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Energy and growth: A Cobb-Douglas comparative analysis of Egypt, Algeria and Nigeria

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ABSTRACT

This study explores the interplay between energy, capital, and labour as critical factors of production influencing economic growth in Algeria, Egypt, and Nigeria. The study determined a comparative analysis of the direction and impact of the energy-growth hypothesis on the economic growth of Algeria, Egypt, and Nigeria. Utilizing a modified Cobb-Douglas production model examined through Fully Modified Ordinary Least Squares (FMOLS) and other analytical techniques, the study analyzed time series data from 1990 to 2016 sourced from the World Development Index. The dependent variable analyzed in this study was GDP per capita, while the independent variables included capital (measured by gross capital formation), labour (represented by physically active individuals), and energy (indicated by electricity consumption) for Algeria, Egypt, and Nigeria, respectively. The findings revealed a significant positive relationship between capital and economic growth exclusively in Algeria, while no substantial effects were observed in Egypt and Nigeria. Conversely, labour consistently demonstrated a strong positive impact on economic development across all three countries, highlighting the labour-intensive nature of their economies. Electricity consumption was significantly linked to economic growth in Nigeria but showed no significant effects in Algeria and Egypt, indicating potential inefficiencies in their energy sectors. The study underscores the need for strategic physical capital investments, human capital development, and energy infrastructure to harness the full potential of these economies, thereby enhancing growth and sustainability in the region.

Contribution/Originality: This study contributes to the existing literature by integrating energy as a key factor of production in the Cobb-Douglas function, alongside capital and labor. It uniquely explores the interplay of these factors in influencing economic performance within developing countries, expanding the existing debate.

1. INTRODUCTION

The energy transition in the global economy from an organic (biomass/labor-based) model to an inorganic (fossil-based) one occurred at a swift pace (Erb & Gingrich, 2022). Pre-industrial economies relied almost entirely on plant photosynthesis for energy (food, wood fuel, animal feed) (Erb & Gingrich, 2022). Massive economic growth began with the Industrial Revolution in England during the 18th century, with heavy reliance on coal as a major source of energy (Turnbull, 2021). The transition from coal to oil and natural gas unlocked the vast stock of stored energy, enabling a massive and rapid increase in energy consumption and economic growth that was previously unachievable (Kalair, Abas, Saleem, Kalair, & Khan, 2021).

In alignment with this transition, the United Nations Sustainable Development Goal (SDG 7) seeks to ensure access to affordable, reliable, sustainable, and modern energy for all by 2030 (Agbaitoro & Oyibo, 2022; Minas et al., 2024). Energy is increasingly recognized as a crucial third factor of production, alongside capital and labour, making

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it an indispensable driver of economic growth (Asaleye, Garidzirai, & Ncanywa, 2025). Energy plays a vital role in all production processes, as transformations occur at multiple stages. Every economic activity, including services, relies on energy, directly or indirectly (Mahjabeen, Shah, Chughtai, & Simonetti, 2020). Additionally, energy is essential for maintaining capital goods and producing labor, as well as for fostering knowledge accumulation and technological development (Asaleye et al., 2025). Ultimately, energy must be integrated into machinery, labor, and natural resources to enhance productivity (Mahjabeen et al., 2020).

The classical and neoclassical theorists, however, failed to account for the impact of energy in their developmental economic analysis (Mahjabeen et al., 2020; Udo, Idamoyibo, Inim, Akpan, & Ndubuaku, 2021). The neoclassical construct of an economy considers only three factors of production: capital, labour, and technology (Mahjabeen et al., 2020; Udo et al., 2021). The neoclassicals suggested that production in each period starts with a given amount of capital, labor, and technology and ends with the production of goods (Mahjabeen et al., 2020). Missing from the equation is the impact of energy, which is the primary force that drives all economic activity (Mahjabeen et al., 2020).

A background check of the selected economies of Nigeria, Algeria, and Egypt showed mixed outcomes. Firstly, Nigeria still finds it difficult to meet the energy demands of its ever-increasing population, and various public sector reforms aimed at rescuing the energy sector have resulted in little or no impact, as the sector continues to fall behind expectations (Ali, Nathaniel, Uzuner, Bekun, & Sarkodie, 2020). The access to electricity data for Algeria and Egypt during the last decade neared 100 percent, while Nigeria had struggled with 30-50% access, showing that less than half of Nigeria's population had access to electricity (Awuah, 2023; Olaniyan, Caux, & Maussion, 2024). Nigeria has therefore been ranked highest among the countries with an electricity deficit when efficiency and access to renewable energy are on the rise in many developing nations such as Algeria and Egypt (Ali et al., 2020; Awuah, 2023; Olaniyan et al., 2024). Algeria and Egypt, however, have made progressive efforts in providing accessible electricity to the majority of their populations (Awuah, 2023).

In many developing economies, energy consumption patterns are shaped by various factors, including industrialization, urbanization, population growth, and energy infrastructure development (Ahzan & Kankanamge, 2024; Mombekova, Arystanbekova, Yessengabyl, & Omarova, 2024). These factors can interact in complex ways, making it challenging to generalize the relationship between energy and economic growth. Additionally, the impact of energy on economic growth may fluctuate over time, especially during periods of structural transformation, such as the shift from agriculture-based to industrial or service-oriented economies (Bousnina & Bousrih, 2024; Burke & Fankhauser, 2020; Omaye, Sa'ad, Hamma Adama, & Dotti, 2022). Consequently, existing theories and models that analyze energy-economy interactions may not adequately capture the complexities present in developing economies.

The objective of this study was therefore to comparatively determine the direction and impact of labour, capital, and electricity consumption on economic growth in Algeria, Egypt, and Nigeria, respectively. These nations have common features as they have large populations; they are oil-dependent and are developing African nations. This study also projected the combinative estimation technique of FMOLS, supported by DOLS and Canonical Regression (CRR) techniques, to analyze the data as a divergence from previous studies. The FMOLS technique has the advantage of correcting autocorrelation and endogeneity problems, as well as errors emerging from sample bias (Ali et al., 2020).

