8. Error correction model representation for selected ARDL model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.334476	1.222944	1.908898	0.080475
D(LNEA)	-0.077701	0.064682	-1.201270	0.252820
D(LNEC)	0.021648	0.033125	0.653535	0.525737
D(LNINV)	-0.020037	0.028047	-0.714400	0.488645
D(LNOPN)	0.015678	0.045704	0.343044	0.737500
D(LNINF)	0.045276	0.033539	1.349951	0.201946
ECT(-1)	-0.392668	0.210039	-1.869501	0.086142

Source: Author's computation. **Note:** D(.) denotes first difference. ECT(-1) is the lagged error correction term.

4.7. Diagnostic Tests

To validate the reliability of the estimated UECM, diagnostic checks were conducted for normality, serial correlation, and heteroskedasticity of residuals (Table 9). The respective null hypotheses are: (i) residuals are normally distributed, (ii) no serial correlation, and (iii) homoskedasticity. These diagnostic categories are standard in applied time-series regression to verify that inference is not distorted by residual non-normality, autocorrelation, or non-constant variance [29].

Table 9. Results of diagnostic tests (UECM residuals).

Test	Result	Conclusion
Normality (Jarque–Bera)	JB p-value = 0.436	Residuals are approximately normally distributed
Serial correlation (Breusch–Godfrey, 2 lags)	F p-value = 0.380; LM p-value = 0.413	No evidence of serial correlation up to 2 lags (F p = 0.380; LM p = 0.413); fail to reject the null of no autocorrelation at conventional levels.
Heteroscedasticity (Breusch–Pagan)	BP p-value = 0.199	No strong evidence of heteroscedasticity

Source: Author's computation.

4.8. Stability Test

CUSUM

The CUSUM test assesses whether the model parameters drift gradually over time (Figure 4). Because the CUSUM line stays within the 5% critical bounds, the null of parameter stability is not rejected at conventional significance levels. This supports the interpretation that the estimated relationship between income per capita and the electricity/investment/trade/inflation variables is broadly stable over the sample [24].

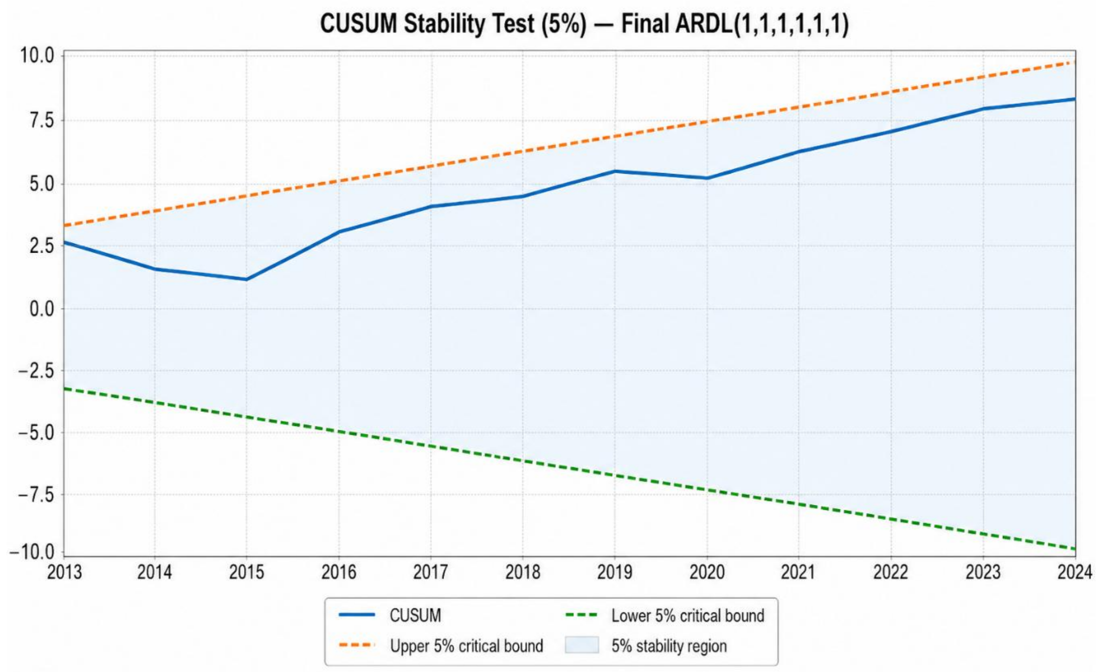

Figure 4. CUSUM stability test for the estimated ARDL/UECM model.

