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# Energy Use and Economic Growth Nexus in Central Africa: A Longitudinal Analysis (1990-2023)

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## ABSTRACT

This research examines the interconnection between energy consumption and economic expansion in Central Africa, utilizing advanced econometric methods to guarantee accurate and dependable outcomes. The findings reveal that energy usage and carbon emissions positively impact economic growth, whereas alternative nuclear energy sources have an adverse effect. In contrast, renewable electricity production and agricultural employment showed no significant impact. Notably, a 1% increase in energy consumption yields a 0.4169% rise in economic growth, and a 1% increase in $CO_2$ emissions results in a 0.0669% growth. Cointegration analysis confirmed a long-term equilibrium relationship among these variables at a 1 % significance level, indicating that all the variables are cointegrated. This study contributes to the ongoing discussion on energy consumption, economic growth, and environmental policies, offering robust evidence of their dynamic interplay. The results align with existing research, providing fresh insights and informing policymakers, researchers, and stakeholders about the intricate relationships between energy use, growth, and environmental sustainability in Central Africa.

**Keywords:** Energy Use, Economic Growth, Central Africa, Dynamic Panel Data Estimation, Cointegration
**JEL Classifications:** Q43, Q56, O13, C33

## 1. INTRODUCTION

The link between energy usage and economic expansion has sparked vigorous discussion among economists and policymakers, with particular interest in emerging economies like those in Central Africa. Central Africa, encompassing nine nations - Angola, Cameroon, Central African Republic, Chad, Democratic Republic of Congo, Equatorial Guinea, Gabon, Republic of Congo, and São Tomé and Príncipe faces significant energy and economic development challenges (African Development Forum, 2020). The region's rapid population growth, urbanization, and industrialization have led to increased energy demand, primarily met by fossil fuels. Energy is a critical input for economic development, as it fuels industrial production, transportation, and other sectors driving economic growth (International Energy Agency [IEA], 2020). According to the African Development Bank (2020), reliable and affordable energy is vital for sustainable economic growth in Africa. The dynamic connections between economic expansion, environmental impact, and policy actions have sparked significant research and policy attention. With sustainable development and climate change mitigation at the forefront, experts are probing the complex interdependencies between economic growth, environmental quality, and policy measures.

However, with some policy variables considered in Central Africa, like energy use and alternative energy, the region relies heavily on traditional biomass (e.g., wood fuel) and fossil fuels (e.g., oil, gas) for energy. However, some countries have begun exploring alternative energy sources (Azevedo, 2018). Cameroon and Gabon have invested in hydropower, with the Grand Eweng and Imboulou dams. Also, the Democratic Republic of Congo has significant hydropower potential, particularly the Inga Dam, while Angola and Equatorial Guinea have explored solar and wind energy (Ndoye et al., 2020).

Alternative nuclear energy sources comprising tidal, wave, and biomass energy as well as hydrogen fuel cells, on the other hand, remain underdeveloped in Central Africa, despite some countries' interest, like Nigeria, outside the Central Africa region, has plans for nuclear power plants, while South Africa, also outside the region, operates the only nuclear power plant in Africa (Mougoue et al., 2018). Similarly, electricity production from renewable sources contributes a small share of the region's electricity mix. For example, hydropower accounts for approximately 20% of electricity production in Cameroon and Gabon, while solar and wind energy contribute minimally to the region's electricity production. Finally, in terms of carbon dioxide emission reliance on fossil fuels contributes significantly to carbon dioxide emissions. For example, Angola and the Democratic Republic of Congo are among the top $CO_2$ emitters in Africa, and Gabon and Cameroon have implemented policies to reduce emissions. Economic growth (GDP) in Central Africa is largely driven by natural resource extraction, as oil-rich countries like Angola and Equatorial Guinea have experienced rapid economic development, and agricultural sectors in countries like Chad and Central African Republic contribute significantly to GDP (Kabaseke et al., 2019).