This study contributes to the existing literature by integrating energy as a pivotal factor of production alongside capital and labour in the analysis of economic growth in Algeria, Egypt, and Nigeria. By employing a modified Cobb-Douglas production model and utilizing robust empirical techniques like Fully Modified Ordinary Least Squares (FMOLS), this research expands the debate on how these factors interact to influence economic performance in developing countries. The study enlarges the existing literature on the energy-growth relationship. The findings of the study will be of value to policy managers in developing economies for formulating and implementing energy policies.

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2. REVIEW OF RELATED LITERATURE

This section presents a review of the literature, focusing on the interplay between capital, labour, and energy as key factors of production. The study builds on the work of Rumanzi, Turyareeba, Kaberuka, Mbabazize, and Ainomugisha (2021), and the framework captures the relationships illustrating how they contribute to economic development. Figure 1 shows the conceptual framework of the revised Cobb-Douglas function.

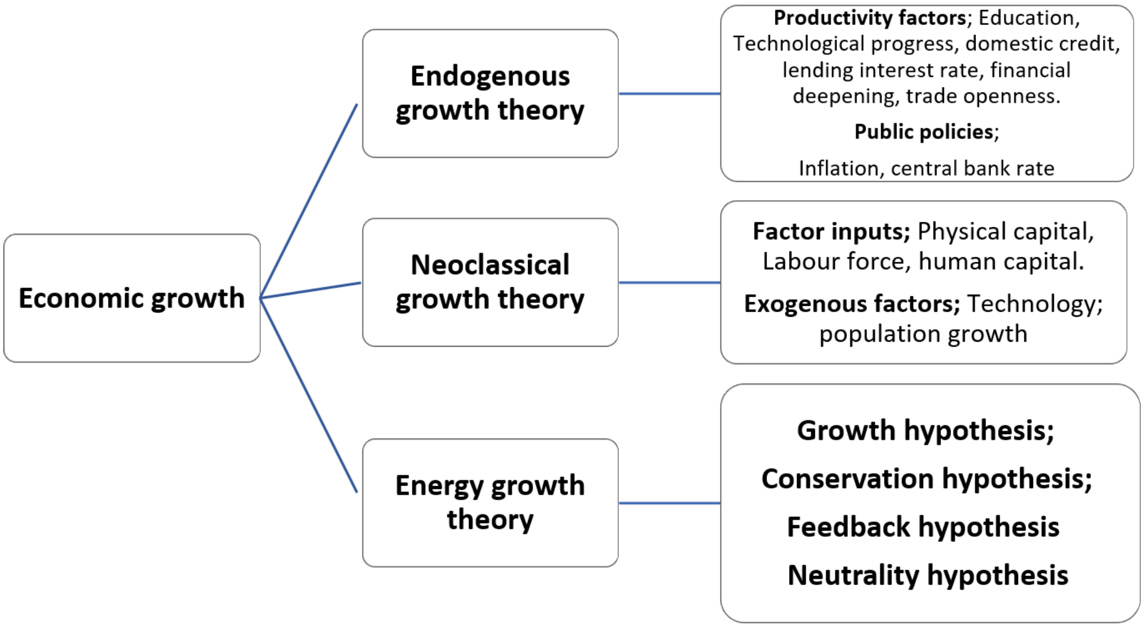

Figure 1. A conceptual framework for determinants of economic growth.

Source: Rumanzi et al. (2021)

2.1. Overview of the Energy Sector in Algeria, Egypt, and Nigeria

The available sources of energy in Algeria are electricity, natural gas, petroleum products, and liquefied propane gas (LPG) (Tahchi, 2024). Recent data showed that approximately 99 percent of all Algerians, both in urban and rural populations, had access to electricity (Tahchi, 2024). The Algerian Ministry of Energy and Mines coordinated the energy sector, the Algerian Electricity and Gas Regulation Commission (CREG) was the sector regulator, while SONELGAZ (the National Society for Electricity and Gas) focused on electricity and natural gas distribution in the country (Himri et al., 2022). The sector was vertically organized, with different companies handling generation, transmission, and distribution. Recently, Algeria's electricity demand has significantly increased due to the expansion of economic activities and population growth, and Algeria's electricity consumption is projected to reach 130–150 TWh in 2030 (Himri et al., 2022).

Egypt's estimated population of 118 to 119 million in November 2025 is one of the top 10 countries worldwide that has made the most progress in providing electricity to its population (United Nations, 2025). By 2024, 100 percent of the population (both urban and rural) had access to electricity and 99.99 percent to non-solid fuels (United Nations, 2025). The Ministry of Electricity and Energy (MOEE) supervises the energy sector, while the energy regulator is the Egyptian Electric Utilities and Consumer Protection Regulatory Agency (EgyptERA) (Hasan, Al-Aqeel, & El-Salmawy, 2020; United Nations, 2025). The state-owned Egyptian Electricity Holding Company (EEHC) dominates the electricity sector in Egypt and has 16 affiliated companies: six for production, nine for distribution, and the Egyptian Electricity Transmission Company (United Nations Environment Programme, 2017).

Nigeria, on the other hand, with a population of over 180 million people, is endowed with enormous energy resources, such as petroleum, natural gas, coal, nuclear, and tar sands (Manasseh, Oyewole, & Oloni, 2019). However, the development and exploitation of such energy sources have been skewed in favor of hydro, petroleum, and natural

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gas (Olaniyan et al., 2024). It is believed that about 75-100 million people in Nigeria, mostly in rural areas, have little or no access to electricity (Ali et al., 2020; Olaniyan et al., 2024). The epileptic nature of electricity has impeded both domestic and industrial performance, forcing citizens to resort to generators, petrol, diesel, kerosene, and charcoal to meet their energy needs. Other alternative energy sources, such as solar and wind, are generally underutilized and underdeveloped in the country (Olaniyan et al., 2024).

