International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(4), 472-480.

# Economic Growth Effects of Energy Infrastructure and Human Capital in a Resource-Rich Nation: Accounting for the Moderating Role of Oil Price Uncertainty

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**Received:** 30 January 2025 **Accepted:** 28 May 2025 **DOI:** https://doi.org/10.32479/ijeep.19867

**ABSTRACT**

Despite being richly endowed with array of non-renewable and renewable energy resources, including oil, coal, gas, solar, wind, and water, Nigeria still faces severe energy crises and weak economic growth. This study explores the impact of energy infrastructure and human capital on economic growth, incorporating the moderating effect of oil price uncertainty. Using annual time series data from 1996 to 2022, the analysis employs Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegration Regression (CCR) techniques. The findings from both models indicate that energy infrastructure and human capital have a positive and statistically significant influence on economic growth. Additionally, the FMOLS results reveal a negative and statistically significant coefficient for oil price uncertainty. However, the inclusion of the interaction term yields a positive and significant coefficient across the models, indicating that energy infrastructure investment can partially offset the negative impact of oil price uncertainty. These findings are confirmed by the results of dynamic Autoregressive Distributed Lag (ARDL) simulations. The study therefore recommends the diversification of the energy sector by increasing the share of renewable energy in the total energy mix and improving the quality of education and health, as well as upgrading the work force.

**Keywords:** Energy infrastructure; Human capital development; Oil price uncertainty; Economic growth
**JEL Classifications:** J24; O13; O47; Q43

## 1. INTRODUCTION

Economic growth remains the central goal for most economies of the world, especially in emerging and resource-dependent economies. Among the critical drivers of stable economic growth are energy infrastructure and human capital, both of which can enhance productivity, technological adoption, and overall economic resilience (Alaali et al., 2015). Energy infrastructure enables efficient production and distribution systems, facilitates industrialization, and supports the functioning of all sectors of the economy. Similarly, human capital which involves education, skills, and health constitutes the bedrock of innovation, labor productivity, and institutional effectiveness.

The Energy Information Administration (EIA) (2020), forecasts that, the world energy usage would increase by approximately 50% by 2050, due largely to the growth in Asia and parts of Africa where economic growth is driven by energy demand in areas such as industrialization and transportation. Transportation energy consumption increases by nearly 40% between 2018 and

2050. In Nigeria, despite the huge natural and human resources, infrastructure deficiencies, especially in the energy, health and education sectors have continued to impact high and sustained economic growth. According to the National Bureau of Statistics (2024), the Nigeria economy measured by gross domestic product (GDP) grew by 2.98% (year-on-year) in real terms in the first quarter of 2024 representing an increase of 2.31% compared to the first quarter of 2023, and lower than the fourth quarter of 2023 growth by 3.46%. There is no gain saying that Nigeria's reliance on fossil energy resources, poor infrastructure, and low investment in human capital have contributed to its erratic growth rates. Energy is an essential input in almost all the sectors of an economy and has been found to be a major catalyst to sustained economic growth (Usman et al., 2024). Similarly, human capital which is the bedrock of every economic leverage on the available energy infrastructure to propel economic growth.

The effectiveness of these growth-enhancing inputs can be influenced by external macroeconomic shocks, such as variability in the global oil markets. While the independent effects of energy infrastructure and human capital on economic growth have been extensively studied (Mahmood et al., 2024; Fedajev et al., 2023, Kuang et al., 2023; Wang et al., 2022) less attention has been given to how volatile oil price environments may condition the impact of infrastructure development on growth performance. Oil prices are considered to be a volatile variable compared to other natural resources (Adeosun et al., 2022). Higher oil prices typically lead to higher production costs, which in turn lead to inflationary pressures and hinder economic growth (Narayan et al., 2014; Su et al., 2021). Theoretically, oil-exporting economies can benefit financially from a positive oil price shock, while an increase in oil prices immediately raises production costs for oil-importing economies (Adeosun et al., 2022).

Uncertainty about oil prices adds a significant degree of risk to energy infrastructure investment and economic growth, especially for countries like Nigeria that are heavily dependent on oil. Kuziboev et al. (2025) note that dependence on oil resources can create energy risk in developing countries, unlike in developed countries. Oil price uncertainty can weaken the transmission mechanism through which energy infrastructure supports economic growth by increasing financing costs, delaying project implementation, or reducing investor confidence. Conversely, strong and resilient infrastructure systems can help buffer economies against the adverse effects of oil price uncertainty by improving energy security and reducing dependence on volatile markets.

Therefore, this study evaluates the effects of energy infrastructure and human capital to economic growth, accounting for the moderating role of oil price uncertainty on the infrastructure-growth nexus. By modeling oil price uncertainty as a moderating variable, this study uncovers whether the positive effect of energy infrastructure on economic growth holds consistently under different levels of oil price uncertainty and variability, or if its impact is conditional upon a more stable energy pricing environment. Understanding this interaction is crucial for formulating adaptive and resilient infrastructure investment strategies in the face of global energy challenges.