Oil exports largely drive economic growth in most Central African countries like Angola, Chad, the Republic of Congo, and Equatorial Guinea (IMF, 2020). Population growth which contributes to increased energy consumption in these areas ranges between 2.7% and 4.4% annually (World Bank, 2022). Energy use, primarily from oil and natural gas, accounts for 70% of Angola's electricity generation (IEA, 2022). The study by Azevedo (2018) and Ndoye et al. (2020) suggests that renewable energy, solar energy, as well renewable energy investment can drive sustainable economic growth.

Similarly, economic growth in Cameroon and Congo is linked to agricultural production, and mining, but hindered by conflict and stability in areas like the Central African Republic. The population growth ranges from 2.6% to 3.2% annually (World Bank, 2022). Energy consumption is primarily driven by wood fuel, biomass, and charcoal (IEA, 2022). Energy use is primarily from oil and natural gas (IEA, 2022). However, it is evident that population growth drives energy demand in Central African countries, renewable energy investment can contribute to sustainable economic growth while challenges faced with energy access can hinder economic development.

Research has consistently highlighted the crucial role of policy interventions in mitigating environmental degradation and promoting sustainable development. Studies by Aichele and Felbermayr (2019) and Burke et al. (2019) demonstrate that stringent environmental policies can drive innovation and economic growth. However, findings on the energy-growth nexus have been mixed, with some studies (Apergis and Payne, 2019; Ozturk and Acaravci, 2013) showing a positive correlation, while others (Saboori and Soleymani, 2011; Wolde-Rufael, 2009) report neutral or negative relationships. Recent research emphasizes the importance of dynamic relationships between economic growth, environmental degradation, and policy interventions. Shahbaz (2019) and Al-Mulali et al. (2020) utilize dynamic panel data models to explore these connections.

In Africa, studies have focused on the energy-growth nexus, with Adewuyi and Awodumi (2017) finding unidirectional causality in Nigeria and Alola et al. (2020) revealing a positive renewable energy consumption and economic growth nexus. However, research in Central Africa is limited. Notable exceptions include Mignamissi and Sankara (2019) in Cameroon, where energy consumption significantly impacts economic growth, and Ntalamu et al. (2022) in the Democratic Republic of Congo, which found bidirectional causality.

Despite these contributions, apart from the shorter time frame(periods) covered by existing research, overlooking the long-term dynamics of the energy-growth nexus, there remains a need for robust methodological, comprehensive, longitudinal analyses covering the entire Central African region as previous studies had only focused on individual countries or broader regions, neglecting the specific context of Central Africa. This study aims to bridge this gap by exploring the nexus between energy consumption and growth in Central Africa (1990-2023) and employing advanced econometric techniques to account for linear relationships, structural breaks, and robustness of relationships amongst variables under study. This will help provide reliable evidence to policymakers and stakeholders with insights into the energy-growth nexus informing energy policy and planning decisions and proffering recommendations for sustainable energy use in Central Africa.

## 2. LITERATURE REVIEW

### 2.1. Global Trends

Research indicates a positive correlation between energy consumption and economic growth worldwide (Apergis and Payne, 2010; Ozturk, 2010). Population growth drives energy demand, contributing to increased carbon emissions (York, 2012). Studies emphasize the need for sustainable energy solutions to mitigate climate change impacts (IPCC, 2022).

### 2.2. Developed and Developing Economies

In developed economies, energy efficiency improvements often lead to decreased energy consumption despite economic growth (Haines et al., 2017). Renewable energy investment drives economic growth and reduces carbon emissions in developed nations. Research highlights the importance of energy policy and technological innovation in developed countries (Gillingham et al., 2018). Energy access is crucial for economic development in developing countries (IEA, 2022). Population growth and urbanization drive energy demand in developing nations (Sethi et al., 2018). Renewable energy investment can stimulate economic growth and improve energy access in developing countries (Mendelson et al., 2019).

### 2.3. Comparative Analysis

Developed nations tend to have higher energy efficiency and lower energy intensity compared to developing nations (World

Bank, 2022). The relationship between energy consumption and economic growth is more pronounced in developing countries (Ozturk, 2010). Global cooperation and technology transfer can support sustainable energy development in developing nations (UNDP, 2020).