CUSUMSQ

CUSUMSQ is more sensitive to abrupt structural change and volatility shifts (Figure 5). The plot indicates at least one excursion near the stability boundary around 2016. This timing is consistent with Sierra Leone's mid-2010s shock environment, including the Ebola crisis period and subsequent macro-fiscal stress [30]. However, since the overall pattern does not indicate sustained and statistically significant instability at the 5% level, the model is treated as sufficiently stable for interpretation [24].

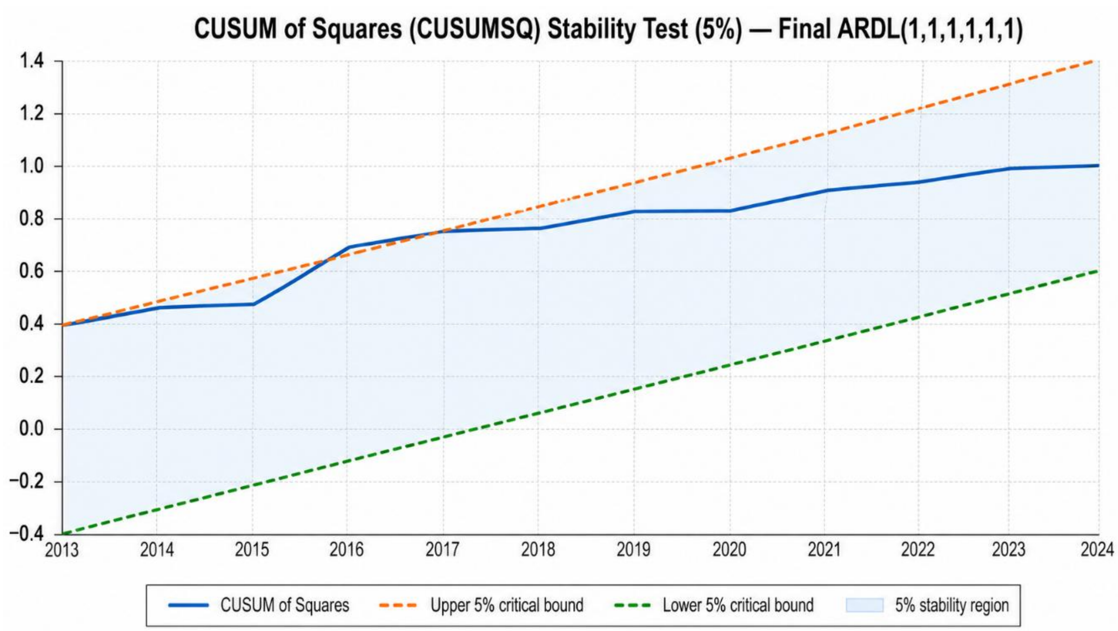

Figure 5. CUSUMSQ stability test for the estimated ARDL/UECM model.

5. Discussion

The ARDL bounds results indicate the presence of a stable long-run relationship between economic performance and the set of electricity and macroeconomic variables included in the model. This broad result is consistent with recent African evidence showing that electricity is an important long-run driver of economic activity, even though the strength and direction of the relationship vary across settings and according to the specific dimension of electrification being measured [4, 3].