This study is of great importance, especially at a time when Nigeria is projected to be among the top 20 countries by 2050 - a dream whose realisation requires repositioning the economy's energy sector amidst uncertainties in oil prices and improving human capital. It is widely believed that the epileptic supply of energy (electricity) in the country is a major setback to economic growth. Similarly, the issue of human capital development is central to the growth of the Nigerian economy especially that the economy is still largely labour intensive. The findings of the study will provide the government, its agencies and policy makers with information on the impact of energy infrastructure as well as the moderating role of oil price uncertainties on ensuring economic growth.

The rest of the paper is planned as follows: Section 2 focuses on the review of empirical literature. Section 3 treats the methodology. Section analyses the results and discusses the findings, while section 5 presents and conclusions and the recommendations.

## 2. EMPIRICAL REVIEW

Most extant empirical studies on the economic growth effects of energy and human capital development support the proposition that energy and human capital development bolster economic growth. For example, Mahmood et al. (2024) investigate the potential of energy projects and sustainable infrastructure as major forces behind the development of economic resilience. Further, the study looks at how globalization and sustainable supply chain management function as mediators. Applying the structural equation modeling the results show that energy projects, including energy infrastructure, improves energy security, reduce possible hazards related to energy scarcity, and stimulate economic growth.

Fedajev et al. (2023) analyze a panel of fifteen Central and Eastern European countries covering the period from 1995 to 2021. The study employs various analytical techniques, including the Augmented Mean Group estimator, unit root and cointegration tests, as well as tests for cross-sectional dependence. The findings reveal that, irrespective of the control variables used, inefficient electricity infrastructure negatively affects both GDP and industrial value-added growth. In contrast, electricity generation from renewable energy sources has a positive impact on GDP.

Kuang et al. (2023) evaluate the success of energy infrastructure investment projects in Jiangsu Province using a three-stage DEA model. The study also looked at how energy investment efficiency affected regional growth, economic stability, and industrial structure optimization. The results of the study show that the energy infrastructure investment efficiency in Jiangsu varies widely and is closely related to the economic growth model, level of economic development, and industry importance of the region. The study also demonstrates that Jiangsu's increased energy infrastructure investment efficiency contributes significantly to increasing social wealth and altering the industrial structure and economy of the region, even though it does not fully reflect the situation of the economy in the area.

Ding and Liu (2023) assess how China's green financial development from 2008 to 2020 was impacted by green economic growth, transportation infrastructure, and renewable energy. The endogeneity of this relationship is taken into account using a two-stage ordinary least squares approach. The relevance of green financing in China's sustainable development is supported by empirical research, which shows that GDP growth and renewable energy are important factors in determining sustainable development.

Saidi et al. (2018) examine the role of energy infrastructure on economic growth of the MENA countries over the period 2000-2016. Applying a battery of second generation econometrics techniques such as the GMM and Dumitrescu-Hurlin panel causality, the study revealed that modern infrastructure enhances economic growth in the MENA region. Corroborating this finding, Maciulyte-Sniukiene and Butkus (2022) analyze the effect of infrastructural development including energy infrastructure on economic growth of the EU countries covering the period 2000-2019. Using the Huber–White Sandwich correction, the study finds a positive correlation between energy infrastructure and economic growth in EU countries, similar to other types of infrastructure. Additionally, the results indicate that transport infrastructure contributes to economic growth across all regions examined. The robustness of these findings is supported by evidence of a positive feedback effect, as demonstrated through the D-H Granger causality approach. In a related study, Khan et al. (2020) examine the role of infrastructure in promoting economic growth in South Asia using the pooled mean group estimator, and their results also confirm a positive relationship between infrastructure and economic growth.

Achour and Belloumi (2016) analyze the relationship between transport infrastructure, economic growth, and environmental impact over the period from 1971 to 2012. Utilizing the Johansen multivariate cointegration technique, along with generalized IRF and VD, their study reveals a long-run, one-way causal link from road infrastructure to transport sector value added, energy consumption in road transport, carbon dioxide emissions, and gross fixed capital formation. A long-term unidirectional causal relationship is also found between rail transport energy consumption and rail infrastructure, transport value added, gross capital formation and transport $CO_2$ emissions. In addition, the analysis finds a short-run, unidirectional causal relationship between transport value added and road infrastructure. Shiu et al. (2016) examine the causal relationship between economic growth and infrastructure investment in energy and transportation using China's Western Development Strategy (WDS) over the period 1991-2012. The Granger causality test disclosed a unidirectional causal relationship between economic growth as well as between economic growth and energy investment in the post-WDS period.

