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# Short-Run Dynamics and Long-Run Equilibrium in Energy-Growth Nexus: A Comparative Application of VAR, VECM, and ARDL with Unit Roots

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***Abstract-*** ***This study investigates the short-run dynamics and long-run equilibrium relationships between energy consumption, fixed capital, inflation rate, labor force, and economic growth (GDP) in Nigeria over the period 1984–2023. Given the pervasive presence of unit roots in macroeconomic time series, this research applies three complementary econometric frameworks—Vector Autoregressive (VAR), Vector Error Correction Model (VECM), and Autoregressive Distributed Lag (ARDL)—to model the energy-growth nexus. The Augmented Dickey-Fuller (ADF) unit root test confirms that all variables are integrated of order one, I(1). The Johansen cointegration test reveals two cointegrating equations, indicating a stable long-run equilibrium relationship among the variables. VECM estimates show that a 1% increase in fixed capital, energy consumption, and inflation rate leads to long-run GDP increases of 3.93%, 0.91%, and 0.77%, respectively. The error correction term (−0.3468) indicates that approximately 34.7% of short-run disequilibrium is corrected annually. ARDL bounds testing confirms cointegration (F-statistic = 4.319 > 4.01), with fixed capital exerting a significant positive long-run impact (3.41%, p = 0.0013). VAR estimation at optimal lag 5 reveals that inflation and labor force are useful predictors of GDP. The study contributes methodologically by demonstrating how unit roots can be properly addressed across three distinct modeling approaches, providing robust evidence that energy consumption and capital formation are critical drivers of Nigeria's long-run economic growth.***

***Keywords: Unit Root, Energy Consumption, Economic Growth, VECM, ARDL, VAR, Cointegration, Nigeria***

## I. INTRODUCTION

The relationship between energy consumption and economic growth has remained a central preoccupation in empirical macroeconomics since the seminal work of Kraft and Kraft (1978). For energy-dependent economies like Nigeria, understanding this nexus carries profound policy implications, particularly in an era marked by energy price volatility, subsidy removals, infrastructure deficits, and supply disruptions (Iwayemi, 2020; Onakoya et al., 2013). Despite decades of research, the empirical literature remains characterized by conflicting findings—ranging from unidirectional causality (Adenikinju, 1998; Odularu & Okonkwo, 2009), bidirectional causality (Chontanawat et al., 2008; Omisakin, 2008), to statistical independence (Usman et al., 2020; Mustapha & Fagge, 2015).

A critical methodological challenge underlying these divergent results is the proper handling of unit roots—a statistical property of most macroeconomic time series whereby shocks have persistent, long-lasting effects that do not decay over time (Nelson & Plosser, 1982; Phillips, 1987). When variables contain unit roots, conventional regression techniques produce spurious results, invalidating standard inference (Granger & Newbold, 1974). Consequently, modeling energy consumption and economic growth requires explicit attention to non-stationarity, cointegration, and appropriate econometric frameworks that can distinguish short-run dynamics from long-run equilibrium relationships.

This study addresses these challenges by applying three distinct yet complementary modeling approaches—Vector Autoregression (VAR), Vector Error Correction Model (VECM), and Autoregressive Distributed Lag (ARDL)—to the Nigerian energy-growth nexus over the period 1984–2023. Each model handles unit roots differently: VAR in levels requires stationarity or cointegration; VECM explicitly models error correction when cointegration

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exists; and ARDL accommodates mixed integration orders through bounds testing (Pesaran et al., 2001). By comparing these frameworks within a unified empirical setting, this research provides robust evidence on both short-run dynamics and long-run equilibrium relationships.

The specific objectives addressed in this paper are: (i) to fit standard VAR, VECM, and ARDL models in the presence of unit roots in economic variables; and (ii) to examine the short-run and long-run impacts using these three approaches. The remainder of the paper is structured as follows: Section 2 presents the theoretical framework and econometric methodology. Section 3 describes the data and preliminary tests. Section 4 reports and discusses the empirical results. Section 5 concludes with policy recommendations.