## 2.4. Theoretical Framework

### 2.4.1. Economic growth theories

Solow Growth Model (1956) explains economic growth through technological progress, population growth, and savings rates. Harrod-Domar Model (1948) emphasizes the role of savings and investment in driving economic growth. However, the Endogenous Growth theory highlights innovation and human capital as drivers of economic growth (Romer, 1990),

### 2.4.2. Energy-economy theories

Energy-intensity theory posits that energy consumption per unit of GDP decreases as economies develop (Smil, 2008). Energy-Led Growth Hypothesis suggests that energy consumption drives economic growth (Stern, 2011). Environmental Kuznets Curve describes the relationship between economic growth, energy consumption, and environmental degradation (Grossman and Krueger, 1991).

### 2.4.3. Population-economy theories

Theories such as the Malthusian Theory (1798), warns of population growth outpacing resource availability, hindering economic growth. Bloom et al., 2015 examined the economic implications of aging populations in its theory, while the demographic transition theory explained population growth and economic development through demographic stages (Notestein, 1945).

In addition, integrated theories such as IPAT and STRIPAT models link environmental impact to population growth, affluence, and technology, as well as economic and social factors (Dietz and Rosa, 1997).

# 3. METHODOLOGY AND DATA

## 3.1. Study Area

As presented in Figure 1, Central Africa encompasses nine countries comprising, Angola, Cameroon, the Central African Republic, Chad, the Democratic Republic of the Congo, the Republic of the Congo, Equatorial Guinea, Gabon, and São Tomé and Principe. The region spans latitudes 5°N to 15°S and longitudes 5°W to 30°E. It experiences a tropical climate, with temperatures ranging from 18°C to 30°C. The region receives significant rainfall, with an annual average of 1,000-2,000 mm (39-79 in), varying by country and season. Research as it that, its population (as of 2020) was approximately 172 million with a GDP growth rate (2020) of 3.4% (World Bank, 2020). Also, energy consumption (as of 2020) was 34.6 million tons of oil equivalent (TOE) and a renewable energy share (as of 2020) of 44.8% of total energy consumption (International Energy Agency, (2022); African Development Bank, (2020)).

## 3.2. Data Collection

Data used for the study were obtained from secondary sources (global economy database).

## 3.3. Model Specification

### 3.3.1. Pedroni cointegration model

$$Y_{it} = \alpha_i + \beta_i X_{it} + \delta_i T + \epsilon_{it} \qquad (1)$$

Where:

$Y_{it}$ = GDP for panel i at time t
$X_{it}$ = independent variables (Energy use, alternative nuclear energy, employment from agriculture, carbon dioxide emission, and electricity production from renewable sources) for panel I at time t
$\alpha_i$ = panel-specific intercept
$\beta_i$ = panel-specific slope coefficient
$\delta_i$ = panel-specific time trend coefficient
$\varepsilon_{it}$ = error term

### 3.3.2. Kao cointegration model

Long-Run relationship

$$Y_{it} = \alpha_i + \beta_i X_{it} + \delta_t + \in_{it} \qquad (2)$$

Where:

$Y_{it}$ = GDP for panel i at time t
$X_{it}$ = independent variables for panel i at time t
$\alpha_i$ =panel-specific intercept
$\beta$ = cointegrating vector (same across panels)
$\delta_t$ = time-specific effect (optional)
$\varepsilon_{it}$ = error term

Short-Run Dynamics

$$\Delta Y_{it} = YY_{it} + \theta \Delta X_{it} + \emptyset X_{it-1} + \mu_i + \varphi_t + V_{it} \qquad (3)$$

Where:

$\Delta Y_{it}$ = first difference of the dependent variable (GDP)
$\gamma$ = coefficient on the lagged dependent variable (GDP)
$\theta$ = coefficient on the first difference of the independent variable
$\varphi$ = coefficient on the lagged independent variable
$\mu_i$ = panel-specific fixed effect
$\varphi_t$ = time-specific fixed effect (optional)
$V_{it}$ = error term

Cointegrating equation

$$Y_{it} - \beta X_{it} = \alpha_i + \delta_t + \varepsilon_{it} \qquad (4)$$

### 3.3.3. Dynamic panel data models

This model used a combination of the Arellano-Bond Generalized Method of Moments (AGMM) and the Blundell-Bond System (BGMM) models in its estimation.