Ogunjobi et al. (2021) in a study on human capital and energy infrastructure: implications for economic growth in Nigeria over the period 1981-2018, applies the Autoregressive Distributed Lag (ARDL) Model. The study findings show that education positively influence economic growth. Islam and Alam (2023) examine the impact of human capital on economic growth in Bangladesh over the period 1990-2019. Applying the Autoregressive distributed lag model, the study finds that human capital exerted both positive and negative long-run effect on economic growth depending on the measure used. While expenditure on education impacts economic growth positively, education expenditure negatively impacts economic growth in the long. The Granger causality estimates further support these findings. In a separate study, Saroj et al. (2024) explore the relationship between human capital and economic growth in India using the Autoregressive Distributed Lag (ARDL) model. Their results indicate that human capital exerts a positive and statistically significant influence on the country's economic growth. Similarly, Sultana et al. (2022) conduct a panel data analysis involving 141 developed and developing nations to assess the impact of human capital on economic performance. Utilizing the system GMM estimator over the period 1980-2008, the study found that all dimensions of human capital positively contribute to economic growth in developing countries, with life expectancy having a particularly strong effect. Conversely, the impact in advanced economies appears to differ. Furthermore, Wang et al. (2022) examine the role of human capital in sustainable development by evaluating the interactive coupling mechanism between human capital and sustainable economic growth. The findings show that human capital and sustainable economic growth in Shandong Province have varying degrees of growth; from gradual to mild over different contexts of economic structure. Keji (2021) examines the nexus between human capital and economic growth in Nigeria between 1981 and 2017. Employing the vector autoregressive and Johansen techniques, the findings show that human capital have long-run significant impact on economic growth in Nigeria.

A summary of the empirical review shows that there is a paucity of research on the moderating effect of oil price uncertainty on energy infrastructure in economic growth literature. While prior studies have extensively examined the individual impacts of infrastructure and human capital on economic growth, there remains a significant gap in literature concerning the conditional effects of energy market dynamics, specifically, how oil price uncertainty moderate the relationship between energy infrastructure investment and economic growth. Failing to account for this moderating influence may simply lead to overestimating the benefits of infrastructure investment, especially in resource-sensitive economy as Nigeria. This study seeks to address this research gap so as to provide informed, resilient, and context-sensitive economic policies that can withstand external shocks.

## 3. DATA AND EMPIRICAL MODELLING

### 3.1. Data

The data used in this study are basically secondary time series data, sourced on annual basis. It is derived from well-organized sources such as the Central Bank of Nigeria (CBN) Statistical Bulletin, the World Bank Development Indicators (WDI), Penn World Table (PWT), the World Governance Indicators (WGI) and Economic Policy Uncertainty (EPU).[1] The data cover the period from 1996 to 2022. The choice of 1996 as the starting year is based on the fact that data on the institutional quality variables reported by the

1 The data for oil price uncertainty was originally calculated based on a monthly frequency. However, we transformed this series to a yearly frequency using the quadratic match sum approach.

World Governance Indicators started to count from 1996 onwards. Also, the choice of 2022 as the end year of the analysis is based on the availability of data for all the variables used in the study. Most of the annual time series data are only available up to 2022. Table 1 presents the data acronyms, measurement and sources.

### 3.2. Empirical Modelling

Considering innovation and human capital investment, which encompasses contemporary energy infrastructure, the model for the study is functionally stated as;

$$EEG = f\,(EIF,\ HC,\ INQ,\ INFL,\ OPU,\ EIF \times OPU) \tag{1}$$

The basic model to estimate the Fully Modified Ordinary Least Squares(FMOLS) and Canonical Cointegration Regression (CRR) to uncover the long-run effect is given as;

$$EEG = \alpha_0 + \alpha_1 EIF + \alpha_2 HC + \alpha_3 INQ + \alpha_4 INFL + \alpha_5 OPU + \alpha_6 (EIF \times OPU) + \varepsilon_t \tag{2}$$

Where $\alpha_0$ is the intercept, $\alpha_1$-$\alpha_6$ are the parameters and $\varepsilon_t$ is the error term.

Furthermore, we check for the robustness of the restimates using the Dynamic Autoregressive Distributed Lag (DNARDL) developed by Jordan and Philips (2018).This model can be expressed as follows:

$$\begin{aligned}\Delta EEG = {} & \psi_0 + \beta_1 EEG_{t-1} + \beta_2 EIF_{t-1} + \beta_3 HC_{t-1} + \beta_4 INQ_{t-1} \\ & + \beta_5 INFL_{t-1} + \beta_6 OPU_{t-1} + \beta_7 (EIF \times OPU)_{t-1} + \\ & \sum_{i=1}^{P} \varphi_1 \Delta EEG_{t-i} + \sum_{i=1}^{P} \varphi_2 \Delta EIF_{t-i} + \\ & \sum_{i=1}^{P} \varphi_3 \Delta HC_{t-i} + \sum_{i=1}^{P} \varphi_4 \Delta INQ_{t-i} \\ & + \sum_{i=1}^{P} \varphi_5 INFL + \sum_{i=1}^{P} \varphi_6 \Delta INQ_{t-i} + \\ & \sum_{i=1}^{P} \varphi_7 \Delta (EIF \times OPU)_{t-i} + ECM_{t-1} + \varepsilon_t\end{aligned} \tag{3}$$

Where $\psi_0$ is the intercept, $\beta_1$-$\beta_7$ capture the long-term effects, $\varphi_1$-$\varphi_7$ are presents the short-run effects. *ECM* is the error correction term and $\varepsilon_t$ is the error term. Δ is the difference operator.