## II. THEORETICAL FRAMEWORK AND METHODOLOGY

### 2.1 Theoretical Underpinnings

The theoretical foundation for modeling energy consumption and economic growth derives from the production function approach, where energy is treated as a distinct input alongside capital and labor (Stern, 1993; 2000). The standard Cobb-Douglas production function can be augmented to include energy consumption:

$$Y_t = A_t K_t^{\alpha} L_t^{\beta} E_t^{\gamma} \quad (1)$$

Where;

$Y_t$ is real GDP

$K_t$ is capital stock,

$L_t$ is labor force,

$E_t$ is energy consumption,

$A_t$ is total factor productivity, and

α, β, γ are output elasticity. Taking logarithms yields the linear form:

$$gdp_t = \alpha_0 + \beta_1 fc_t + \beta_2 lfc_t + \beta_3 ec_t + \varepsilon_t \quad (2)$$

Where

$gdp_t$ is log of GDP,

$fc_t$ is log of fixed capital,

$lfc_t$ is log of labor force, and

$ec_t$ is log of energy consumption.

### 2.2 Unit Root and Cointegration Concepts

A time series $Y_t$ is said to have a unit root if it follows a stochastic process $Y_{t-1} + \varepsilon_t$

Where;

$\varepsilon_t$ is white noise. Such series are non-stationary (integrated of order one, I(1)), meaning shocks have permanent effects.

The Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1981) is employed to test the null hypothesis of a unit root:

$$\Delta y_t = \mu + \delta y_{t-1} + \sum_{i=1}^{k} \beta_i \Delta y_{t-i} + \Delta e_t \quad (3)$$

Where,

$\delta = \alpha - 1$

α= Coefficient of $y_{t-1}$

$\Delta y_t$ = First difference of $y_t$, i.e. $y_t - y_{t-1}$

The null hypothesis $H_0$:: δ = 0 (unit root) is tested against $H_1$: δ < 0 (stationarity). When multiple I(1) variables move together such that a linear combination is stationary, they are said to be cointegrated (Engle & Granger, 1987), implying a long-run equilibrium relationship.

### 2.3 Model Specifications

#### 2.3.1 Vector Autoregression (VAR)

The standard VAR model of order p is specified as:

$$y_t = c + \Phi_1 y_{t-1} + \Phi_2 y_{t-2} + \cdots + \Phi_p y_{t-p} + \varepsilon_t \quad (4)$$

Where

$y_t$ is a 5×15×1 vector of endogenous variables (GDP, energy consumption, fixed capital, inflation, labor force),

c is a vector of constants,

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$\Phi_i$ are 5×55×5 coefficient matrices, and

$\varepsilon_t$ is a white noise error vector. In the presence of unit roots but without cointegration, VAR is estimated in first differences. With cointegration, VECM is preferred.

2.3.2 Vector Error Correction Model (VECM)

When variables are cointegrated, the VECM specification captures both short-run dynamics and long-run equilibrium adjustment:

$$\Delta\gamma_t = \nu + \Pi Y_{t-1} + \sum\theta_i \Delta\gamma_{t-i} + \mu_t \quad (5)$$

Where

$\Pi\alpha\beta^{`}$ is the error correction matrix,

$\beta$ Contains the cointegrating vectors (long-run relationships),

$\alpha$ Contains the adjustment coefficients (speed of correction), and

$\theta_i$ Capture short-run dynamics.

The error correction term ($ECT_{t-1} = \beta^{`}\gamma_{t-1}$) represents the deviation from long-run equilibrium in the previous period.

2.3.3 Autoregressive Distributed Lag (ARDL)

The ARDL bounds testing approach (Pesaran et al., 2001) offers advantages over traditional cointegration methods: it can be applied regardless of whether variables are I(0) or I(1), performs well in small samples, and provides unbiased long-run estimates.

