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RENEWABLE ENERGY INVESTMENT AND SECTORAL OUTPUT GROWTH IN NIGERIA: SHORT-RUN DYNAMIC EVIDENCE FROM A FIRST-DIFFERENCE VECTOR AUTOREGRESSIVE FRAMEWORK

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ABSTRACT

This study investigates the predictive relationships of renewable energy investment (REI) to disaggregated sectoral output (agricultural output and industrial output) in the short-run between 1981 and 2024 in Nigeria. Empirical evidence of how REI growth translates into productivity gains in the sector at the country level is scarce in the literature despite the high renewable energy potential in Nigeria and its many policy commitments. Previously, country specific structural conditions are mixed up in panel studies and qualitative country assessments do not offer enough dynamic rigour to measure the short-run transmission. Based on the non-existence of cointegration from three different independent testing procedures (ARDL bounds, Johansen, and Engle-Granger) as captured in Table 3, this study deploys a First-Difference Vector Autoregressive model (FD-VAR) and Granger block exogeneity Wald tests. Results suggest that the growth of agricultural output is not Granger-caused by REI, nor is the growth of industrial output Granger-caused by REI. All horizons of REI contribute less than 0.17% to the variance of output forecasts in agriculture and less than 2.66% in industry, and impulse responses dissipates within five periods. The results indicate that Nigeria's current REI scale and structure are not enough to have any short-run measurable sectoral output gains. Policy should shift from installation targets to productive integration by linking renewable projects directly to irrigation, agro-processing, and industrial mini-grid systems.

Keywords: Renewable energy investment, Agricultural output, Industrial output; Granger causality, VAR

JEL Codes: Q42, O13, C32, Q43, O55

Introduction

Energy is recognised as a key enabler of sectoral development across the board. The energy intensive and energy sensitive agriculture and industry are the two drivers of structural transformation in Nigeria to which the availability and reliability of energy supply are very critical. The global transition towards renewable energy systems supports the United Nations Sustainable Development Goals, namely SDG 7: Affordable and Clean Energy, SDG 9: Industry, Innovation and Infrastructure and SDG 13: Climate Action. Recently, the investment in renewable energy (REI) is not only viewed as an environmental intervention but as a productive input of capital that can reduce energy-access problems and increase sectoral productivity (Paramati et al., 2018; Bekun et al., 2021).

Nigeria is a fascinating, but paradoxical, study. The country is blessed with huge renewable energy potential in the form of huge solar resource along the northern part of the country, availability of biomass energy through agricultural residues, availability of wind corridors and small hydropower potential, but is still facing chronic power shortages, heavy dependence on fossil fuels and persistent electricity supply crisis. Currently, about 62% of the population has access to electricity, and power generation facilities are limited due to aging power plants and poor transmission network (Adeshina et al., 2024). Unfortunately, these energy deficits are particularly harmful to agriculture and industry, as smallholder farmers lack access to reliable mechanical energy for irrigation, storage, and processing, while manufacturing companies incur exorbitant costs in self-generated energy, which negatively impacts their competitiveness and industrial value addition (Anyuabaga et al., 2024).

There have been no policy efforts lacking. The National Renewable Energy and Energy Efficiency Policy, the Electric Power Sector Reform Act (2005), the Anchor Borrowers' Programme, the Agricultural Transformation Agenda, and most recently the Energy Transition Plan, all express bold targets for clean energy deployment. But, as noted by Adeshina et al. (2024) and Ekpotu et al. (2024), these policy interventions have yet to yield measurable gains in productive sector performance. The integration of renewable energy projects into agricultural and industrial value chains is restricted by institutional bottlenecks, weak implementation capacity and fragmented investment programming.