### 3.3. Estimation Techniques

This study employs both descriptive statistics and inferential statistics in analyzing the data. The descriptive tools comprises the mean, median standard deviation, minimum and maximum, skewness, kurtosis and Jarque Bera statistics, while the inferential statistics involves the unit root test using the Zivot Andrews (ZA) test, the cointegration test using bounds test and the ARDL test as well as the accompanying diagnostic tests.

The Zivot Andrews approach, which yields details about the series' structural break points, is used in the testing process for the unit root test in this investigation (Usman et al., 2019). The Zivot Andrews test is chosen because it has better predictive capabilities and is superior to other traditional unit root tests that do not take structural shocks into consideration, such as the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and KPSS (Goshit and Iorember, 2020).

The study uses the Bayer and Hanck cointegration test, which combines several different cointegration tests into one, to ascertain whether there is a long-term link between the variables. In particular, it integrates the cointegration tests developed by Engle and Granger (1987), Johansen (1995), Boswijk (1994), and Banerjee et al. (1998), producing a robust outcome that helps to avoid arbitrary decision-making in cases where the individual test results may be conflicting (Iorember et al., 2020).

Concerning the main analysis, the study uses the the FMOLS and CRR to examine the dynamic long- and short-term effects of energy infrastructure, human capital and oil price uncertainty on the growth of the Nigerian economy. According to Hamit-Haggar (2012), the FMOLS approach is robust to endogeneity and serial correlation problems. Both the FMOLS and the CRR are applied to series that are non-stationary but have a stable cointegration relationship.

Furthermore, the study applies the dynamic ARDL technique to check for the robustness of the estimates given that it also accounts for the potential endogeneity of the explanatory factors and is also robust to I(0), I(1) or both series.

## 4. RESULTS AND DISCUSSION

### 4.1. Summary Statistics and Correlation Matrix

The descriptive statistics and correlation analysis of the variables used in the study are disclosed in Table 2. Evidently, the results of the summary statistics in Panel A of Table 2 reveal that economic growth (EEG) has the highest mean score, followed by energy infrastructure, oil price uncertainty, inflation rate, human capital and then institutional quality respectively. The result also show that all the variables have minimum standard errors implying less volatility in the variables, thereby making the estimates thereof reliable. Moreover, judging from the Jaque Bera statistic and the probability values, the results reveal that all the variables except institutional quality are normally distributed, since their null hypotheses of normally distributed cannot be rejected at 5% level of significance. Furthermore, the results of the correlation matrix in Panel B of Table 2 show that all variables are moderately correlated to each other without any evidence of extremely high correlation, suggesting the absence of multiclollinearity problems.

**Table 1: Variable acronym, measurement and source**

| Variable | Acronym | Measurement | Source |
|---|---|---|---|
| Economic Growth | EEG | Gross Domestic Product per capital (Constant, 2015) | Central Bank of Nigeria (CBN) |
| Energy Infrastructure | EIF | Electric power production and consumption (kWh per capita) | World Development Indicators (WDI) |
| Human Capital | HC | Index of returns on education | Penn World Table (PWT) |
| Institutional Quality | INQ | Index for six governance variables | Worldwide Governance Indicators (WGI) |
| Inflation Rate | INFL | Inflation Rate | World Development Indicators (WDI) |
| Oil Price Uncertainty | OPU | Index of variability in oil prices | Economic Policy Uncertainty (EPU) |

**Table 2: Summary statistics and correlation matrix**

| Statistic/Variable | EEG | EIF | HC | INQ | INFL | OPU |
|---|---|---|---|---|---|---|
| Panel A: Descriptive Statistics | | | | | | |
| Mean | 10.7238 | 3.9133 | 0.5309 | -0.2516 | 4.4808 | 4.5507 |
| Maximum | 11.2204 | 4.1087 | 0.7174 | 0.4772 | 6.0428 | 4.6072 |
| Minimum | 10.0243 | 3.6774 | 0.3072 | -2.0404 | 3.0795 | 2.9306 |
| Standard Deviation | 0.4266 | 0.1231 | 0.1270 | 0.6668 | 0.8909 | 0.5961 |
| Jarque-Bera | 2.8090 | 1.4443 | 1.8621 | 12.0493 | 1.4702 | 4.9440 |
| Probability | 0.2455 | 0.4857 | 0.3941 | 0.0024 | 0.4795 | 0.0844 |
| Panel B: Correlation Matrix | | | | | | |
| EEG | 1.0000 | | | | | |
| EIF | 0.7289 | 1.0000 | | | | |
| HC | 0.8879 | 0.7407 | 1.0000 | | | |
| INQ | 0.7417 | 0.6118 | 0.7772 | 1.0000 | | |
| INFL | −0.0567 | 0.0609 | −0.0444 | −0.0532 | 1.0000 | |
| OPU | 0.7656 | 0.6331 | 0.7890 | 0.8096 | −0.4090 | 1.0000 |