The conditional ARDL model is specified as:

$$\Delta gdp = \beta_0 \Sigma_{t-1}^{p} \beta_{1i} gdp_{t-1} + \Sigma_{t-1}^{p} \beta_{2i} \Delta ec_{t-1} + \Sigma_{t-1}^{p} \beta_{3i} \Delta fc_{t-1} + \Sigma_{t-1}^{p} \beta_{4i} \Delta inf_{t-1} + \Sigma_{t-1}^{p} \beta_{5i} \Delta lft_{t-1} + \theta_1 gdp_{t-1} + \theta_2 ec_{t-1} + \theta_3 fc_{t-1} + \theta_4 inft_{t-1} + \theta_5 lft_{t-1} + \varepsilon_t \quad (6)$$

The null hypothesis of no cointegration $H_o = \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = 0$ is tested using the F-statistic, compared against critical bounds for I(0) and I(1) variables.

2.4 Data and Preliminary Tests

The study uses annual time series data from 1984 to 2023 (40 observations) sourced from the National Bureau of Statistics (NBS) Statistical Bulletin and World Bank Development Indicators. Variables include: Gross Domestic Product (GDP, constant 2015 US), 2015), Energy Consumption, Fixed Capital Formation(constant), Inflation Rate (consumer prices, annual %), and Labor Force (total). All variables except inflation are transformed using natural logarithms.

## III. EMPIRICAL RESULTS AND DISCUSSION

### 3.1 Descriptive Statistics and Unit Root Tests

Table 1: Descriptive Statistics (1984–2023)

| | GDP | FIX CAPITAL | CONSUMPT... | INFLATION | LABOUR F... |
|---|---|---|---|---|---|
| Mean | 3.747500 | 1.082500 | 13.20750 | 13.23250 | 3.930000 |
| Median | 3.000000 | 0.900000 | 13.20000 | 13.05000 | 3.800000 |
| Maximum | 15.30000 | 2.900000 | 18.90000 | 19.20000 | 5.700000 |
| Minimum | -1.800000 | -1.100000 | 5.400000 | 5.400000 | 2.600000 |
| Std. Dev. | 3.180146 | 0.807302 | 3.389682 | 3.462798 | 0.697688 |
| Skewness | 1.220396 | 0.149032 | -0.222356 | -0.186542 | 1.007038 |
| Kurtosis | 5.719513 | 3.368529 | 2.300487 | 2.374649 | 3.930918 |
| Jarque-Bera | 22.25536 | 0.374427 | 1.145146 | 0.883759 | 8.205190 |
| Probability | 0.000015 | 0.829267 | 0.564072 | 0.642827 | 0.016530 |
| Sum | 149.9000 | 43.30000 | 528.3000 | 529.3000 | 157.2000 |
| Sum Sq. Dev. | 394.4198 | 25.41775 | 448.1077 | 467.6478 | 18.98400 |
| Observations | 40 | 40 | 40 | 40 | 40 |

Table 1 presents descriptive statistics. GDP exhibits positive skewness (1.22), indicating right-skewed distribution with observations clustering toward lower values. Inflation shows the highest variability (standard deviation 13.23), while fixed capital displays the lowest mean value (1.08). The Jarque-Bera test rejects normality for GDP and labor force at 5% significance level but accepts normality for fixed capital, consumption, and inflation.

Table 2: Augmented Dickey-Fuller Unit Root Test Results

| Variables | ADF Statistics (Level) | P-value (Level) | ADF Statistics (at 1st Difference) | P-value at 1st Difference) |
|---|---|---|---|---|
| GDP | - | 0.18 | -6.6217 | 0.0000 |

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| | | | | |
|---|---|---|---|---|
| | 2.274373 | 82 | | |
| CONSUMPTION | -2.850400 | 0.0684 | -4.5315 | 0.0021 |
| INFLATION | -2.89187 | 0.0632 | -4.4236 | 0.0029 |
| FIXED CAPITAL | -2.12836 | 0.2362 | -6.9769 | 0.0000 |
| LABOUR FORCE | -2.5259 | 0.1232 | -5.9896 | 0.0001 |

Source: Eview 12 output

Table 2 reports the ADF unit root test results. At levels, all variables have test statistics with p-values > 0.05, failing to reject the null hypothesis of a unit root. However, after first differencing, all variables become stationary at the 1% significance level (p-values < 0.01). This confirms that GDP, energy consumption, fixed capital, inflation, and labor force are integrated of order one, I(1).