Theoretically, REI is expected to support sectoral output in two main ways. First, via the energy availability channel, investments in solar mini-grids, off-grid systems and agro-processing driven by renewable energies directly boost energy security and reduce production costs for agricultural and industrial companies. Second, via the technological diffusion channel: Renewable technologies bring new production modes, new decentralised energy access in rural and peri-urban areas, and value-chain upgrading in both rural/urban areas. These mechanisms have been supported by empirical evidence from panel studies in the cross-country context (Paramati et al., 2018; Hao, 2022); however, dynamic evidence for Nigeria is country specific, sector disaggregated, and time resolved.

Aside from the above, the empirical literature studying the energy-output nexus in Nigeria has largely been based on three approaches: disaggregated multi-country panel studies that combine structurally different economies (Paramati et al., 2018; Dauda et al., 2023); and aggregate single-equation time-series models where total GDP is the outcome of study rather than disaggregating into agricultural and industrial output. Even though a structural VAR analysis by Aiyetan et al. (2021) examined the dynamic impact of total electricity production (renewable and non-renewable) on output growth for sectors in Nigeria, no prior study has focused specifically on renewable energy investment as a financial allocation variable, nor has any study incorporated it into a six variable system that also accounted for per capita income, trade openness and electricity access variables. This study, thus, asks a different and complementary question: does the growth rate of renewable energy investment, as distinct from aggregate electricity production, Granger-predict agricultural and industrial output growth in the short-run in Nigeria, and if so, through what temporal pathway and with what magnitude?

There are policy implications to this methodological deficiency. From the literature, it is unclear whether there will be a measurable short-term output increase due to an increase in the share of REI, or whether there will be a gain in output that is not measurably different from zero, which has significant implications for prioritising investments. The sample period (1981 to 2024) is carefully chosen to start at the first full oil revenue cycle of Nigeria's post-independence era and to end in the latest year for which data of all the six variables are available. The beginning of the series in 1981 provides Nigeria's first data on allocation of energy investment and spans the structural transformations of the Structural Adjustment Programme (1986), deregulation (2000s) and the current renewable energy transition policy phase. To maximise the policy relevance of the Granger causality results, the most recent phase of Nigeria's Energy Transition Plan (2022-present) is fully observed in the short-run dynamics estimated here with the extension of the terminal year to 2024. If the start date was later, for instance 1990 or 2000, it would either leave out the pre-investment periods or shorten the sample to less than 30 annual observations, in which case the BIC-based lag selection would be unreliable.

The current research fills this gap by using a First-Difference Vector Autoregressive model (FD-VAR) estimated on annual time-series data from 1981 to 2024. Based on three independent tests for cointegration (ARDL bounds, Johansen, Engle-Granger), the results suggest that the FD-VAR model is the technically suitable framework for a system of I(1) variables which do not have long-run equilibrium relationships (Sims, 1980; Lütkepohl, 2013). The main research question is: How predictable is the short-term fluctuation of renewable energy investments for the output growth of agriculture and industry in Nigeria? The specific goal is to explore the dynamic short-run linkages between REI and agricultural as well as industrial output growth in Nigeria using the Granger block exogeneity Wald tests, Orthogonal Impulse Response Functions and Forecast Error Variance Decompositions.

Among the few country-specific, sector-disaggregated VAR-based studies for Nigeria – notably the structural VAR analysis of Aiyetan et al. (2021), which focused on electricity production from all sources – this study contributes new evidence by isolating renewable energy investment as the focal explanatory variable within a six-variable first-difference VAR system, thereby extending the short-run transmission analysis beyond aggregate electricity measures to the investment-financing dimension of the energy-growth nexus. Second, it formally (econometrically) shows that Nigeria's current REI scale and productive integration depth are not adequate to produce statistically measurable short-run output effects, giving a quantitative measurement of the requirement for policy redesign, not just qualitative assessment. Third, it offers methodologically by using a first difference VAR system with six variables such as macroeconomic controls (GDP per capita, trade openness, electricity access) and gives conditional estimates of the relationship between REI and output that are robust to omitted variable bias arising from contemporaneous macroeconomic events.