### 4.2. Unit Root Test

To check for the stationary of the series, the study employs the Zivot Andrews unit root test approach given its robustness, and the result is presented in Table 3. The level form results demonstrate that the test statistics of the ZA unit root test is less than the corresponding critical value at 5% level of significance in absolute terms for all the variables. Hence, we do not reject the null hypotheses of unit root at level. This suggests that the series are not stationary at levels. For the first difference, the results show that the test statistics of ZA for all the variables are greater than the corresponding critical values at 5% level of significance in absolute terms, hence, we reject the null hypothesis of unit root and conclude that all the series are stationary at first difference. This results support further investigation of the existence or otherwise of the long-run relationship.

**Table 3: Results of Zivot Andrews (ZA) unit root test with structural breaks**

| | ZA Test at level | | ZA Test at first difference | |
|---|---|---|---|---|
| Variable | ZA statistic | Break point | ZA statistic | Break point |
| EEG | −2.0539 | 2016 | −7.0657*** | 2016 |
| EIF | −3.1350 | 2013 | −5.682228*** | 2011 |
| HC | −3.3594 | 2016 | −10.2940*** | 2009 |
| INQ | −3.0675 | 2012 | −6.5216*** | 2001 |
| INFL | −2.2117 | 2010 | −6.9065*** | 2008 |
| OPU | −2.4514 | 2012 | −5.5778*** | 2012 |
| Sig. Level | Crit. Values | | | |
| 1% | −5.34 | | −5.34 | |
| 5% | −4.93 | | −4.93 | |
| 10% | −4.58 | | −4.58 | |

***Imply stationarity of the series – I (0) at 1% level of significance

### 4.3. Cointegration Analysis

Since the unit root test results indicate that all variables follow an I(1) process, the Bayer-Hanck cointegration test is employed to assess the presence of a cointegrating relationship. As presented in Table 4, the test results demonstrate that, across all models, the Fisher statistics for the EG–JOH and EG–JOH–BO–BDM combinations exceed the critical values at the 1%, 5%, and 10% significance levels. This confirms the existence of cointegration among the variables, regardless of which variable is treated as endogenous, thereby leading to the rejection of the null hypothesis of no cointegration.

### 4.4. Coefficient Estimates

To examine the effects of energy infrastructure and human capital on economic growth and account for the moderating role of oil price uncertainty on energy infrastruture, the study applies the FOMLS and CRR models and the results are presented in Table 5. For both models, the results show a consistent and statistically significant relationship between economic growth (EEG) and the explanatory variables of interest. Energy infrastructure (EIF) shows a positive and highly significant effect on economic growth across both models (FMOLS: 0.0272; CCR: 0.0282; $P < 0.01$), implying the role of stable and developed energy systems in fostering long-term economic expansion. Energy is the major driver of the Nigerian economy and an increase in its infrastructure is expected to increase supply and consumption and consequently improve the level of economic activities. The finding agrees with the findings of Ogunjobi et al. (2021) who established that a small rise in the rate of electricity output per household leads to higher economic growth.

Similarly, human capital (HC) is found to exert a significant and statistically significant impact (both FMOLS: 3.693 and CCR: 3.683; $P < 0.01$), suggesting that improvements in education and workforce quality directly support economic growth. The importance of human capital in the growth of an economy such as the Nigeria's economy cannot be overemphasized, especially given the high population of the country. Increases in human capital imply improvement in skilled labour, which in turns brings about efficiency in job delivery. The positive relationship between human capital and economic growth has been long established in both economic policy and literature, to the point that it is often used as a metric of economic development. This result is consistent with the findings of Saroj et al. (2024) and Sultana et al. (2022), who reported a positive association between human capital and economic growth.

Furthermore, the results show that the coefficient on oil price uncertainty (OPU) is negative and statistically significant in the FMOLS model, implying that greater uncertainty in global oil prices impedes economic growth. However, the inclusion of the