2.2. Theoretical Framework

This study was guided by critical growth theories: the exogenous, endogenous, and energy growth theories. Both the exogenous growth theory (specifically, the Solow-Swan neoclassical model) and the endogenous growth theory offer frameworks for the determinants of long-term economic growth, primarily differing in their assumptions about returns to scale and the origin of technological progress (Rumanzi et al., 2021).

2.2.1. Exogenous Growth Theory

The exogenous growth theory posits that economic expansion is primarily driven by factor accumulation (physical capital, labour, and human capital) and an external, or "exogenous," technological progress. The model relies on constant returns to scale (CRS) for all inputs combined and the principle of diminishing returns to capital. Growth is driven by the accumulation of physical capital and labour, with long-term per capita growth dependent entirely on a non-economic factor: exogenous technological progress (also called Total Factor Productivity or TFP). The theory predicts conditional convergence, meaning that poorer economies will grow faster than richer ones until they reach the same steady-state level of income, provided they have similar structural characteristics (like savings rates and population growth). Critics point to unrealistic assumptions such as perfect competition, a constant savings rate, and homogeneous capital, which simplify real-world economic complexities.

2.2.2. Endogenous Growth Theory

In contrast, the endogenous growth theory emerged to address the limitations of the neoclassical model by incorporating technology and innovation as outcomes of purposeful economic activity within the model itself. The theory argues that sustainable increases in growth rates arise from the assumption of increasing returns to capital (or constant returns to a broader set of capital, including human capital). Growth is driven by endogenous factors (factors determined within the economic system). These include investments in human capital, research and development (R&D), information and communication technology (ICT), and the adoption of new technologies. The theory suggests that permanent increases in policy-influenced variables (like R&D subsidies or education spending) can lead to permanent increases in an economy's long-run growth rate.

2.3. Energy-Growth Theory

Critiques of the traditional and neoclassical models contest the production function based only on capital and labour, largely excluding energy as a crucial factor of production. This study argues that this is a major oversight, as economic activities, especially those involving machines, inherently require energy. The introduction of new energy converters (e.g., watermills, steam engines) has allowed economies to harness increasing and more affordable energy supplies (Rehman & Islam, 2023). For "fossil economies," growth is primarily constrained by the rate at which energy can be harnessed for economic activities (Rehman & Islam, 2023). The growth rate of these economies depends on the capital and technology deployed to extract fossil fuels, convert fossil fuels into usable energy, and utilize this energy to create goods and services (Fong, Sun, & Chen, 2022; Rehman & Islam, 2023).

In other words, the magnitude of energy flowing into the economy via capital accumulation and technology creates a dynamic force of cumulative economic growth (Udo et al., 2021). Capital accumulation activates energy sources in the economy through a variety of feedback mechanisms, which produce more capital accumulation

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(Szymczyk, Şahin, Bağcı, & Kaygın, 2021). Defining the functions of labour and capital is therefore more straightforward within the framework of an energy-system-based economy (Szymczyk et al., 2021). Labour, capital, and technology perform supporting functions and optimize energy flows by controlling, directing, and manipulating the usable energy to produce goods and services (Szymczyk et al., 2021). In standard neoclassical models, such as the widely used Cobb-Douglas function, output is typically represented as a function of only two or three primary factors: capital (K), labour (L), and sometimes "land" (A) (Greer, 2022).

$$(\text{e.g., } Y = AK^{\alpha}L^{\beta})$$

In these models, energy is considered a "secondary" or intermediate input, implicitly bundled into the costs of capital and labour or treated as a simple material input of only marginal importance (Greer, 2022; Keen, Ayres, & Standish, 2019). This approach omits the physical reality that energy is an essential, indispensable input for all economic activity, and neither capital nor labour can produce anything without a flow of useful energy to power machinery and human activity (Greer, 2022; Keen et al., 2019).

The consequence of omitting energy as a distinct primary factor in traditional models may misattribute the contribution of energy to economic growth (often captured in the "Solow Residual," a measure of technological progress) (Greer, 2022; Keen et al., 2019). This can lead to an incomplete understanding of the sources of economic growth and the implications of energy constraints or efficiency gains (Greer, 2022; Keen et al., 2019). In response to this critique, alternative economic theories propose production functions that explicitly include energy (E) as a distinct and critical input alongside capital and labour (Greer, 2022; Keen et al., 2019).

$$Y = f(K, L, E)$$

These models often emphasize the physical laws governing energy, such as the laws of thermodynamics, to argue for its fundamental role and unique characteristics, distinct from capital and labour.

2.4. Empirical Review

The energy-growth relationship has resulted in a series of empirical debates without a common conclusion. Research findings vary by country, with developed economies often showing a link to energy efficiency (conservation), and developing economies more strongly supporting the energy-led growth model due to industrialization. The fact that electricity consumption forms a higher percentage of energy consumption in most countries has strengthened the debate. Four major strands of thought on the energy-growth causality debate persist.

The first strand (energy-led growth hypothesis) concludes that energy (electricity) consumption causes economic growth (Isah, Aiyedogbon, & Aigbedion, 2024; Oliveira, Moutinho, & Afonso, 2025; Sarkodie & Adams, 2020; Yakubu, Manu, & Bala, 2020). This implies that economic growth is dependent on energy consumption, and a decrease in energy consumption may restrain economic growth (see Table 1). The second component, the growth-led energy or conservation hypothesis, posits that economic growth causes energy consumption (Ibukun, Osinubi, & Oladunjoye, 2021; Mombekova et al., 2024). In this case, the demand for energy is assumed to be driven largely by the growth of the real sector. This may mean that a country is not entirely dependent on energy for its economic growth, and that energy conservation policies can be implemented with little or no adverse effects on economic growth (see Table 2).