### 3.3.4. Arellano-bond GMM model

$$\Delta Y_{it} = \alpha Y_{it-1} + \beta_1 \Delta X_{1it} + \cdots \beta_k \Delta XK_{it} + \varepsilon_{it} \qquad (5)$$

Where:

$\Delta Y_{it}$ = first difference of the dependent variable (GDP)
$Y_{it-1}$= lagged dependent variable
$X_{1it}$-$X_{nit}$ = first differences of the explanatory variables (as already defined in equation (1))

$\alpha$ = individual-specific fixed effect
$\varepsilon_{it}$ = error term

### *3.3.5. Blundell-bond system GMM model*

$$\Delta Y_{it} = \alpha Y_{it-1} + \beta_1 \Delta X_{1it} + \cdots \beta_k \Delta XK_{it} + \delta_i + \varepsilon_{it} \quad (6)$$

$$Y_{it} = YY_{it-1} + \theta_1 X_{1it} + \cdots \theta XK_{it} + \mu_i + v_{it} \quad (7)$$

Where,
Difference equation (similar to the Arellano-Bond model)… (6)
Level equation … (7)
Y = coefficient on the lagged dependent variable in … (7)
$\theta_1, \ldots, \theta_k$ are the coefficients on the explanatory variables in the level equation
$\mu_i$ = individual-specific fixed effect in the level equation
$V_{it}$ = error term.

## 4. RESULTS AND DISCUSSION

### 4.1. Descriptive Statistics

As presented in Table 1, the average GDP is approximately \$7.06 billion, ranging from \$1.47 billion to \$22.85 billion. Average energy use is around 757.76 MTOE, varying between 194.91 and 2970.05 MTOE. Nuclear energy sources account for approximately 71.67% on average, with a range of 3.68-98.34%. Average energy production from renewable sources was about 10.58 GW, with significant variation (0-643 GW). Carbon dioxide emissions average 1.19 million tons, ranging from 0.03 to 6.68 million tons, and finally, employment in Agriculture averages 55.62%, with a range of 17.15-83.4%. In essence, significant variation exists across countries/observations in terms of GDP, energy use, and emissions, while nuclear energy sources dominate the energy mix. Employment in Agriculture was a challenge, with an average rate of 55.62%, while carbon emissions are substantial, indicating room for improvement in sustainability.

### 4.2. Linear Relationships between Economic Growth and its Determinants

According to Table 2, dynamic panel-data estimation reveals that $CO_2$ emissions and energy use significantly and positively influence

**Table 1: Descriptive statistics of the variables**

| Variable | Mean | Standard deviation | Min. | Max. |
|---|---|---|---|---|
| GDP | 7.062037 | 7.062037 | 1.47 | 22.85 |
| Energy use | 757.7629 | 757.7629 | 194.91 | 2970.05 |
| Nuclear Energy sources | 71.6652 | 71.6652 | 3.68 | 98.34 |
| Electricity prod. | 10.57795 | 10.57795 | 0 | 643 |
| Carbon emission | 1.19254 | 1.19254 | 0.03 | 6.68 |
| Employment in Agriculture | 55.61578 | 12.7340 | 17.15 | 83.4 |

**Figure 1:** Map of Africa, showing the Central African countries

**Table 2: Dynamic panel data estimation**

| Variable | Coefficient | Standard Error | z-value | P-value |
|---|---|---|---|---|
| Electricity production from renewable sources | 0.0054902 | 0.0246947 | 0.22 | 0.824 |
| Carbon dioxide ($CO_2$) emission | 0.0669436 | 0.019541 | 3.43 | 0.001 |
| Employment in Agriculture | −0.0259548 | 0.1796253 | −0.14 | 0.885 |
| Alternative/nuclear energy sources | −0.1631281 | 0.0434702 | −3.75 | 0.000 |
| Energy use | 0.4169062 | 0.0859979 | 4.85 | 0.000 |

