ELECTRICITY CONSUMPTION AND MANUFACTURING OUTPUT IN SUB-SAHARAN AFRICA: A REGIONAL COMPARATIVE PANEL ANALYSIS (1995-2024)

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Abstract

This paper examines whether electricity consumption's effect on manufacturing output in Sub-Saharan Africa (SSA) is uniform across the region or conditioned by structural differences between its sub-regions. Using annual panel data (1995-2024) for fifteen SSA countries across East, West, Central, and Southern Africa, the study applies second-generation panel techniques Pesaran's cross-sectional dependence test, the CSADF panel unit root test, Westerlund cointegration, and the CS-ARDL/PMG estimator separately to each sub-region. The results reveal marked heterogeneity: electricity consumption has a positive and significant effect on manufacturing output in East, West, and Southern Africa, both short- and long-run, but a negative and insignificant effect in Central Africa. Institutional quality (rule of law) significantly strengthens the relationship in West Africa but is negatively associated with manufacturing output in Central Africa. The findings show that the electricity-manufacturing nexus in SSA cannot be meaningfully understood or acted upon by policy at the regional level alone, since sub-regional infrastructural and institutional differences alter both the sign and significance of the relationship. The paper concludes with region-differentiated policy recommendations.

Keywords: *electricity consumption, manufacturing output, Sub-Saharan Africa, regional heterogeneity, panel ARDL, cross-sectional dependence.*

JEL Classification: *Q41, L60, O14, O55, C23*

1. Introduction

Reliable electricity supply is widely regarded as a precondition for industrial competitiveness, yet Sub-Saharan Africa (SSA) continues to record some of the lowest electricity access and consumption levels in the world. Average per-capita electricity consumption in the region ranges between 430 and 450 kWh, against a global average of roughly 2,167 kWh, and firms across the region report an average of eight to ten power outages per month, with associated productivity losses estimated at 6-8 percent annually (International Energy Agency [IEA], 2023).

Manufacturing value added in SSA has remained stagnant at 11-12 percent of GDP for more than a decade, far below the 20-30 percent typical of successfully industrialised economies (African Development Bank [AfDB], 2024).

What is less well established in the empirical literature, however, is whether this electricity–manufacturing relationship holds uniformly across SSA, or whether it is conditioned by the region's substantial internal diversity in infrastructure, institutional quality, and industrial capacity. Existing cross-country studies of SSA (e.g., Anyanwu, 2024; Anyanwu & Kur, 2024; Effiong, 2025) typically pool all countries into a single panel and report an average regional effect, while single-country studies (e.g., Onwe & King, 2020, for Nigeria; Tshuma & Choga, 2022, for South Africa) cannot speak to regional comparison by design. Sub-regional evidence remains comparatively scarce, with the main exceptions being Aderemi and Sikwela (2025) for ECOWAS and Mmbaga (2024) for Eastern Africa both singles sub-regions rather than a comparative treatment of SSA's major sub-regions side by side.

This paper addresses this gap directly. Rather than estimating a single pooled coefficient for the whole of SSA, the paper explicitly partitions the panel into four sub-regions which include; East Africa, West Africa, Central Africa, and Southern Africa and re-estimates the electricity-manufacturing relationship separately within each, using an identical model specification and estimation technique throughout to ensure that any differences in findings reflect genuine structural heterogeneity rather than methodological inconsistency. The paper's specific objective is to examine the effect of electricity consumption on manufacturing output across the different regions of Sub-Saharan Africa, and its guiding hypothesis (H0) is that electricity consumption has no significant effect on manufacturing output across the regions of Sub-Saharan Africa.

The remainder of the paper is organized as follows. Section 2 reviews the theoretical and empirical literature, with particular attention to sub-regional and cross-country evidence. Section 3 presents the data and econometric methodology. Section 4 presents and discusses the regional estimation results. Section 5 concludes with region-differentiated policy recommendations.

2.1 Literature Review

According to United Nations Industrial Development Organization (UNIDO, 2024) defines electricity consumption as the electrical energy utilized in production activities, which directly influences manufacturing output and productivity. Likewise, the African Development Bank (AfDB, 2024) highlights electricity consumption as a key determinant of industrial competitiveness and economic growth, particularly in developing regions such as Sub-Saharan Africa. However, the African Development Bank (AfDB, 2024) defines manufacturing output as the contribution of the manufacturing sector to Gross Domestic Product (GDP), typically measured as manufacturing value added at constant prices. Similarly, International Monetary Fund (IMF, 2024) views manufacturing output as the real production level of manufacturing industries, often proxy by industrial production indices.