The third constituent (the feedback hypothesis) proposes bidirectional causality between energy (electricity) consumption and economic growth (Hunker, 2022; Kabeyi & Olanrewaju, 2021; Udo et al., 2021). This view, however, maintains that both energy consumption and economic growth Granger-cause each other, i.e., that there is a bidirectional causality between energy consumption and economic growth (see Table 3). Finally, the fourth proponents (the neutrality hypothesis) argue that there is no significant causal link between energy (electricity) consumption and economic growth (Le, Boubaker, & Nguyen, 2021). This implies that neither of the two has considerable effects on the other, and that the empirically observed correlation between them is merely the result of coincidence (see Table 4).

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Table 1. Empirical summary on the energy-led growth hypothesis.

Author(s)	Scope	Methodology	Conclusion (s)
Kouton and Amonle (2019)	44 African countries (1991-2015)	generalized Method of Moments (GMM)	EC→Y
Yakubu et al. (2020)	Nigeria (1981-2019)	Autoregressive Distributed Lag (ARDL) bounds cointegration test	ELC→Y
Sarkodie and Adams (2020)	Sub-Saharan Africa (1990 to 2017)	nonparametric regression technique; Driscoll–Kraay standard errors	ELC→Y
Isah et al. (2024)	Nigeria (1990-2022)	Threshold Regression Approach	Higher ELC→Y (+); Lower ELC→Y (-)
Oliveira et al. (2025)	18 Countries (2009-2019)	Bias-Corrected Estimation (BC) and Generalized Method of Moments (GMM) techniques.	ELC→Y
Phadkantha and Yamaka (2022)	Thailand (1990-2019)	Markov Switching Autoregressive Distributed Lag (MS-ARDL)	ELC→Y; Non-linear relationship

Note: i) → unidirectional causality ii). EC, ELC, and Y connotes energy consumption, electricity consumption, and income (GDP), respectively. iii) (+/-) positive/significant relationship.

Table 2. Selected studies on the growth-led energy (conservation) hypothesis.

Author(s)	Scope	Methodology	Conclusion (s)
Ibukun et al. (2021)	Nigeria (1971-2018)	Non-linear Autoregressive Distributed Lag (NARDL)	Significant asymmetric effect of economic growth on energy consumption in the long run (Y → ELC)
Mombekova et al. (2024)	7 developing countries (China, India, South Africa, Indonesia, Turkey, Mexico, Thailand) (1990-2022)	Swamp Random Coefficient model; Seemingly Unrelated Regression (SUR)	(Y → ELC)

Note: i) → unidirectional causality ii). EC, ELC, and Y connotes energy consumption, electricity consumption, and income (GDP), respectively.

Table 3. Empirical summary on the feedback hypothesis.

Author(s)	Scope	Methodology	Conclusion (s)
Hunker (2022)	30 European countries (2015Q1 and 2021Q3.)	Panel unit root, panel causality, and dynamic panel estimation tests	ELC↔Y
Kabeyi and Olanrewaju (2021)	Nigeria	Granger causality	ELC↔Y
Lawal, Ozturk, Olanipekun, and Asaleye (2020)	African economies	System Generalized Methods-of-Moments (System GMM)	ELC↔Y
Udo et al. (2021)	Nigeria (2000Q1-2018Q4)	ARDL bounds test approach, and Error Correction Model; Granger Causality Test	ELC↔Y

Note: i) ↔ Multidirectional causality ii) EC, ELC, and Y denote energy consumption, electricity consumption, and income (GDP), respectively.

Table 4. Selected studies on the Neutrality hypothesis.

Author(s)	Scope	Methodology	Conclusion (s)
Le et al. (2021)	107 Countries (1996-2014)	dynamic fixed effects (DFE) estimator; ARDL	Long run EC∞Y

Note: i) ∞ non-causality ii). EC, ELC and Y connotes energy consumption, electricity consumption and income (GDP) respectively.

3. METHODOLOGY

Secondary data on the Real Gross Domestic Product (RGDP), electricity consumption (ELC), capital (K), labour (L), and technology (T) for the countries of Algeria, Egypt, and Nigeria spanning the period 1990-2016 were obtained

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from the World Development Indicators of the World Bank. The estimation technique used in this study is the Fully Modified Least Squares (FM-OLS). FM-OLS is a semi-parametric estimation technique that provides optimal estimates of cointegrating regressions. In contrast to the Johansen and ARDL approaches, FM-OLS is more robust to endogeneity and serial correlation (Ali et al., 2020; Olusegun, 2021). Hence, the estimates are more robust and more consistent. Additionally, it is applicable irrespective of the order of integration of the variables, whether I(0) or I(1).

The *a priori* expectation posited that electricity consumption, labor, and capital had a positive impact on economic growth, respectively. This *a priori* expectation also assumed an energy-led growth hypothesis between electricity consumption and economic growth in the countries of study, *ceteris paribus*. The study tested the implications of returns to scale on the Cobb-Douglas production function (CODPF) and suggested that if $\alpha+\beta > 1$, there will be increasing returns to scale; if $\alpha+\beta < 1$, there will be decreasing returns to scale; and if $\alpha+\beta = 1$, there will be constant returns to scale (Greer, 2022). An increase in all inputs by 'z' amount (z is a constant), impacted on output of the (CODPF) as follows.

$$Q(L, K)=A(L^{\beta})(K^{\alpha}) \quad (1)$$

$$Q\ (zL, zK) = A\ (zL)^{\beta}\ (zK)^{\alpha} = Az^{\beta}\ z^{\alpha}\ L^{\beta}\ K^{\alpha} = Az^{\alpha+\beta}\ L^{\beta}\ K^{\alpha} \quad (2)$$

The multivariate energy-growth model adapted the Solow growth model and the Romer model to include the impact of the energy system in the Cobb-Douglas production function. The production function under the Solow growth model implied that income (Y) was a function of capital (K) and labour (L); {Y = f (K, L)}, where technology was exogenous. Romer's model modified the Solow growth model to include technology as an endogenous variable. This study, therefore, modified the Romer model to include energy (A) in the model.