Wald Chi-square (5)=53.74, Prob>Chi-square=0.0000; Chi-squared statistic=53.74

**Table 3: Dynamic panel data estimation using the Arellano-Bond GMM Model**

| Variable | Coefficient | Standard Error | z-value | P-value |
|---|---|---|---|---|
| Gross Domestic product | −0.0444 | 0.0562 | −0.79 | 0.429 |
| Alternative nuclear sources | −0.1209 | 0.0447 | −2.71 | 0.007 |
| Carbon dioxide emission | 0.0432 | 0.0187 | 2.31 | 0.021 |
| Electricity from renewable sources | 0.0060 | 0.0242 | 0.25 | 0.804 |
| Energy use | 0.2893 | 0.0747 | 3.87 | 0.000 |
| Employment in Agriculture | 0.0512 | 0.2058 | 0.25 | 0.804 |
| _cons | −5.83e-11 | 0.0075 | −0.00 | 1.000 |

Model Diagnostics: Number of observations: 300; Wald Chi-square (6)=29.27; Prob>Chi-square=0.0001

**Table 4: The pedroni cointegration results**

| Variable | Coefficient | P-value |
|---|---|---|
| Modified Variance Ratio | −4.2639 | 0.0000 |
| Modified Phillips-Perron t | −5.9265 | 0.0000 |
| Phillips-Perron t | −11.8490 | 0.0000 |
| Augmented Dickey-Fuller t | −11.5787 | 0.0000 |

Null Hypothesis (Ho): No cointegration; Alternative Hypothesis (Ha): All panels are cointegrated

economic growth in Central Africa at a 5% significance level. Conversely, alternative nuclear energy sources exhibit a significant negative impact. In contrast, electricity production from renewable sources and employment in agriculture show no substantial effect on economic growth in Central Africa. Specifically, a 1% increase in $CO_2$ emissions, energy use, and renewable electricity production corresponds to 0.0669%, 0.4169%, and 0.00549% economic growth increments, respectively while a 1% increase in alternative/nuclear energy and agricultural employment lead to 0.1631% and 0.0259% decrease in growth. These findings align with Baltagi (2020) and Dogan and Seker (2019) but diverge from Shahbaz (2019), who reported a negative $CO_2$ emissions-economic growth relationship. This study's results also support Tugrul et al. (2022) findings on energy use's positive impact on economic growth in Central Africa.

However, for the robustness of the results, a single dynamic panel data estimation using only the Arellano-Bond GMM Model was used as presented:

Table 3 reveals robust evidence of the dynamic interplay between economic growth and its drivers, informing the ongoing discussion on economic growth and environmental policies. Notably, energy consumption exhibits a positive, significant effect (coefficient: 0.289, z-score: 3.87, P: 0.000), indicating a 0.289% increase in economic growth for every 1% rise in energy use. Similarly, $CO_2$ emissions show a positive, significant relationship (coefficient: 0.043, z-score: 2.31, P: 0.021), with a 1% increase in emissions yielding a 0.043% growth increase. Conversely, alternative nuclear energy sources in Central Africa display a negative, significant impact (coefficient: −0.121, z-score: −2.71, P: 0.007), resulting in a 0.121% decrease in economic growth per 1% increase in energy consumption. These findings reaffirm the study's robustness and align with Apergis and Payne (2020) discovery of a negative energy consumption-economic growth relationship.

## 4.3. Long-run Relationship among the Variables

The Pedroni test for cointegration yielded statistically significant results at 1%, 10%, and 5% levels, indicating strong evidence of cointegration among the variables across the five panels/variables used for the study, suggesting that the variables are cointegrated (there is a long-run equilibrium relationship). The results are as presented:

As presented in Table 4, the test results strongly reject the null hypothesis (Ho), that there is no cointegration, suggesting that the panels are cointegrated. The t-statistics for the modified variance ratio (coefficient = −4.2639, P = 0.0000) suggest strong evidence against the null hypothesis of no cointegration, indicating that the variables are likely to have a long-term equilibrium relationship. The negative coefficient suggests deviations from this equilibrium will likely correct themselves over time, reinforcing the notion of mean reversion in the data. Modified Phillips-Perron t (coefficient = −5.9265, P = 0.0000), provides robust evidence for cointegration among the variables. This statistic adjusts for serial correlation and heteroskedasticity, enhancing the reliability of the results. The strong negative value indicates significant evidence that the time series under consideration are not only non-stationary in levels but also integrated in the same order, suggesting a long-term relationship.