**Table 4: Results of Bayer-Hanck cointegration test**

| Model | EG–JOH | EG–JOH–BO–BDM | Cointegration |
|---|---|---|---|
| *EEG=f (EIF, HC, INQ, INFL, OPU, EIF×OPU)* | 55.280** | 65.852** | Cointegrated |
| *EIF=f (EEG, HC, INQ, INFL, OPU, EIF×OPU)* | 55.546** | 114.27** | Cointegrated |
| *HC=f (EIF, EEG, INQ, INFL, OPU, EIF×OPU)* | 55.26** | 110.52** | Cointegrated |
| *INQ=f (HC, EIF, EEG, INFL, OPU, EIF×OPU)* | 55.827** | 114.82** | Cointegrated |
| *INFL=f (INQ, HC, EIF, EEG, OPU, EIF×OPU)* | 60.609** | 171.133** | Cointegrated |
| *OPU=f (INFL, INQ, HC, EIF, EEG, EIF×OPU)* | 57.427** | 115.071** | Cointegrated |
| *EIF×OPU=f (OPU, INFL, INQ, HC, EIF, EEG)* | 58.269** | 71.355** | Cointegrated |

**Denotes rejection of $H_0$ of no cointegration at 5% level of significance. Critical value at 5% level is 10.352 for EG–JOH and 19.761 for EG–JOH–BO–BDM

**Table 5: Results of FMOLS and CRR models**

| Dep. Var.: EEG | FMOLS estimates | CRR estimate |
|---|---|---|
| *EIF* | 0.0272*** | 0.0282*** |
| | (0.0051) | (0.0080) |
| *HC* | 3.693*** | 3.683*** |
| | (0.0586) | (0.0706) |
| *INQ* | 0.0565*** | 0.0536*** |
| | (0.0115) | (0.0162) |
| *INFL* | −0.00851*** | −0.00829*** |
| | (0.0009) | (0.0012) |
| *OPU* | −0.0383** | −0.0358 |
| | (0.0155) | (0.0258) |
| *EIF×OPU* | 0.00915*** | 0.0080* |
| | (0.0028) | (0.0042) |
| *Constant* | 8.833*** | 8.837*** |
| | (0.0469) | (0.0811) |
| R-squared | 0.962 | 0.975 |

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

**Table 6: Results of dynamic long-run ARDL simulations for robustness test**

| Variables | Coefficient | Std. Error | t-stat | Prob. |
|---|---|---|---|---|
| Dependent Variable: EEG | | | | |
| EIF | 0.0203** | 0.0089 | 2.27 | 0.036 |
| HC | 2.6672** | 1.1127 | 2.40 | 0.028 |
| INQ | −0.0259 | 0.0192 | −1.35 | 0.195 |
| INFL | −0.0022* | 0.0012 | −1.91 | 0.074 |
| OPU | −0.0443* | 0.0232 | −1.91 | 0.074 |
| *EIF×OPU* | 0.0080* | 0.0419 | 1.91 | 0.073 |
| Constant | 2.8953** | 0.0042 | 2.78 | 0.013 |
| ECTt-1 | −0.2994** | 0.1089 | −2.75 | 0.014 |
| R2 | 0.7541 | | | |
| Simulations | 10000 | | | |
| F-stat (Prob.) | 6.52*** (0.0006) | | | |

**, and*represent significance at 5% and 10% significance levels

interaction term (EIF × OPU) yields a positive and significant coefficient (FMOLS: 0.0091; CCR: 0.0080) across the models, indicating that energy infrastructure investment can partially offset the negative impact of oil price uncertainty. This finding points to a potential buffering role played by energy resilience in mitigating external price shocks.

Institutional quality (INQ) also contributes positively and significantly to economic growth, reinforcing the notion that sound governance and legal frameworks are essential for long-term development. On the other hand, inflation (INFL) demonstrates a negative and statistically significant effect on economic growth (FMOLS: −0.0085; CCR: −0.0083), emphasizing its adverse influence on economic stability. Additionally, both models show strong explanatory power, with R-squared values of 0.962 and 0.975, suggesting that the included variables collectively explain more than 96% of the variations in economic growth.

### 4.5. Robustness Checks

To further confirm the robustness of the FMOLS and CRR estimates in Table 5, we estimate the dynamic ARDL simulations, as it is suitable for small sample size and all I(1) series, as is the case in the current study. The results of the dynamic ARDL are reported in Table 6. The results or simulations align with the earlier findings of the FMOLS and CRR. The coefficients of EIF and HC remain positive and statistically significant ($P < 0.05$), confirming their important role in promoting long-term economic growth. Oil price uncertainty retains its negative and statistically significant impact ($P < 0.1$), and the interaction term (EIF × OPU) continues to exhibit a positive and significant effect, further supporting the confirming that robust energy infrastructure can shield the economy from the adverse effects of oil market fluctuations. The negative effect of inflation persists, although with slightly reduced magnitude, while the effect of institutional quality becomes statistically insignificant in the dynamic context.

Additionally, the error correction term (ECT) is negative and statistically significant (−0.2994; $P < 0.05$), indicating the presence of a valid long-run relationship among the variables. The coefficient suggests that approximately 30% of any short-run disequilibrium is corrected within one period, reflecting a relatively moderate speed of adjustment toward long-run equilibrium. The plots of the dynamic-ARDL simulations method, showing the effects of the positive (negative) counterfactual shocks of the exogenous variables (energy infrastructures, human capital, institutional quality, inflation, oil price uncertainty and the interaction term of energy infrastructures and oil price uncertainty) on economic growth. As displayed in Appendix A, our results reaffirm the positive effect of energy infrastructure, human capital, and institutional quality, on economic growth while inflation rate and oil price uncertainty have a negative effect on economic growth. However, the interaction term is found to positively affecting economic growth. This shows that our findings are similar and robustness.