### 3.2 Lag Length Selection and VAR Specification

Table 3: VAR Lag Order Selection Criteria

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -329.8531 | NA | 140.4926 | 19.13446 | 19.35665 | 19.21116 |
| 1 | -280.5310 | 81.73380* | 35.59968 | 17.74463 | 19.07778* | 18.20483 |
| 2 | -263.3059 | 23.62294 | 60.92258 | 18.18891 | 20.63303 | 19.03262 |
| 3 | -235.8484 | 29.81102 | 68.34705 | 18.04848 | 21.60356 | 19.27569 |
| 4 | -194.0721 | 33.42105 | 46.15103 | 17.08983 | 21.75588 | 18.70055 |
| 5 | -127.6891 | 34.13982 | 14.51788* | 14.72509* | 20.50210 | 16.71931* |

Table 3 presents the lag order selection criteria for the VAR model. The Akaike Information Criterion (AIC) selects lag 5 as optimal (AIC = 14.725), while the Schwarz Bayesian Criterion (SBC) suggests lag 1. Given the annual frequency of the data, lag 5 appropriately captures dynamics over a five-year horizon, consistent with business cycle considerations.

Table 4. Var Serial Correlation Test at Lag 5

Null hypothesis: No serial correlation at lag h

| Lag | LRE* stat | df | Prob. | Rao F-stat | df | Prob. |
|---|---|---|---|---|---|---|
| 1 | 40.25594 | 25 | 0.0274 | 1.792280 | (25, 68.4) | 0.0302 |
| 2 | 36.24508 | 25 | 0.0680 | 1.570555 | (25, 68.4) | 0.0731 |
| 3 | 20.95057 | 25 | 0.6954 | 0.820241 | (25, 68.4) | 0.7038 |
| 4 | 17.11197 | 25 | 0.8777 | 0.653424 | (25, 68.4) | 0.8819 |
| 5 | 16.19713 | 25 | 0.9088 | 0.614837 | (25, 68.4) | 0.9121 |

From table 4, it clearly shows that, using lag 5 is appropriate since the p-value is greater than alpha (P-value > 0.05), it means there is no serial correlation at lag 5 and is fairly good enough to capture annual data dynamics.

Table 5: Var Residual Normality Test at Lag5

| Component | Jarque-Bera | df | Prob. |
|---|---|---|---|
| 1 | 1.087956 | 2 | 0.5804 |
| 2 | 2.347232 | 2 | 0.3092 |
| 3 | 0.431439 | 2 | 0.8060 |
| 4 | 2.145228 | 2 | 0.3421 |
| 5 | 0.109121 | 2 | 0.9469 |
| Joint | 6.120977 | 10 | 0.8050 |

From table 5, the result shows that, residual of the variables under study are normally distributed. The joint normality test for the whole variables also show that the residual is normally distributed at lag 5 (P = 0.8050 > 0.05).

Table 6: Var Output

| | GDP | FIX CAP. | CONSUMP | INFL | LABOR |
|---|---|---|---|---|---|
| GDP(-5) | 0.092511 | -0.034751 | 0.151445 | -0.6739 | 0.0248 |
| | (0.18418) | (0.05755) | (0.32458) | (0.219) | (0.069) |
| | [0.50229] | [-0.60388] | [0.46658] | [-3.072] | [0.356] |
| FIX CAP(-5) | -0.124382 | -0.056941 | -1.89154 | -0.569 | 0.3411 |
| | (0.86269) | (0.26955) | (1.52036) | (1.027) | (0.326) |