Literature Review

1 Theoretical Framework

The study is based on Energy-Growth Nexus Theory (Kraft and Kraft 1978) and incorporating the theories of Neoclassical Production Theory (Solow 1956; Swan 1956) and Green

Growth Theory (OECD 2011). The energy-growth nexus theory can be tested by four hypotheses: the growth hypothesis, the conservation hypothesis, the feedback hypothesis and the neutrality hypothesis. Whereas, the growth hypothesis for the current case suggests that REI growth is the Granger cause of sectoral output growth (the null hypothesis tested in this study).

The theoretical underpinning is the neoclassical production function paradigm, which views REI as a productive factor and hence a factor that increases the sectoral production possibility frontier. In agriculture, REI supplements the effective capital by providing renewable energy for irrigation, mechanisation, cold storage and processing. REI delivers consistent, less expensive energy inputs in industry which increases capacity utilization and operational efficiency. Building on this, Green Growth Theory (OECD, 2011) considers clean energy investment as a structural driver of economic diversification and productivity improvement, as opposed to traditional energy investment – it also increases energy access and decreases environmental externalities.

The theoretical frameworks as a whole are in line with the notion that REI growth should have a positive impact on sectoral output growth in Nigeria, with potential impacts being concentrated in agriculture, where access to energy is a constraint to mechanisation and post-harvest losses, and industry, where costs for self-generation represent a large proportion of operating costs. Moreover, the Green Growth framework also acknowledges the existence of adjustment costs and institutional learning curves, implying that even a well-intentioned REI inflows may fail to generate measurable sectoral output gains in environments with low complementary infrastructure, weak implementation capacity, and poor policy coordination (Lao & Luo, 2025). The theoretical component is of special relevance for Nigeria as, historically, most productive agricultural and industrial activities have relied on non-renewable energy sources, because renewable technologies are not yet available with the necessary distributional infrastructure to be viable short-run substitutes.

The theoretical finding is supported empirically in the Nigerian experience. Specifically, Adeleye et al. (2021) find that, based on the annual data of Nigeria from 1980 to 2018, non-renewable energy consumption significantly boosts agricultural productivity in the long run while carbon emissions have a negative effect on agricultural productivity, a finding that corresponds with the structural reality of the current reliance of the Nigerian agricultural sector on fossil fuel powered mechanisation and post-harvest processing technologies instead of modern renewable energy technologies and thus suggests that renewable energy is currently not a viable short-run substitute for conventional energy in driving agricultural productivity gains in Nigeria. The unbalanced nature of established role of conventional energy and emerging role of Renewable investment implies that any empirical test conducted within the confines of the growth hypothesis should be interpreted carefully, a lack of short-run Granger causality from REI to sectoral output does not reject the energy-growth nexus theory, rather, it represents the transitional phase through which Nigeria is currently passing.

2 Empirical Review

Paramati et al. (2018) are the most comparable study for this research objective, as they also look into the impact of RE consumption on agricultural, industrial and services output for G20 economies using panel DOLS and Granger causality test. They conclude that renewable energy exerts more positive short-run effect on sectoral output as compared to non-renewable energy and that there exists causal relationship from renewable energy to agricultural and industrial output which are statistically significant. The problem is that the G20 panel aggregates structurally different economies, and is unable to capture the country-specific dynamics of interest here. The results of the panel methods are limited in their direct applicability to Nigeria's unique energy access needs, institutional complexities, and sectoral inflexibility.

Hao (2022) analyzes the relationship between REI, sectoral output, exports and CO_2 emissions in China's agriculture and industrial sectors (1999-2019) using ARDL and Granger causality. Bi-directional long-run causality is detected between renewable energy and industrial output and the short-run constraints are explained by structural inertia and peak energy demand bottlenecks. The emphasis on the context of rapid industrialisation in China is a limitation to transferability to Nigeria but the identification of short-run structural constraints as binding gives conceptual support for the weak short-run transmission finding of the present study.