## 5. CONCLUSION AND POLICY IMPLICATIONS

This study investigates the influence of energy infrastructure and human capital development on Nigeria's economic growth, utilizing annual time series data spanning from 1996 to 2022.

The study applies the Zivot Andrews unit root test with structural breaks and the results suggest that all the variables are stationary at first difference judging by 5% level of significance. Further, the Bayer-Hanck test reveal the presence of cointegration or long-run relationship among the variables. For the main analysis, the study applies the FMOLS and CRR techniques, and the results of show a positive and statistically significant effect of energy infrastructure and human capital on economic growth. Furthermore, the results show that the coefficient of oil price uncertainty (OPU) is negative and statistically significant in the FMOLS model, implying that greater uncertainty in global oil prices impedes economic growth. However, the inclusion of the interaction term (EIF × OPU) yields a positive and significant coefficient across the models, indicating that energy infrastructure investment can partially offset the negative impact of oil price uncertainty. This finding points to a potential buffering role played by energy resilience in mitigating external price shocks.

For robustness checks, the results of the dynamic ARDL simulations align with the findings of the FMOLS and CRR. The coefficients of EIF and HC remain positive and statistically significant, confirming their important role in promoting long-term economic growth. Oil price uncertainty retains its negative and statistically significant impact, and the interaction term (EIF × OPU) continues to exhibit a positive and significant effect, further supporting the confirming that robust energy infrastructure can shield the economy from the adverse effects of oil market fluctuations.

In summary, the results of this study provide several critical insights into the role of energy infrastructure, human capital and oil price uncertainty in shaping long-term economic growth. In particular, the positive and statistically significant effects of energy infrastructure and human capital confirm their importance as key determinants of economic growth in Nigeria. Conversely, oil price uncertainty poses a significant threat to macroeconomic stability, although its negative effects can be mitigated through strategic investments in energy infrastructure.

Based on these findings, the study recommends that although energy infrastructure has a positive and significant impact on economic growth, there is a need to redesign and promote the growth of energy infrastructure through increased public and private investment in the energy sector for sustainability. Furthermore, diversifying the energy sector by increasing the share of renewable energy in the overall energy mix will improve energy security, which is important for economic growth. In addition, it is recommended that governments intensify efforts to improve education systems, vocational training programmes and access to health care. Improving the quality and accessibility of human capital resources will increase labour productivity, foster innovation and improve the overall competitiveness of the economy. The world is changing rapidly and it is therefore necessary to continuously develop human capital to keep pace. Regarding the moderating effect of oil price uncertainty, the positive and significant interaction between energy infrastructure and oil price uncertainty highlights the buffering capacity of robust infrastructure systems. Policy makers should build resilience and adaptability into infrastructure planning to ensure continuity of energy services even during periods of oil price uncertainty. Moreover, although this study mainly concentrates on the effects of energy infrastructure and human capital on economic growth, considering the moderating influence of oil price uncertainty, it is likely that additional economic and environmental factors could also contribute to explaining this relationship. Therefore, future research could include more of these variables to enrich and extend the literature.

## REFERENCES


Achour, H., & Belloumi, M. (2016). Investigating the causal relationship between transport infrastructure, transport energy consumption and economic growth in Tunisia. Renewable and Sustainable Energy Reviews, 56, 988-998

Adeosun, O. A., Tabash, M. I., & Anagreh, S. (2022). Oil price and economic performance: Additional evidence from advanced economies. Resources Policy, 77, 102666.

Alaali, F., Roberts, J., & Taylor, K. (2015). The effect of energy consumption and human capital on economic growth: an exploration of oil exporting and developed countries. SERPS (Sheffield Economics Research Papers Series), 015.

Banerjee, A., Dolado, J., & Mestre, R. (1998). Error-correction mechanism test for cointegration in a single-equation framework. Journal of Time Series Analysis, 19, 267–283.

Boswijk, H. P. (1994). Testing for an unstable root in conditional and structural error correction models. Journal of Econometrics, 63, 37–60.

Ding, X., & Liu, X. (2023). Renewable energy development and transportation infrastructure matters for green economic growth? Empirical evidence from China. Economic Analysis and Policy, 79, 634-646.

Energy Information Administration (EIA, 2020). Annual Energy Outlook. https://www.eia.gov/outlooks/aeo/pdf/aeo2020%20full%20report.pdf

Engle, R. F., & Granger, C. (1987). Cointegration and error correction representation: Estimation and testing. Econometrica, 55, 251–276.