(i) The energy-growth hypothesis is illustrated in the generalised functional, econometric and symmetric multivariate Equations 3-5.

$$Y=f\,(A,K,L) \quad (3)$$

$$Y_t= \beta_0 + \beta_1 A + \beta_2 K + \beta_3 L + \mu \quad (4)$$

$$Yt = \beta 0 + B1A + \beta 2K + \beta 3L + \sum_{i=-Q}^{\infty} ß1\underline{\Delta} A + \sum_{i=-Q}^{\infty} ß2\underline{\Delta} K + \sum_{i=-Q}^{\infty} ß3\underline{\Delta} l + \mu \quad (5)$$

(ii) The functions contained in equations 6-8 were restructured into a natural logarithm (*ln*) and an estimable form. The equations represent the revised Cobb-Douglas models for Algeria (ALG), Egypt (EGY), and Nigeria (NIG), respectively.

$$\ln Y_{t\,i}= \beta_0+ \beta_1 \ln ELC_t +\beta_2 \ln CAP_t + \beta_3 \ln LBOR_t + \mu_t \quad (6)$$

$$\ln Y_t = \beta_0+ \beta_1 \ln ELC_t +\beta_2 \ln CAP_t + \beta_3 \ln LBOR_t + \mu_t \quad (7)$$

$$\ln Y_{t\,i}= \beta_0+ \beta_1 \ln ELC_{t-1} +\beta_2 \ln CAP_t + \beta_3 \ln LBORt + \mu_t \quad (8)$$

(iii) Where: Y=output; A=ELC=Energy/Electricity; β0=Intercept; β1-β4=Coefficients of variables; K=Gross Fixed Capital Formation; L=LBOR=Labour force; μ=error term.

iv. The justification of the model was founded in the literature about economic growth, which emphasized that human capital (labour), physical capital (capital development), and energy (electricity) are the key factors for economic growth (see Table 5).

Table 5. Variables description.

Variable/ Indicators	Measures	Source	*A priori*	Empirical justification
Economic development (Y)	GDP per capita	WDI	+	Wen et al. (2022)
Energy (A)	Electricity consumption	WDI	+	Ifa and Guetat (2021)
Capital (K)	Gross fixed capital formation	WDI	+	Oliveira et al. (2025)
Labour (L)	Physically active individuals between the age of 15-64 years	WDI	+	Oliveira et al. (2025)

Note: + Positive expectation; WDI: World development index.

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4. RESULT AND DISCUSSION

In this section, we delve into the findings of our analysis on the relationship between various factors: capital, electricity consumption, and the labour force and economic development in Algeria, Egypt, and Nigeria, respectively. The results are discussed within the context of existing literature, providing a comparative analysis against previous studies, and examining the robustness of our findings across different methodologies. This section aims to present the statistical results and interpret their implications for economic policy and development strategy.

4.1. Descriptive Statistics

Table 6 portrays the descriptive statistics of the mean, median, standard deviation, Skewness, kurtosis, and Jarque-Bera (JB) statistics of Algeria, Egypt, and Nigeria. The variables for Algeria showed GDP, ELC, and CAP were positively skewed to the right ($S>0$), while INF and LBOR were negatively skewed to the left ($S<0$), while the Kurtosis for Algeria variables were all platykurtic ($k<3$). The variables for Egypt showed that GDP, CAP, INF, and LBOR were positively skewed to the right($S>0$), while ELC was negatively skewed to the left ($S<0$). The Kurtosis for Egypt variables showed that GDP, ELC, AND LBOR were platykurtic ($k<3$); INF was mesotokurtic ($k=3$); CAP was leptokurtic ($k>3$). The variables for Nigeria showed that GDP, CAP, INF, and LBOR were positively skewed to the right($S>0$), while ELC was negatively skewed to the left ($S<0$). The variables for Nigeria were all platykurtic ($k<3$). The Jarque-Bera (JB) statistics ($P>0.05$) suggested that the data were normally distributed for Algeria, Egypt, and Nigeria.

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Table 6. Descriptive statistics of Algeria, Egypt, and Nigeria.

Country	ALGERIA (log)					EGYPT (log)					NIGERIA (log)				
Stat.	**GDP**	**INF**	**LBOR**	**ELC**	**CAP**	**GDP**	**ELC**	**CAP**	**INF**	**LBOR**	**GDP**	**ELC**	**CAP**	**INF**	**LBOR**
Mean	9.3	77.2	16.1	6.7	3.5	9.0	7.0	2.9	69.2	16.9	8.2	4.7	2.3	61.9	17.5
Skewness	0.0	-0.2	-0.4	0.4	0.4	0.0	-0.1	0.2	1.0	0.0	0.2	-0.1	0.0	0.8	0.0
Kurtosis	1.4	2.4	2.0	1.9	2.3	1.6	1.5	3.8	3.0	1.6	1.3	1.6	1.6	2.5	1.8
JB	2.8	0.6	1.8	2.1	1.3	2.3	2.6	0.9	4.8	2.3	3.6	2.2	2.3	3.0	1.6
Prob.	0.2	0.7	0.4	0.4	0.5	0.3	0.3	0.6	0.1	0.3	0.2	0.3	0.3	0.2	0.5
Obs.	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27

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4.2. Unit Root Test

Using the ADF test, the time series data is subjected to unit root tests to ascertain whether the variables are non-stationary and possess a unit root. If there is the presence of a unit root, the null hypothesis will be accepted, and if not, we reject the null hypothesis (Gujarati & Porter, 2009; Manasseh et al., 2019). Hence, the null hypothesis is rejected if the ADF statistic value exceeds the Mackinnon critical value at the 5% significance level. The ADF lag length was automatically selected using the Schwarz Information Criterion. Table 7 shows that the series are integrated of order one, I(1), and order zero, I(0). Since the majority of the variables are I(1), we suspect cointegration.

Table 7. Showing the augmented Dickey-Fuller unit root test.