The positive long-run coefficient on electricity access suggests that expanding electrification supports income growth over time. This interpretation is in line with newer evidence that electricity access improves economic participation and development outcomes when it increases the ability of households and firms to participate more effectively in modern economic activity. Also, the negligible coefficient on electricity consumption suggests that being connected and actually receiving electricity of sufficient quality for productive use are not the same thing. Recent Sierra Leone evidence supports this interpretation. Osunmuyiwa and Wall [7] showed that poor electricity quality and reliability materially constrain MSME productivity in Freetown, and Meriggi and Mével [13] found that unreliable electricity imposes substantial costs on SMEs and that current coping mechanisms do not fully offset those losses. More broadly, recent review evidence showed that electricity access does not always produce positive development outcomes when service capacity, affordability, and reliability are weak [31].

The strong positive coefficient on investment reinforces the argument that electrification generates larger economic payoffs when it is complemented by capital deepening and other productive investments. Recent synthesis work showed that the benefits of electrification vary with complementary investments, and World Bank research on Africa argued that electricity access alone does not automatically lead to productive use unless firms and households face an enabling environment that includes complementary infrastructure, finance, and local economic opportunities. This makes the Sierra Leone result economically plausible: electricity access appears more growth-supporting when accompanied by investment that position users to convert electricity into machinery use, agro-processing, service delivery, and business expansion.

The negative coefficient on trade openness should be interpreted cautiously. In Sierra Leone’s case, it is a reflection of the structure of openness in a small, import-dependent and externally fragile economy. Similarly, the positive inflation coefficient should not be interpreted as evidence that inflation promotes growth. Given Sierra Leone’s recent macroeconomic environment of high inflation, fiscal strain, and power-sector subsidy pressures, the inflation term is more plausibly capturing cyclical co-movement and post-shock adjustment and not a genuine growth benefit from rising prices [16, 2]. Finally, the weak short-run coefficients are not unusual in annual macroeconomic data, especially where infrastructure effects operate with lags and where short-run outcomes are affected by reliability problems, macro volatility, and institutional frictions.

6. Conclusion and recommendations

The findings of this study point to a clear policy message for Sierra Leone. Electricity access is positively associated with long-run economic performance, but the growth payoff from electrification depends less on the simple expansion of connections and more on whether access lead to reliable, usable, and productive electricity service. The weak role of electricity consumption in the long run suggests that connection is not enough where outages, and affordability constraints can prevent electricity from being converted into meaningful productive activity. By contrast, the strong positive contribution of investment indicates that electrification is more likely to support income growth when it is complemented by capital deepening and a broader enabling environment for firms and households.

This simply imply that Sierra Leone’s electricity strategy should move beyond counting new connections and place greater emphasis on effective service delivery. Improving feeder performance, reducing outages, strengthening voltage stability, and addressing technical and commercial losses would do more to convert electrification into growth than connection expansion. The findings also suggest that productive uses of electricity should be more deliberately integrated into energy policy, especially through support for small enterprises, and other activities that utilize electricity to raise output and incomes. In addition, stronger sector governance is essential. A credible and financially sustainable power sector would help reduce stop–go cycles in electricity provision, improve maintenance and operations, and create the stability needed for electrification to yield broader economic returns.

Overall, the study shows that electricity is essential for development in Sierra Leone, but that the nature of that contribution is conditional. What drives growth is not merely access in a nominal sense, but access that is reliable, affordable, and embedded in a broader investment and institutional framework. Future research could build on this by incorporating more direct measures of electricity reliability, losses, and power quality, as better data become available, in order to deepen understanding of how electrification can more effectively support inclusive economic transformation.

Ethics approval/declaration: This study did not involve human participants, animal subjects, clinical materials, household surveys, interviews, experiments, or the collection of personal or sensitive data. The analysis was based entirely on secondary annual macroeconomic and electricity-sector time-series data for Sierra Leone covering 2000–2024, obtained from publicly available and official institutional sources, including the World Bank's World Development Indicators and relevant national electricity-sector institutions. Therefore, formal ethical approval was not required

Consent to participate: Not applicable. This study did not involve human participants.

Consent for publication: Not applicable.

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