2.2 Theoretical Framework

This paper draws on two complementary theoretical perspectives. The Energy-Led Growth Hypothesis (ELGH), originating with Kraft and Kraft (1978) and extended by Ozturk (2010), treats energy and electricity specifically not merely as a production input but as an active driver of industrial and economic growth. The theory argued that increases in electricity availability enable continuous production, support technological adoption, and permit industrial expansion, implying a broadly unidirectional causal channel running from electricity consumption to manufacturing output. Endogenous Growth Theory, associated with Lucas (1988) and Romer (1990), complements this by explaining the mechanism through which reliable electricity supply raises long-run productivity, it allows firms to adopt modern machinery and automation, absorb technological spillovers, and make fuller use of human capital. Read together, the two theories predict that electricity consumption should support manufacturing output, but that the strength of this relationship should itself depend on the underlying industrial and institutional capacity of the economy in question a proposition that motivates a sub-regional, rather than a purely pooled, empirical test.

2.2 Empirical Literature

A growing empirical literature confirms a positive electricity industrial output relationship in SSA and comparable developing regions, though findings on the strength and consistency of this relationship vary considerably by geography and methodology. Aderemi and Sikwela (2025) examined the relationship between electricity consumption and industrial output across ECOWAS (West African) countries over 2000-2023 using panel dynamic OLS and Granger causality tests, and found that electricity consumption exerted a significant positive long-run effect on industrial output, with unidirectional causality running from electricity consumption to industrial output. Onatunji (2022), also focused on ECOWAS but over a longer 1971-2017 window using ARDL bounds testing with Toda-Yamamoto and bootstrap-corrected causality tests, found that increasing electricity supply enhanced industrial output in several member states including Benin, Côte d'Ivoire, the Gambia, Guinea, Liberia, Nigeria, Senegal, and Sierra Leone but explicitly noted heterogeneity in the size and significance of the effect across countries, without identifying its structural source. Adebisi, Alenoghena and Charles (2023), focusing specifically on Nigeria, examined the impact of energy supply on economic growth and found a statistically significant positive relationship, reinforcing the case for treating electricity supply as a binding constraint on West Africa's largest economy rather than a marginal one.

Mmbaga (2024) examined the short- and long-run impacts of electricity consumption on economic growth in Eastern Africa specifically, using a panel ARDL model over 2000-2021, and found that electricity consumption significantly enhanced GDP in both the short and long run, though the study left the direction of causality between electricity consumption and growth unresolved. Tshuma and Choga (2022) took a different, reliability-focused approach for South Africa (1994–2020), applying a Structural Vector Autoregressive (SVAR) model and finding that electricity supply shock that is, outages significantly reduced industrial production, while stable provision had a positive effect, underscoring that reliability, not consumption volume alone, may be the binding constraint in more industrially developed Southern African economies. This reliability-focused finding is reinforced by Ziramba (2009), who examined disaggregated energy consumption and industrial production in South Africa using the ARDL bounds testing approach and Toda-Yamamoto causality tests, and found that industrial production and employment function as long-run forcing variables for electricity consumption that is, causality runs predominantly from industrial output to electricity demand in South Africa's relatively mature industrial base, a pattern more consistent with Wagner's Law than with the Energy-Led Growth Hypothesis, and one that stands in contrast to the unidirectional electricity-to-output causality found in the less industrially developed ECOWAS economies studied by Aderemi and Sikwela (2025). Extending this Southern African evidence across a wider country set, Hlongwane, Lenoke and Daw (2023) analysed electricity generation, supply, and economic growth across selected SADC countries and found a generally positive relationship between electricity generation capacity and growth, though the strength of the relationship varied by country depending on the extent of generation diversification and grid reliability.

For Central Africa specifically, direct sub-regional evidence is scarcer, though Amadu and Samuel (2020) examined the effect of electricity supply on manufacturing growth in Cameroon using Fully Modified Ordinary Least Squares (FMOLS) for 1977-2014 and found a strong positive long-run relationship between power supply and manufacturing performance, with reductions in electricity supply significantly hindering growth a finding that, notably, runs counter to what this paper finds for the Central African sub-region as a whole, and which is discussed further in Section 4.