Countries	Variables	Test Stat	1%	5%	10%	Order of integration
Algeria	GDP per capita	-3.37	-3.72	-2.98	-2.63	I(1)
	Labour	-3.37	-3.77	-3.00	-2.64	I(0)
	Capital	-4.94	-2.66	-1.96	-1.60	I(1)
	Electricity	-5.93	-3.72	-2.98	-2.63	I(1)
	*D(Inflation)	-5.22	-2.66	-1.96	-1.61	I(1)
Egypt	Capital	-5.01	-2.66	-1.95	-1.60	I(1)
	Labour	-3.92	-3.72	-2.98	-2.63	I(1)
	EGYGDP	-4.66	-4.39	-3.61	-3.24	I(0)
	*D(Electricity)	-9.05	-2.66	-1.96	-1.61	I(1)
	*D(Inflation)	-4.55	-2.66	-1.96	-1.61	I(1)
Nigeria	Labour	-3.96	-4.37	-3.60	-3.23	I(1)
	GDP per capita	-3.35	-2.66	-1.96	-1.61	I(1)
	Electricity	-5.61	-2.66	-1.96	-1.61	I(1)
	Capital	-5.06	-2.66	-1.96	-1.61	I(1)
	*D(Inflation)	-3.06	-2.66	-1.96	-1.61	I(1)

Note: *D indicates differenced data; ALG: Algeria; EGY: Egypt; NIG: Nigeria.

4.3. Cointegration Test: Hansen's Parameter Instability Test

To apply FMOLS for estimation, a cointegration relationship must first be established among the set of variables. For that reason, the presence of a cointegrating relation is tested using Hansen's Parameter Instability cointegration test. Hansen (1992) outlines a test of the null hypothesis (of cointegration) against the alternative (of no cointegration). He notes that under the alternative hypothesis of no cointegration, one should expect to see evidence of parameter instability. He proposed the use of Lc test statistics, which arise from the theory of the Lagrange Multiplier test for parameter instability, to evaluate the stability of the parameters. The decision criterion states that if the p-value is less than 0.05, we reject the null hypothesis (of cointegration); otherwise, we fail to reject the null hypothesis. Therefore, the cointegration model is specified in equation 9 below as.

$$\Delta\mu_t = \delta\mu_{t-1} + \gamma_i \sum_{i=1}^{K} \Delta\mu_{t-1} + \varepsilon_t \quad (9)$$

Δ; is the first difference operator; μ_t refers to the errors generated from cointegration regression, while μ_{t-1} is the one-period lag of the error term, and k describes the number of lags used. Hence, ε_t is assumed to be normally distributed and white noise.

Table 8. Hansen's parameter instability cointegration test.

Equation	Lc Stat	Stochastic Trends	Prob	Conclusion
Equation 4 (Algeria)	0.36*	4	>0.2	Presence of cointegration
Equation 5 (Egypt)	0.54*	4	>0.2	Presence of cointegration
Equation 6 (Nigeria)	0.38*	4	>0.2	Presence of cointegration

Note: * significant at 5%; Cointegrating Deterministic: C.

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Table 8 showed that the null hypothesis of co-integration cannot be rejected for Algeria, Egypt, and Nigeria, as the p-value of 0.2 is greater than the significance level of 0.05. In other words, a long-run (cointegration) relationship exists among the variables in these countries.

4.4. Statistical Results

This section presents the analytical results obtained through a combination of regression and analytical tools.

Table 9. Analytical results of model 4 (Algeria).

Dependent Variable: lnY(GDP PER CAPITA)						
SERIES NAME	FMOLS		DOLS		CCR	
Model 4 (Algeria)	**Coefficient**	**T-Stat**	**Coefficient**	**T-Stat**	**Coefficient**	**T-Stat**
Constant	0.78	0.29	2.85	1.22	0.76	0.32
lnCAP	0.24*	2.79	0.20*	2.32	0.27*	3.01
lnLBOR	0.46*	2.25	0.30	1.63	0.47*	2.50
lnElC	0.05	0.38	0.15	1.26	0.02	0.19
$lnINF_{t-1}$	-0.01*	-2.53	-0.01*	2.01	0.01*	-2.84
R^2	0.95	-	0.96	-	0.95	-
$(z^{\alpha+\beta})$	0.7	-	0.50	-	0.74	-

Note: * significant at 5%.

The results in Table 9 showed the analytical results for Model 4 (Algeria) as follows;

a. The coefficient of determination (R^2) revealed that the explanatory variables explain about 95% of the changes in economic development.

b. The result indicated a positive and significant relationship between capital and economic development of Algeria (β=0.24; Pe<0.05). This suggested that 1 percent increase in the value of capital would lead to a 24% percent increase in the value of GDP per capita of the country, *ceteris paribus.* The results were validated using different methodologies; dynamic ordinary least squares (β = 0.20; Pe < 0.05); Canonical Cointegrating Regression (β = 0.27; Pe < 0.05). These results are consistent with the findings of Szymczyk et al. (2021) and Udo et al. (2021). The findings align with theoretical assumptions from exogenous, endogenous and energy-growth theories, and support *a priori* expectations and foundational economic principles. These observed relationships might be attributed to factors such as increased investment, better allocation of capital towards growth-promoting sectors, government policies fostering capital accumulation and investment.

c. It also indicated a *non-significant* relationship between electricity consumption and the economic development of Algeria (β=0.05; p>0.05). This suggests that increases in electricity consumption are not significantly linked to economic development outcomes in the country. Results from alternative methodologies of dynamic ordinary least squares (β = 0.15; p > 0.05) and canonical cointegrating regression (β = 0.02; p > 0.05) showed a non-significant relationship. These findings align with the works of Le, Boubaker, & Nguyen (2021). Conversely, they contradict the findings of Yakubu et al. (2020); Sarkodie and Adams (2020); Isah et al. (2024), and Oliveira et al. (2025).