Phillips-Perron t, (coefficient = −11.8490, P = 0.0000), further confirms the findings of the previous tests. This statistic assessed the presence of unit roots in the data. The extremely negative value signifies a strong rejection of the null hypothesis, reinforcing the argument that the variables share a long-term stochastic trend. Finally, the Augmented Dickey-Fuller t (coefficient = −11.5787, P = 0.0000) is a cornerstone for unit root testing in time series analysis, and the strong negative coefficient indicates a robust

**Table 5: Kao cointegration test results**

| Variable | Coefficient | z-value | P-value |
|---|---|---|---|
| Modified Dickey-Fuller t | −37.2612 | −37.2612 | 0.0000 |
| Dickey−Fuller t | −16.6372 | −16.6372 | 0.0000 |
| Augmented Dickey−Fuller t | −10.4412 | −10.4412 | 0.0000 |
| Unadjusted Modified Dickey-Fuller t | −40.6124 | −40.6124 | 0.0000 |
| Unadjusted Dickey-Fuller t | −16.6305 | −16.6305 | 0.0000 |

Null Hypothesis (Ho): No cointegration, Alternative Hypothesis (Ha): All panels are cointegrated

rejection of the presence of a unit root, thus supporting the idea of cointegration among the series. However, all four test statistics indicate strong evidence of cointegration among the variables. The consistent significance across all tests suggests that despite any short-term fluctuations, the variables in question exhibit a stable long-term relationship, which is vital for subsequent econometric modeling or forecasting efforts. These findings underline the importance of considering the interdependencies of the variables in analyses and policymaking. Also, the results have proven that the panels are independently distributed, the error terms are homoscedastic and serially uncorrelated, and the cointegrating vector is the same across panels. These results are in line with studies carried out by, Adewuyi and Awodumi, (2018), and Pedroni and Vogelsang, (2018) in their studies linked to panel cointegration and causality analysis of the relationship between energy consumption and growth in developing countries.

For robustness, these results were confirmed using the Kao test which uses Ordinary Least Squares (OLS), Generalized Least Squares (GLS), and Maximum Likelihood Estimation (MLE) estimation methods.

As presented in Table 5, the test statistics and P-values indicate strong evidence of cointegration among the variables at a 5% level across the five variable panels, suggesting a long-run equilibrium relationship. This result is supported by Kao (1999), who reported on spurious regression and residual-based tests for cointegration in panel data. This analysis is justified in line with the study as it relates to economic growth and trade as well as energy, trade, energy, and environmental economics.

## 5. CONCLUSION AND RECOMMENDATIONS

This research examined the nexus between energy use and growth in the Central African economy, utilizing dynamic panel data estimation and cointegration techniques. The results demonstrate a robust, positive relationship between energy use and $CO_2$ emissions with economic growth at a 5% significance level, whereas alternative/nuclear energy exhibits a significant negative impact. Results showed that 1% energy consumption increases yields by 0.4169% and 0.289% economic growth; 1% $CO_2$ emissions increase yield by 0.0669% and 0.043% economic growth; 1% alternative/nuclear energy increases decrease economic growth by 0.1631% and 0.121% and finally, renewable electricity production and agricultural employment had negligible effects on economic growth. Cointegration tests confirm a long-run equilibrium relationship (existence of cointegration) among these variables. This study provides valuable insights for Central African policymakers, researchers, and stakeholders, highlighting complex relationships between energy consumption, economic growth, and environmental sustainability. Key policy implications for this study were prioritizing energy infrastructure development, renewable energy investments, and promoting energy efficiency while considering potential economic benefits.

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