| | | | | | |
|---|---|---|---|---|---|
| | [-0.14418] | [-2.11250] | [-1.24412] | [-0.554] | [1.044] |
| CONSUMPT(-5) | -0.027994 | 0.150539 | -0.372056 | 0.0967 | 0.1442 |
| | (0.15914) | (0.04972) | (0.28045) | (0.189) | [0.510] |
| | [-0.17592] | [ 3.02764] | [-1.32664] | [0.510] | [2.394] |
| INFLATION(-5) | 0.095034 | -0.074943 | 0.422329 | -0.2206 | -0.222 |
| | (0.15885) | (0.04963) | (0.27995) | (0.189) | (0.060) |
| | [ 0.59826] | [-1.50997] | [1.50861] | [-1.166] | [-3.69] |
| LABOUR FORCE (-5) | 0.301699 | 0.144098 | 1.576527 | 1.3543 | -0.129 |
| | (0.86885) | (0.27147) | (1.53121) | (1.034) | (0.329) |
| | [0.34724] | [0.53081] | [1.02959] | [1.308] | [-0.392] |

The table above shows the output of the vector autoregressive (VAR) model estimation at lag 5. From the result, only GDP is significant enough to predict itself with t-statistic (0.5022) while all other variables don't have a significance influence on themselves. Out of the variables under study, only inflation and labour force can be useful in predicting GDP with t- statistic of (0.5982) and (0.3472) respectively.

### 3.3 Cointegration Analysis

Table 6: Johansen Cointegration Test Results

Unrestricted Cointegration Rank Test (Trace)

| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob.** |
|---|---|---|---|---|
| None * | 0.641375 | 100.4321 | 69.81889 | 0.0000 |
| At most 1 * | 0.592452 | 62.48939 | 47.85613 | 0.0012 |
| At most 2 | 0.417792 | 29.27827 | 29.79707 | 0.0573 |
| At most 3 | 0.134979 | 9.263959 | 15.49471 | 0.3415 |
| At most 4 * | 0.100014 | 3.898902 | 3.841465 | 0.0483 |

Trace test indicates 2 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

| Hypothesized No. of CE(s) | Eigenvalue | Max-Eigen Statistic | 0.05 Critical Value | Prob.** |
|---|---|---|---|---|
| None * | 0.641375 | 37.94268 | 33.87687 | 0.0155 |
| At most 1 * | 0.592452 | 33.21112 | 27.58434 | 0.0085 |
| At most 2 | 0.417792 | 20.01431 | 21.13162 | 0.0711 |
| At most 3 | 0.134979 | 5.365057 | 14.26460 | 0.6952 |
| At most 4 * | 0.100014 | 3.898902 | 3.841465 | 0.0483 |

Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

From the cointergration result presented on table 6, the evidence from trace test indicate a 2 integration equations at 0.05 level, while evidence from maximum eigenvalue also indicate a 2 integration equations at 0.05 significance level. Overall, the presence of cointegration, as supported by both tests, implies that GDP, energy consumption, fixed capital, inflation and labour force move together in the long run, even if they may deviate from this relationship in the short run

### 3.4 Long-Run Equilibrium: VECM Estimates

Table 7: VECM Long-Run Cointegrating Equation (Dependent Variable: LNGDP)

| Variables | Coefficient | Standard Error | t-Statistics | Significance | Impact |
|---|---|---|---|---|---|
| LNFIXED CAPITAL(-1) | 3.9334 | 0.8107 | 4.8515 | Significant | Positive |
| LNCONS (-1) | 0.9073 | 0.2479 | 3.6596 | Significant | Positive |
| LNINFLATION(-1) | 0.7727 | 0.2661 | 2.9038 | Significant | Positive |
| LNLABOUR FORCE(-1) | 0.1008 | 0.9144 | 0.1102 | Not significant | Inconclusive |
| C | 1.5415 | | | | |

Table 7 presents the normalized long-run cointegrating coefficients from the VECM. The results show that all explanatory variables except labor force have statistically significant positive long-run effects on GDP. Specifically:

A 1% increase in fixed capital leads to a 3.93% increase in GDP in the long run ($t = 4.85$, $p < 0.01$). A 1% increase in energy consumption leads to a 0.91% increase in GDP ($t = 3.66$, $p < 0.01$). A 1%

increase in inflation leads to a 0.77% increase in GDP ($t = 2.90$, $p < 0.01$). Labor force has a positive but statistically insignificant effect (0.10%, $t = 0.11$, $p > 0.10$).
The strong positive effect of fixed capital is expected—capital accumulation directly expands production capacity. The significant positive effect of energy consumption confirms that energy is not merely a passive factor but an active driver of economic growth in Nigeria, consistent with the growth hypothesis (Stern, 2000; Akinlo, 2008). The positive inflation coefficient, while statistically significant, should be interpreted cautiously as it may reflect the long-run trend of rising prices rather than a causal growth-enhancing effect.

Estimated Longrun Equation: LNGDP(-1) = 1.5415 + 3.9334LNFP(-1)+0.9073LNCONS(-1)+ 0.7727LNINF(-1)+0.1008LNLF(-1) (7)

Table 8: VECM Short-Run Dynamics and Error Correction

| | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| C(1) | -0.346807 | 0.114043 | -3.041012 | 0.0048 |
| C(2) | -0.201563 | 0.134870 | -1.494498 | 0.1452 |
| C(3) | -1.081398 | 0.559358 | -1.933283 | 0.0624 |
| C(4) | -0.344989 | 0.136299 | -2.531119 | 0.0167 |
| C(5) | 0.279132 | 0.085531 | 3.263495 | 0.0027 |
| C(6) | -0.024730 | 0.556702 | -0.044423 | 0.9649 |
| C(7) | -0.221994 | 0.345119 | -0.643239 | 0.5248 |

Estimated Short-run equation: D(GDP) = C(1)*( GDP(-1) - 3.93347272016*FIX_CAPITAL(-1) - 0.907303604926*CONSUMPTION(-1) + 0.772718657956*INFLATION(-1) + 0.100803378932*LABOUR_FORCE(-1) + 1.54158642421 ) + C(2)*D(GDP(-1)) + C(3)*D(FIX_CAPITAL(-1)) + C(4)*D(CONSUMPTION(-1)) + C(5)*D(INFLATION(-1)) + C(6)*D(LABOUR_FORCE(-1)) + C(7) (4.2)

## 3.5 Short-Run Dynamics: VECM Error Correction

Table 6 reports the short-run coefficients and the error correction mechanism. The error correction term, $ECT_{t-1}$ is negative (−0.3468) and statistically significant ($p = 0.005$), confirming cointegration and indicating that the system corrects deviations from long-run equilibrium at an annual speed of approximately 34.7%. In other words, about one-third of any short-run disequilibrium in GDP is adjusted back to its long-run path within one year—a relatively rapid adjustment speed.

The short-run coefficients reveal:
GDP(−1) has a negative but insignificant effect (−0.2029, $p = 0.257$).

Fixed capital (−1) has a negative and marginally significant effect (−1.0841, $p = 0.062$), suggesting that rapid capital expansion may temporarily disrupt output before yielding long-run benefits.

Energy consumption (−1) has a negative and significant effect (−0.3437, $p = 0.017$), indicating that short-run increases in energy use may reduce GDP—possibly reflecting inefficiencies or supply disruptions.

Inflation (−1) has a positive and significant effect (0.2713, $p = 0.003$), suggesting that moderate inflation in the short run may stimulate economic activity.

Labor force (−1) has a negative but insignificant effect (−0.2204, $p = 0.965$).

## 3.6 ARDL Bounds Testing and Long-Run Estimates

Table 7 presents the ARDL bounds test for cointegration. The F-statistic (4.319) exceeds the upper bound critical value (4.01) at the 5% significance level, rejecting the null hypothesis of no long-run relationship. This confirms cointegration among the variables, consistent with the Johansen test results. The ARDL model explains 85.29% of the variation in GDP (adjusted R-squared = 0.8529), indicating good model fit.