The results support theoretical assumptions from exogenous and endogenous growth theories but contradict the expectations derived from energy-growth theory. The non-significance also contradicts *a priori* expectations and established knowledge regarding the role of electricity consumption in driving economic growth. These observations could be attributed to structural inefficiencies in electricity distribution and consumption; a lack of correlation between electricity consumption and productivity in particular sectors. Other factors include technological constraints or substitutions with other forms of energy that can mitigate the impact of electricity on economic development.

d. It indicated **a** *positive and significant* relationship between the labour force and economic development of Algeria (β=0.46; P<0.05). This suggested that a 1 percent increase in the value of the labour force would lead to a 46

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percent increase in the value of GDP per capita of the country, *ceteris paribus*. Results from alternative methodologies of dynamic ordinary least squares (β=0.30; P>0.05; non-significant) and canonical cointegrating regression (β = 0.47; P < 0.05; significant) showed contrasting results. These findings are consistent with the work of Szymczyk et al. (2021) and Udo et al. (2021), who also reported a positive correlation between labour force and economic development.

However, they oppose the findings of Kamal and AboElsoud (2023), which identified a negative relationship. The findings align with theoretical assumptions from exogenous, endogenous, and energy-growth theories. They also support a priori expectations and foundational economic principles related to the role of labour in economic growth. These observed relationships might be attributed to increased productivity and output due to a more extensive labour force; enhanced skills and education levels among workers contributing to economic dynamism; and favourable policies that promote labour participation and employment in growth sectors.

Table 10. Analytical results of Egypt.

Series name	FMOLS		DOLS		CCR	
(Egypt)	Coefficient	T-Stat	Coefficient	T-Stat	Coefficient	T-Stat
Constant	-6.54	-7.84	-6.64	-7.68	-6.4*	-6.53
lnCAP	0.07	1.47	0.07	1.31	0.07	1.25
lnLBOR	0.90*	19.64	0.90*	19.3	0.89*	16.66
$lnELC_{t-1}$	0.32	1.17	0.24	0.82	0.40	1.05
$lnINF_{t-1}$	-0.001	0.75	0.001	0.46	0.002	0.73
R^2	0.98	-	0.99	-	0.99	-
$(z^{\alpha+\beta})$	0.97	-	0.97	-	0.96	-

Note: * significant at 5%.

The results in Table 10 showed the analytical results for Egypt as follows;

a. The coefficient of determination (R^2) revealed that the explanatory variables explain about 97% of the changes in economic development.

b. The result indicated a *non-significant* relationship between capital and economic development of Egypt (β=0.07; Pe>0.05). This suggests that changes in capital do not have a statistically significant impact on economic development outcomes in the country. Results from various methodologies corroborated the non-significance: dynamic ordinary least squares (β=0.07; Pe>0.05); Canonical Cointegrating Regression (β=0.07; Pe>0.05). These findings contradict the results of Szymczyk et al. (2021) and Udo et al. (2021), and Kamal and AboElsoud (2023), who reported a more significant relationship between capital and economic growth.

The results challenge the theoretical assumptions derived from exogenous, endogenous, and energy-growth theories, which typically posit a positive correlation between capital accumulation and economic development. They also deviate from *a priori* expectations and established economic principles that suggest capital is a key driver of growth. These observed relationships might be attributed to factors such as structural inefficiencies within the economy, such as the external debt profile that prevents capital from translating into productive investment. Also, a lack of diversification in capital allocation, which prevents investments in high-growth sectors, and policies that limit the effectiveness of capital may be possible causes.

c. It also indicated a *non-significant* relationship between electricity consumption and the economic development of Egypt (β=0.32; p>0.05). This suggests that increases in electricity consumption are not significantly linked to economic development outcomes in the country. Results from alternative methodologies of dynamic ordinary least squares (β=0.24; p>0.05) and canonical cointegrating regression (β=0.40; p>0.05) also showed non-significant relationships. These findings align with the works of Le et al. (2021). Conversely, they contradict the findings of Yakubu et al. (2020); Sarkodie and Adams (2020); Isah et al. (2024), and Oliveira et al. (2025).

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The results are aligned with theoretical assumptions from exogenous and endogenous growth theories, which do not recognize the potential influence of energy on economic performance. However, they contradict expectations derived from energy-growth theory, which posits that increased energy consumption directly correlates with economic development. The non-significance also contradicts *a priori* expectations and established knowledge regarding the role of electricity consumption in driving economic growth. These observations could be attributed to structural inefficiencies in electricity distribution and consumption; a lack of correlation between electricity consumption and productivity in particular sectors. Other factors include technological constraints or substitutions with other forms of energy, which can mitigate the impact of electricity on economic development.

d. It indicated a *positive and significant* relationship between labour force and economic development of Egypt (β=0.90; Pe<0.05). This suggested that a 1 percent increase in the value of the labour force would lead to a 90% percent increase in the value of GDP per capita of the country, *ceteris paribus*. Results from alternative methodologies of dynamic ordinary least squares (β = 0.90; Pe<0.05; significant) and canonical cointegrating regression (β = 0.89; Pe < 0.05; significant) *corroborated the findings*. These findings are consistent with the work of Szymczyk et al. (2021) and Udo et al. (2021), which also reported a positive correlation between labour force and economic development. However, they oppose the findings of Kamal and AboElsoud (2023), which identified a negative relationship. The findings align with theoretical assumptions from exogenous, endogenous, and energy-growth theories. They also support *a priori* expectations and foundational economic principles related to the role of labour in economic growth. These observed relationships might be attributed to increased productivity and output due to a more extensive labour force; enhanced skills and education levels among workers contributing to economic dynamism; and favourable policies that promote labour participation and employment in growth sectors.

Table 11. Analytical results of Model 6 (Nigeria).

Series name	FMOLS		DOLS		CCR	
(Nigeria)	Coefficient	T-Stat	Coefficient	T-Stat	Coefficient	T-Stat
Constant	-9.25*	-4.39	-9.85	-3.58	-9.78*	-4.43
lnCAP	0.76	1.81	0.09	1.72	0.07	1.76
lnLBOR	0.83*	6.26	0.88*	5.09	0.85*	6.29
lnELC	0.59*	6.99	0.51*	4.46	0.63*	6.64
$\ln INF_{t-1}$	-0.001	-1.05	-0.003	-0.58	-0.008	-1.25
R^2	0.99	-	0.96	-	0.95	-

Note: *, indicate significance at 5percent.