Fedajev, A., Mitić, P., Kojić, M., & Radulescu, M. (2023). Driving industrial and economic growth in Central and Eastern Europe: The role of electricity infrastructure and renewable energy. Utilities policy, 85, 101683.

Goshit, G. G., & Iorember, P. T. (2020). Measuring the asymmetric pass-through of monetary policy rate to unemployment in Nigeria. Nigerian Journal of Economic and Social Studies, 62(3), 369-387.

Hamit-Haggar, M. (2012). Greenhouse gas emissions, energy consumption and economic growth: A panel cointegration analysis from Canadian industrial sector perspective. Energy Economics, 34(1), 358-364.

Iorember, P. T., Goshit, G. G., & Dabwor, D. T. (2020). Testing the nexus between renewable energy consumption and environmental quality in Nigeria: The role of broad-based financial development. African Development Review, 32(2), 163-175.

Islam, M. S., & Alam, F. (2023). Influence of human capital formation on the economic growth in Bangladesh during 1990–2019: an ARDL approach. Journal of the Knowledge Economy, 14(3), 3010-3027.

Johansen, S. (1995). A statistical analysis of cointegration for I(2) variables. Econometric Theory, 11, 25–59.

Keji, S. A. (2021). Human capital and economic growth in Nigeria. Future Business Journal, 7(1), 49.

Khan, H., Khan, U., Jiang, L. J., & Khan, M. A. (2020). Impact of infrastructure on economic growth in South Asia: Evidence from pooled mean group estimation. The Electricity Journal, 33(5), 106735.

Kuang, L., Han, X., & Liu, G. (2023). The Efficiency of Energy Infrastructure Investment and Its Regional Economic Impact. International Journal of Environmental Research and Public Health, 20(3), 2125.

Kuziboev, B., Khodjaniyazov, E., Ozturk, I., Sabirov, K., Makhmudov, S., & Utegenova, S. (2025). Does Oil Dependence Cause Energy Risk? Energy Nexus, 100393.

Maciulyte-Sniukiene, A., & Butkus, M. (2022). Does Infrastructure Development Contribute to EU Countries' Economic Growth? Sustainability, 14 (9), 5610.

Mahmood, S., Misra, P., Sun, H., Luqman, A., & Papa, A. (2024). Sustainable infrastructure, energy projects, and economic growth: mediating role of sustainable supply chain management. Annals of Operations Research, 2024, 1-32

Narayan, P. K., Sharma, S., Poon, W. C., & Westerlund, J. (2014). Do oil prices predict economic growth? New global evidence. Energy economics, 41, 137-146.

National Bureau of Statistics (2024). National Gross Domestic Product Q1 2024. https://www.nigerianstat.gov.ng/elibrary/read/1241506#:~:text=Overview,of%202023%20growth%20of%203.46%25

Ogunjobi, J.O., Eseyin, O., Popoola, O. (2021). Human Capital and Energy Infrastructure: Implications for Economic Growth in Nigeria. International Journal of Energy Economics and Policy, 11(3), 149-154.

Saidi, S., Shahbaz, M., & Akhtar, P. (2018). The long-run relationships between transport energy consumption, transport infrastructure, and economic growth in MENA countries. Transportation Research Part A: Policy and Practice, 111, 78-95.

Saroj, S., Shastri, R. K., Singh, P., Tripathi, M. A., Dutta, S., & Chaubey, A. (2024). In what ways does human capital influence the relationship between financial development and economic growth? Benchmarking: An International Journal, 31(4), 1073-1091.

Shiu, A., Li, R., & Woo, C. K. (2016). Economic growth and infrastructure investments in energy and transportation: A causality interpretation of China's western development strategy. The Energy Journal, 37(China Special Issue).

Su, C. W., Huang, S. W., Qin, M., & Umar, M. (2021). Does crude oil price stimulate economic policy uncertainty in BRICS? Pacific-Basin Finance Journal, 66, 101519.

Sultana, T., Dey, S. R., & Tareque, M. (2022). Exploring the linkage between human capital and economic growth: A look at 141 developing and developed countries. Economic Systems, 46(3), 101017.

Usman, O., Iorember, P. T., & Olanipekun, I. O. (2019). Revisiting the environmental Kuznets curve (EKC) hypothesis in India: the effects of energy consumption and democracy. Environmental Science and Pollution Research, 26, 13390-13400.

Usman, O., Iorember, P. T., Ozkan, O., & Alola, A. A. (2024). Dampening energy security-related uncertainties in the United States: The role of green energy-technology investment and operation of transnational corporations. Energy, 289, 130006.

Wang, S., Lin, X., Xiao, H., Bu, N., & Li, Y. (2022). Empirical study on human capital, economic growth and sustainable development: Taking Shandong province as an example. Sustainability, 14(12), 7221.

# APPENDIX

**Appendix A:** Plots of DYARDL estimates Predicted EEG with ±1% changes in EIF, HC, INQ, INFL, OPU, and EIF × OPU