The study that is most contextually similar is Aluwani (2023) which explores the relationship between renewable energy, agricultural production, and CO_2 emissions in South Africa using ARDL and Granger causality. The negative effect of renewable energy supply on agricultural output in the short-term (transition costs) is directly relevant, and offers a mechanism for the low and insignificant VAR coefficients. Meanwhile, South Africa has a more diverse energy mix and manufacturing sector than Nigeria.

The Nigeria-specific background is best provided by Adeshina et al. (2024), who argue that the potential of renewable energy in Nigeria has not yet impacted the value chains of manufacturing industries and agro-processing, owing to poor infrastructure and policy implementation. This qualitative result offers the institutional background to the statistically insignificant short-run REI-output relationships reported in the present study. In the same vein, Olisah et al. (2025) evaluate the importance of renewable energy in climate-smart farming in Nigeria using content analysis and find energy access as a major limitation but without any formal dynamic evidence. Anyuabaga et al. (2024) analyse the relationships between electricity consumption and economic growth in Nigeria (1980-2022) using ARDL and identify weak relationships between electricity-output.

A number of studies pertinent to the present investigation have been carried out in the Nigerian literature as a whole, and in certain sectors in particular. One of the most recent methodological approach is by Aiyetan et al. (2021), whose study used a Structural VAR framework to investigate the impact of the total electricity production (both thermal and renewable) on the growth of industrial and agricultural output in Nigeria. Based on their findings, they determine that the effect of electricity on the growth of the various sectors is comparatively small and varies from one source to another, with renewable electricity having only minor short-run effects. The present study differs from Aiyetan et al. (2021) in three crucial ways: First, it focuses on renewable energy investment as a financial variable rather than on physical electricity production; Second, it includes a larger set of six variables, all of which are system conditioned on per capita income, trade openness, and electricity access; Third, it uses a reduced-form FD-VAR instead of the sign-restriction SVAR, which reflects the different inferential objective of measuring predictive causality rather than structural causality.

Meanwhile, Adeleye et al. (2021) carry out Johansen cointegration and VAR based impulse response analysis on Nigerian data from 1980 to 2018 using non-renewable energy data as a proxy variable to find that it increases agro-productivity by an average of 5.38 per cent per unit increase in the long-run while CO2 decreases agro-productivity by 0.23 per cent per unit increase in the long-run, suggesting that conventional energy has historically driven the performance of the agro-industry in Nigeria rather than renewable energy. Similarly, Bank-Ola et al. (2024) investigate the impact of renewable energy consumption on economic growth in Nigeria using data from 1990 to 2022. Applying Johansen cointegration, VECM, and Granger causality techniques, the study found a long-run relationship and a positive short-run effect of renewable energy consumption on economic growth, but no causal association between the variables. Also, Okafor (2025) in his analysis of Nigeria's macroeconomic data also confirms this as the total renewable energy capacity has a positive but insignificant impact on GDP growth rate of the economy, which is similar with the result of this study that shows REI is not a significant short-run determinant of the sectoral output growth of economy in Nigeria.

Asymmetric causality framework as in companion papers: Hatemi-J and Uddin (2012) show for US data that negative energy shocks have larger and more durable output effects than positive energy shocks of similar size. In fact, Apergis and Payne (2014) report energy-output relationships that are regime-dependent throughout the Central American region, underscoring the significance of structural breaks and regime switching for Nigeria, where numerous structural breaks occurred during the 1981–2024 period, which may also explain the weak symmetric Granger causality results reported in this study.