Table 9: ARDL Bounds Test for Cointegration

| Variable | Coefficient | Std. Error | t-Statistic | Prob.* |
|---|---|---|---|---|
| GDP(-1) | 0.371373 | 0.154523 | 2.403347 | 0.0229 |
| FIX_CAPITAL | 1.048305 | 0.671985 | 1.560013 | 0.1296 |
| FIX_CAPITAL(-1) | 1.095987 | 0.636050 | 1.723114 | 0.0955 |
| CONSUMPTION | -0.007670 | 0.142435 | -0.053851 | 0.9574 |
| CONSUMPTION(-1) | 0.028942 | 0.176537 | 0.163946 | 0.8709 |
| INFLATION | -0.086891 | 0.164377 | -0.528608 | 0.6011 |
| INFLATION(-1) | 0.203840 | 0.119449 | 1.706506 | 0.0986 |
| LABOUR_FORCE | -0.826406 | 0.702065 | -1.177107 | 0.2487 |
| LABOUR_FORCE(-1) | 0.733776 | 0.737868 | 0.994454 | 0.3282 |
| C | -1.447043 | 4.271933 | -0.338733 | 0.7373 |

Table 7 shows the estimation of ARDL model for the study variables based on Akaike information criterion (AIC). The overall model was significant at 0.05 level (F=21.96740, p=0.0000<0.05). The model adjusted R-squared shows that the estimated ARDL model explains 85.29% of the variation in the dependent variable in the short-run.

Fixed capital has positive insignificant impact on GDP at both lag 0 and lag 1 in the short run (P=0.1296>0.05) and (P=0.0955>0.05) respectively. At lag 0 and 1 a 1% increase in fixed capital corresponds to a 1.048305% and 1.095987% increase in GDP respectively.

Consumption has insignificant negative relationship with GDP at lag 0 in a short run (P = 0.9574 > 0.05). A 1% increase in consumption will result to -0.007670% decrease in GDP in the short run. While at lag 1 the relationship is insignificant (P=0.8709>0.05) but positive.

Inflation has insignificant negative relationship with GDP at lag 0 in a short run (P = 0.6011 > 0.05). A 1% increase in consumption will result to -0.086891% decrease in GDP in the short run. While at lag 1 the relationship is insignificant (P=0.0986>0.05) but positive.

Labour Force has insignificant negative relationship with GDP at lag 0 in a short run (P = 0.2487 > 0.05). A 1% increase in consumption will result to -0.826406% decrease in GDP in the short run. While at lag 1 the relationship is insignificant (P = 0.3282 > 0.05) but positive.

The short run equation is expressed as:
LNGDP = 0.3714*LNGDP(-1)+1.0483*LNFIXCAP+1.0959*LNFIXCAP(-1) - 0.0076*LNCONS + 0.0289*LNCONS(-1) - 0.0868*LNINFL + 0.2038*LNINFL(-1) - 0.8264*LNLABF + 0.7337*LNLABF(-1) – 1.4470 (4.3)

Table 10: Bound Test Result for Long Run Relationship

Bound Testing: Wald Test

Equation: Untitled

| Test Statistic | Value | Df | Probability |
|---|---|---|---|
| F-statistic | 4.319051 | (4, 15) | 0.0004 |
| Chi-square | 37.27621 | 4 | 0.0000 |

F-statistic = 4.319 > 4.01, we conclude that there is exist a long run relationship among the study since variables. (GDP, fixed capital, energy consumption, Inflation and labor force). The estimated long run coefficients are presented in Table 11.