At the pan-SSA level, pooled panel studies have generally reported positive average effects that mask this underlying heterogeneity. Anyanwu (2024) used fixed- and random-effects models on 32 SSA countries (2002-2019) and found that energy consumption positively influenced industrial

performance, with significantly stronger effects in countries with higher electrification rates an early signal, within a pooled framework, of the same underlying heterogeneity this paper investigates directly. Anyanwu and Kur (2024) similarly found a robust long-run positive linkage between energy consumption and industrial output across SSA using FMOLS, PMG, and GLM estimators that account for cross-country heterogeneity and dynamic adjustment. Bello and Oladipo (2021) disaggregated by energy source rather than geography, finding that renewable electricity consumption contributed more strongly to manufacturing output than non-renewable electricity across a panel of SSA countries (1990-2019), consistent with the possibility that the energy mix underlying a country's or sub-region's electricity supply not merely its volume shapes the manufacturing response. Moyo and Sicina (2020) found that countries with higher electricity intensity exhibited stronger manufacturing output, and that this link was strengthened by institutional quality a finding directly relevant to this paper's inclusion of rule of law and control of corruption as regional moderating variables.

The literature reviewed above consistently finds electricity consumption positively associated with industrial or manufacturing output in SSA when examined at the level of a single country or sub-region. What is missing is a study holding the model specification, sample period, and estimation technique constant across SSA's major sub-regions simultaneously so that any observed difference reflects genuine structural heterogeneity rather than variation in method or data across separate studies. This paper addresses that gap.

3. Data and Methodology

3.1 Nature and sources of data

The study adopts a quantitative panel research design covering fifteen SSA countries over 1995-2024, grouped into four sub-regions as follows: East Africa (Ethiopia, Kenya, Tanzania); West Africa (Benin Republic, Ghana, Nigeria, Senegal); Central Africa (Angola, Cameroon, the Republic of the Congo, the Democratic Republic of the Congo, Gabon); and Southern Africa (Botswana, Namibia, South Africa). This grouping follows standard African Union/UN sub-regional classification and was adopted so that the estimated coefficients can be interpreted against the shared infrastructural and institutional characteristics of each sub-region.

3.2 Data Sources and Variable Definitions

Table 1: Variable Definitions, Measurement, and Sources

Variables	Description/unit	Source
Manufacturing output (MANOUT)	Manufacturing value added, constant 2015 US$	World Development Indicators, 2025
Electricity consumption (ELEC)	Electric power consumption, kWh per capita	World Development Indicators, 2025
Economic development (GDP)	GDP per capita, constant 2015 US$	World Development Indicators, 2025
Capital accumulation (GFCF)	Gross fixed capital formation, % of GDP	World Development Indicators, 2025
Trade openness (TRD)	Trade, % of GDP	World Development Indicators, 2025
Rule of Law (ROL)	Rule of Law Estimate	World Governance Indicators, 2025
Control of Corruption (CCE)	Control of Corruption Estimate	World Governance Indicators, 2025

Source: author's computation, 2026.

3.3 Model Specification

Following the Energy-Led Growth Hypothesis and Endogenous Growth Theory outlined in Section 2.1, and adapting the general specification used in comparable SSA panel studies (e.g., Raifu, Nnadozie & Afolabi, 2025), the study specifies the following model, estimated separately for each sub-region r:

$$ln(MANOUT)\_it = \mu\_i + \beta 1\ ELEC\_it + \beta 2\ ROL\_it + \beta 3\ CCE\_it + \varepsilon\_it, \quad for\ i \in r$$

where MANOUT_it is manufacturing value added for country i in year t; ELEC_it is electricity consumption per capita; ROL_it and CCE_it are the rule of law and control of corruption estimates, included to capture the institutional-quality channel highlighted by Moyo and Sicina (2020); μ_i captures unobserved country-specific fixed effects; and ε_it is the error term. The model is estimated identically for each of the four sub-regions defined in Section 3.1, allowing direct comparison of the β1 (electricity) coefficient across regions.

3.4 Estimation Strategy

The estimation proceeds in four stages, following standard practice for panels where cross-country shocks are plausible a priori (energy shortages, commodity price cycles, and regional trade agreements are all shared across neighboring SSA economies).

The estimation proceeds in four stages, following standard practice for panels where cross-country shocks are plausible a priori. First, cross-sectional dependence (CD) is assessed: Pesaran's (2004) CD test is applied to each variable to determine whether first-generation panel techniques (which assume cross-sectional independence) are appropriate, or whether second-generation techniques are required. Second, panel unit root testing is conducted: given confirmed cross-sectional dependence, the Pesaran (2007) Cross-Sectionally Augmented Dickey-Fuller (CSADF) test, which is robust to cross-sectional dependence, is used to determine each variable's order of integration. Third, panel cointegration is tested using the Westerlund (2007) Error-Correction-based panel cointegration test, to determine whether a long-run equilibrium relationship exists among the variables. Finally, estimation is carried out using the Panel Autoregressive Distributed Lag – Cross-Sectionally Augmented Mean Group (CS-ARDL / Pooled Mean Group) estimator of Pesaran, Shin and Smith (1999), applied separately to each sub-regional sub-panel to yield short-run coefficients, an error-correction (adjustment) term, and long-run coefficients for each region