The results in Table 11 showed the analytical results for Nigeria as follows;

a. The coefficient of determination (R^2) revealed that the explanatory variables explain about 99% of the changes in economic development.

b. The result indicated a *non-significant* relationship between capital and economic development of Nigeria (β=0.76; Pe>0.05). This suggests that changes in capital do not have a statistically significant impact on economic development outcomes in the country. Results from various methodologies corroborated the non-significance: dynamic ordinary least squares (β=0.09; Pe>0.05); Canonical Cointegrating Regression (β=0.07; Pe>0.05). These findings contradict the results of Szymczyk et al. (2021) and Udo et al. (2021), and Kamal and AboElsoud (2023), who reported a more significant relationship between capital and economic growth.

The results challenge the theoretical assumptions derived from exogenous, endogenous, and energy-growth theories, which typically posit a positive correlation between capital accumulation and economic development. They also deviate from *a priori* expectations and established economic principles that suggest capital is a key driver of growth. These observed relationships might be attributed to factors such as structural inefficiencies within the economy, such as the external debt profile that prevents capital from translating into productive investment. Also, a

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lack of diversification in capital allocation, which prevents investments in high-growth sectors, and policies that limit the effectiveness of capital may be possible causes.

c. It also indicated a *positive and significant* relationship between electricity consumption and economic development of Nigeria (β=0.59; Pe<0.05). This suggests that increases in electricity consumption are significantly associated with positive economic development outcomes. Results from alternative methodologies corroborated the significance of the relationship: Dynamic Ordinary Least Squares (DOLS): $\beta = 0.51$; $p < 0.05$ (significant); Canonical Cointegrating Regression (CCR): $\beta = 0.63$; $p < 0.05$ (significant). These findings align with the works of Yakubu et al. (2020); Sarkodie and Adams (2020); Isah et al. (2024), and Oliveira et al. (2025), all of which support the positive link between energy consumption and economic growth. Conversely, they contradict the findings of Le et al. (2021), which reported different outcomes.

The results are aligned with theoretical assumptions from energy-growth theory, which posits that increased energy consumption directly correlates with economic development. However, they contradict expectations of exogenous and endogenous growth theories, which do not fully recognize the potential influence of energy on economic performance. The positive significance also agrees with *a priori* expectations and established knowledge regarding the role of electricity consumption in driving economic growth. The results are consistent with energy-growth theory, which posits that increased energy consumption directly correlates with economic development.

However, they contradict the expectations of exogenous and endogenous growth theories, which do not fully account for the influence of energy on economic performance. The positive significance of electricity consumption aligns with established knowledge and expectations regarding its role in driving economic growth, reinforcing the importance of energy infrastructure in supporting economic activities. The implications of these findings suggest that improved electricity supply may facilitate industrialization and productivity in Nigeria. Also, improved **access** to reliable electricity can enhance the efficiency of businesses and services. Finally, higher electricity consumption can signal a robust economic environment, attracting further investments and supporting growth.

d. It indicated a *positive and significant* relationship between labour force and economic development of Nigeria (β=0.83; Pe<0.05). This suggests that a 1 percent increase in the value of the labor force would lead to an 83 percent increase in the value of GDP per capita of the country, *ceteris paribus*. Results from alternative methodologies of dynamic ordinary least squares ($\beta = 0.88$; Pe<0.05; significant) and canonical cointegrating regression ($\beta = 0.85$; Pe < 0.05; significant) corroborated the findings. These findings are consistent with the work of Szymczyk et al. (2021) and Udo et al. (2021) which also reported a positive correlation between labour force and economic development. However, they oppose the findings of Kamal and AboElsoud (2023) which identified a negative relationship. The findings align with theoretical assumptions from exogenous, endogenous, and energy-growth theories. They also support *a priori* expectations and foundational economic principles related to the role of labour in economic growth. These observed relationships might be attributed to increased productivity and output due to a more extensive labour force; enhanced skills and education levels among workers contributing to economic dynamism; favourable policies that promote labour participation and employment in growth sectors.

5. CONCLUSION AND POLICY IMPLICATIONS

The study suggests that Algeria demonstrated a significant positive relationship between capital and economic growth, while Egypt and Nigeria did not find a significant effect. Algeria is the only country where capital has a significant positive impact on economic growth, indicating that investments may be more strategically employed in Algeria compared to Egypt and Nigeria. This may reflect differences in how capital is deployed and utilized across these economies. All three countries indicate a strong and significant relationship between the labour force and economic development, with Egypt showing the highest impact. This implies that the economies of Egypt, Algeria,

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and Nigeria are largely labour-intensive, organic, and manual-based economies, and it highlights the importance of labour force expansion as a crucial tool for boosting economic growth across these nations.

It was opined that a shift from a labour-centric economy to a more capital- and energy-centric economy would stimulate output elasticity, as exemplified in developed countries. While electricity consumption is not significantly linked to economic growth in Algeria and Egypt, it plays a substantial role in Nigeria's economic performance. This disparity may mirror differences in energy infrastructure and economic dynamics in the respective countries, highlighting the role of energy as a driver of economic performance. Though the study for Nigeria showed that electricity consumption had a significant impact on economic development, electricity per capita and access to electricity have been relatively poor.

The policy implications of this study suggest a strategic financial investment in growth-promoting sectors of the economy, which has been amplified by Algeria's success in significant economic development through capital investment. Policymakers should therefore analyze investment allocation to ensure resources are directed toward growth-promoting sectors, further enhancing the impact of capital on economic performance. Governments in Algeria, Egypt, and Nigeria should prioritize human capital development programs aimed at skill development, education, and labour market participation. By doing so, they can leverage the existing labour force for enhanced productivity and economic dynamism. The energy gap in electricity consumption and economic growth underscores the need for developing economies to invest in their energy infrastructure, as improved energy access and reliability can bolster economic activities and support growth strategies.

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