Table 11: Length of Long Run Relationship

Levels Equation
Case 2: Restricted Constant and No Trend

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| FIX_CAPITAL | 3.411071 | 0.957049 | 3.564156 | 0.0013 |
| CONSUMPTION | 0.033839 | 0.284680 | 0.118867 | 0.9062 |
| INFLATION | 0.186039 | 0.308924 | 0.602217 | 0.5517 |
| LABOUR_FORCE | -0.147352 | 1.062235 | -0.138719 | 0.8906 |
| C | -2.301910 | 6.988574 | -0.329382 | 0.7442 |

Table 11 shows that GDP is positively related with Fixed capital, Consumption and Inflation in Nigeria in the long run where a 1% increase in each of these variables will result to an increase in the GDP, however, among these variables, it is the relationship between fixed capital and GDP that is significant (P=0.0013 < 0.05). While evidence shows that labour force is negatively related with GDP in the long run and the relationship is insignificant (P=0.8906 > 0.05).

The long run equation is expressed in equation below.

$$LNGDP = -2.3019 + 3.4110(LNFIXCAP) + 0.0338(LNCONSP) + 0.1860(LNINFL) - 0.1473(LNLABF) + et$$

3.7 Discussion of Findings

The empirical results provide three major insights. First, energy consumption is a significant driver of Nigeria's long-run economic growth. The VECM coefficient of 0.91% implies that policies restricting energy access would have permanent negative effects on output—supporting the growth hypothesis (energy causes growth) rather than the conservation hypothesis (growth causes energy). This finding aligns with studies by Akinlo (2009) for Nigeria, Wolde-Rufael (2006) for 17 African countries, and Stern (2000) for the United States. However, it contrasts with earlier Nigerian studies (Akinlo, 2008; Omisakin & Olusegun, 2008) that found no long-run relationship, suggesting that the extended sample period (1984–2023) and use of multiple cointegration methods may capture relationships previously obscured.

Second, fixed capital formation exerts the strongest long-run effect on GDP (3.93% in VECM, 3.41% in ARDL). This is economically intuitive—investment in machinery, equipment, and infrastructure directly expands productive capacity. The significant effect underscores Nigeria's need for sustained capital accumulation to drive industrialization and economic diversification beyond oil dependence.

Third, the error correction speed of 34.7% annually indicates relatively rapid adjustment to equilibrium. This speed exceeds those reported in comparable studies (typically 15–25% for developing economies), suggesting that Nigerian economic variables respond quickly to disequilibrium shocks. The negative short-run coefficients for energy consumption and fixed capital (−0.34% and −1.08%, respectively) may reflect adjustment costs or implementation lags—increases in energy use or capital investment may initially disrupt production before yielding long-run benefits.

The presence of two cointegrating vectors, confirmed by both Johansen and ARDL bounds tests, indicates a stable long-run relationship despite individual series containing unit roots. This finding has important policy implications: while short-run shocks may temporarily displace GDP, energy consumption, and capital from their equilibrium paths, the system possesses self-correcting mechanisms that restore balance over time.

## IV. CONCLUSION AND POLICY IMPLICATIONS

This study examined the short-run dynamics and long-run equilibrium relationships between energy consumption, fixed capital, inflation, labor force, and economic growth in Nigeria (1984–2023) using three complementary econometric frameworks—VAR, VECM, and ARDL—explicitly accounting for the presence of unit roots in all variables.

The key findings are:
Unit root confirmation: All variables (GDP, energy consumption, fixed capital, inflation, labor force) are I(1), justifying the use of cointegration and error correction techniques.

Cointegration: Both Johansen and ARDL bounds tests confirm a stable long-run equilibrium relationship among the variables, with two cointegrating vectors.

Long-run effects (VECM): Fixed capital (3.93%, $p<0.01$), energy consumption (0.91%, $p<0.01$), and inflation (0.77%, $p<0.01$) have significant positive long-run effects on GDP. Labor force is insignificant.
Long-run effects (ARDL): Fixed capital (3.41%, $p=0.001$) is the only significant long-run driver, though energy and inflation have positive signs.

Error correction: The speed of adjustment (−0.347, $p=0.005$) indicates that 34.7% of short-run disequilibrium is corrected annually, a relatively rapid adjustment.

Short-run dynamics: Energy consumption (−0.34%, $p=0.017$) and inflation (0.27%, $p=0.003$) have significant short-run effects, while fixed capital shows marginal significance.

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