4. Results and Discussion

4.1 Cross-Sectional Dependence and Unit Root Results

Table 2 confirms that all model variables exhibit statistically significant cross-sectional dependence ($p < 0.05$), consistent with the expectation that SSA economies are linked through shared regional shocks such as commodity price movements, cross-border electricity trade, and common exposure to global financial conditions. This result justifies the use of the second-generation CSADF unit root test and the Westerlund cointegration approach rather than first-generation panel techniques

Table 2: Pesaran (2004) Cross-Sectional Dependence Test Results

Variables	CS Statistics	P-value
Manufacturing output	43.450	0.000
Electricity consumption	20.870	0.000
Economic development (GDP)	26.740	0.000
Rule of Law	1.210	0.000
Control of Corruption	-2.630	0.009

The Pesaran (2007) CSADF panel unit root test (not reproduced in full here; see the underlying dissertation for complete results) indicates that manufacturing output, electricity consumption, and GDP are integrated of order one, I(1), becoming stationary only after first differencing, while the institutional variables (rule of law, control of corruption) are stationary in levels, I(0). This mixed

order of integration confirms the appropriateness of the ARDL/CS-ARDL approach, which does not require all variables to share a common order of integration.

4.2 Regional Estimation Results

Table 3: CS-ARDL Mean Group Estimates of the Electricity–Manufacturing Output Relationship, by SSA Sub-Region

Variables	East Africa	West Africa	Central Africa	Southern Africa
Control of Corruption (CCE)	-0.0353 (0.0589)	-0.129 (0.106)	-0.111 (0.184)	-0.0399 (0.0506)
Electricity Consumption (ELEC)	0.00152*** (0.000351)	0.00125* (0.000648)	-0.000355 (0.000255)	0.000145*** (4.20e-05)
Rule of Law (ROL)	0.0947 (0.123)	0.191*** (0.0706)	-0.243* (0.138)	0.0198 (0.0429)
Lg Manufacturing Output	-0.151** (0.0674)	-0.264*** (0.0656)	-0.158** (0.0602)	-0.256*** (0.0725)
Long-run ELEC (lr_ELEC)	0.00130*** (0.000261)	0.00106* (0.000545)	-0.000296 (0.000203)	0.000118*** (3.62e-05)
Long-run ROL (lr_ROL)	0.0852 (0.113)	0.147*** (0.0481)	-0.201* (0.108)	0.0147 (0.0343)
Error Correction Term	-1.151*** (0.0674)	-1.264*** (0.0656)	-1.158*** (0.0602)	-1.256*** (0.0725)
Observations	87	116	116	116
R-squared	0.498	0.725	0.697	0.615
Number of countries	3	4	4	4

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

4.3 Discussion of Findings

The regional estimates in Table 3 show substantial heterogeneity in the electricity-manufacturing relationship across SSA, providing a direct empirical answer to the paper's guiding research question. In East Africa, electricity consumption has a positive and highly significant effect on manufacturing output in both the short run ($\beta = 0.00152$, $p < 0.01$) and the long run ($\beta = 0.00130$, $p < 0.01$), consistent with Mmbaga's (2024) finding that electricity consumption significantly enhances GDP in Eastern Africa in both the short and long run. Institutional variables are statistically insignificant in this sub-region, suggesting that in East Africa, infrastructure availability rather than governance quality is presently the binding constraint on translating electricity into manufacturing output.

In West Africa, electricity consumption also exerts a positive effect on manufacturing output, significant at the 10 percent level in both the short run ($\beta = 0.00125$) and long run ($\beta = 0.00106$) a

weaker but directionally consistent result with Aderemi and Sikwela's (2025) finding of a significant positive long-run ECOWAS-wide effect and Onatunji's (2022) finding of positive effects across several individual West African states. Distinctively, rule of law is positive and highly significant in West Africa ($\beta = 0.191$, $p < 0.01$ short run; 0.147, $p < 0.01$ long run), indicating that in this sub-region, institutional quality is not merely a background condition but an active complement to electricity supply in supporting manufacturing performance is plausibly because stronger contract enforcement and property rights protection allow firms to justify the sunk-cost investments (generators, voltage stabilizers, industrial estates) needed to convert available electricity into reliable production capacity.

In Southern Africa, electricity consumption again shows a positive and highly significant effect in both the short run ($\beta = 0.000145$, $p < 0.01$) and long run ($\beta = 0.000118$, $p < 0.01$), though the magnitude of the coefficient is considerably smaller than in East or West Africa. This is consistent with Tshuma and Choga's (2022) South Africa-specific finding that electricity supply shocks reduce industrial production, and may reflect the fact that Southern African manufacturing more electricity-intensive and further along the industrialisation path than the SSA average responds to consumption changes at the margin rather than showing the larger elasticities characteristic of a sub-region industrializing from a lower base.

Central Africa stands apart as the only sub-region in which electricity consumption shows a negative, and statistically insignificant, relationship with manufacturing output in both the short run ($\beta = -0.000355$) and long run ($\beta = -0.000296$). Rule of law is negative and marginally significant ($\beta = -0.243$, $p < 0.1$ short run; -0.201, $p < 0.1$ long run), the only sub-region in which institutional quality moves in the opposite direction to manufacturing output. Taken together, these results suggest that in Central Africa a sub-region dominated by resource-rich but institutionally fragile economies (Angola, Cameroon, Republic of the Congo, DR Congo, and Gabon) neither electricity supply nor governance quality is presently functioning as an effective lever for manufacturing growth, most plausibly because chronic underinvestment in generation and transmission infrastructure, combined with weak institutional enforcement, prevents available electricity from being reliably or productively channeled into industrial activity. This finding is notably at odds with Amadu and Samuel's (2020) single-country result for Cameroon, where electricity supply was found to have a strong positive long-run effect on manufacturing growth over 1977-2014; the divergence may reflect either genuine change in Cameroon's electricity-manufacturing relationship in more recent years, or the dilution of a country-

specific positive effect when Cameroon is pooled with weaker-performing neighbors in a sub-regional panel, a distinction that itself illustrates the value of sub-regional over purely national or fully pooled analysis.

Across all four sub-regions, the error correction term is negative, greater than one in absolute value, and highly significant (ranging from -1.151 in East Africa to -1.264 in West Africa). While a negative and significant error-correction coefficient is conventionally read as confirming adjustment toward long-run equilibrium, a coefficient whose absolute value exceeds one implies an oscillatory rather than smoothly monotonic adjustment path, the system overshoots equilibrium before correcting and this pattern, common across all four regressions, is worth flagging as a modeling characteristic rather than treated purely as evidence of "fast" adjustment.

5. Conclusion and Policy Recommendations

5.1 Conclusion

This paper set out to examine whether the effect of electricity consumption on manufacturing output in Sub-Saharan Africa is uniform across the region, using an identical model and estimation strategy applied separately to four SSA sub-regions over 1995-2024. The evidence firmly rejects the assumption of regional uniformity, electricity consumption significantly and positively influences manufacturing output in East Africa, West Africa, and Southern Africa, while showing no significant relationship indeed a negative point estimate in Central Africa. Institutional quality, proxies by the rule of law, is a significant positive complement to electricity supply specifically in West Africa, and a significant negative correlate of manufacturing output in Central Africa, pointing to sub-regionally distinct combinations of infrastructural and governance constraints.

5.2 Policy Recommendations

However, the study recommends that policymakers in East Africa should prioritize expanding electricity generation capacity and improving grid reliability through sustained investment in regional power infrastructure, particularly through the Eastern Africa Power Pool. In West Africa, governments should complement energy infrastructure investment with stronger contract enforcement and improved property rights protection to encourage productive private-sector investment. In Central Africa, policymakers should simultaneously address electricity generation and transmission deficits while strengthening institutional frameworks, supported by firm-level studies to identify the most binding

constraints to industrial development. Similarly, Southern African economies should focus on improving electricity reliability and reducing power outages rather than merely increasing electricity supply, given the regions relatively advanced industrial base. Furthermore, regional organizations such as the African Union (AU), ECOWAS, EAC, SADC, and ECCAS should promote coordinated regional energy and industrial policies to address cross-border shocks, reduce energy constraints, and strengthen regional economic integration

5.3 Limitations and Directions for Further Research

The study did not separately re-estimate the Westerlund cointegration test for each sub-region; future research should confirm sub-region-specific long-run relationships directly. The error-correction coefficients exceeding unity in absolute value also warrant further investigation to determine whether they reflect genuine adjustment dynamics or model specification issues. Finally, future studies should disaggregate Central Africa at the country level to determine whether the insignificant sub-regional result masks differences across individual countries.

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