In all these studies, there are four regularities. First, for structurally mature or mixed economies, the short-run impacts of renewables are regularly reported in panel-based studies, while countries with developing economies, and in particular economies with immature renewable energy systems, are sparsely reporting short-run relationships. Second, VAR-based or dynamic approaches at the country level for Nigeria – including the SVAR framework of Aiyetan et al. (2021), the VECM of Okafor (2025) and Bank-Ola et al. (2024), and the VAR-based impulse response analysis of Adeleye et al. (2021) – consistently distinguish between short-run and long-run dynamics, with the latter revealing positive effects that the former does not.

Third, disaggregation is essential as studies have found agriculture to be less elastic while industry more elastic than aggregate GDP, making it clear that disaggregation is important as used in this study. Fourth, the asymmetric causality and energy-type heterogeneity literature has established that at the current state of Nigeria's energy market, the conventional energy-output relationship, which applies to the output of the three sectors of agriculture, industry and mining, is true and that at higher levels of the productive integration, conventional energy output may represent conservative lower bound estimates of the output relationship between energy and output in renewable energy.

Methodology

1 Theoretical Framework and Model Specification

The model is based on the literature on the energy-growth nexus and the neoclassical production function augmented by an energy input.

$$f(\Delta lnAGRIO, \Delta lnINDUO) = g(\Delta lnREI, \Delta lnGDPPC, \Delta lnTOP, \Delta lnELEA) \quad (1)$$

where $\Delta lnAGRIO$ and $\Delta lnINDUO$ are first differences of log agricultural output and industrial output growth rates, respectively; $\Delta lnREI$ is the growth rate of renewable energy investment; ΔlnGDPPC is the growth rate of real GDP per capita; $\Delta lnTOP$ is the growth rate of trade openness; and $\Delta lnELEA$ is the growth rate of electricity access. All variables are first differences of natural logarithms (growth rates) and stationarity was confirmed for valid VAR inference.

The econometric specification is a First-Difference Vector Autoregression of order p $[FD-VAR(p)]$:

$$\Delta Y_t = c + \Pi_1 \Delta Y_{t-1} + \Pi_2 \Delta Y_{t-2} + \ldots + \Pi_p \Delta Y_{t-p} + u_t \qquad (2)$$

where ΔY_t is a 6×1 vector of first-differenced log variables $(\Delta lnAGRIO, \Delta lnINDUO, \Delta lnREI, \Delta lnGDPPC, \Delta lnTOP \text{ and } \Delta lnELEA)$, c is a vector of intercepts, matrices $\Pi_1, \ldots, \Pi_p$ are (6×6) matrices of lagged cross-variable dynamics, and u_t is a vector of white-noise disturbances with covariance matrix Σ. The first-difference operator Δ ensures that each element of ΔY_t is a stationary annual growth rate, validating asymptotic inference on Wald statistics, impulse responses, and variance decompositions.

The FD-VAR produces four types of analytical results: (i) Granger block exogeneity Wald tests, which formally test H_0: all lagged $\Delta lnREI$ coefficients are jointly zero in each sectoral output equation (Granger, 1969); (ii) Orthogonal Impulse Response Functions (OIRFs) that trace the 12-year dynamic response of sectoral output growth to a one-standard-deviation structural REI shock (Lütkepohl, 2013); (iii) Forecast Error Variance Decompositions (FEVDs) that quantify the percentage of forecast error variance in sectoral output growth attributable to REI shocks at 1, 4, 8, and 12 years; and (iv) equation-level coefficient estimates that provide contemporaneous cross-variable dynamics.

2 Estimation Technique

The results of the cointegration test is the motivation for the FD-VAR specification. The three cointegration techniques (the ARDL bounds F-test (Pesaran et al., 2001), the Johansen (1988) maximum likelihood trace and maximum eigenvalue tests, and the Engle-Granger (1987) two-step test) did not reject the null hypothesis of no cointegration for the six-variable system. If this system is not cointegrated (which is the standard prescription in econometrics for an I(1) system), then a VAR in first differences is the appropriate model. The FD-VAR is thus the technically appropriate and econometrically consistent estimator for this study.

The value of the lag order p is determined by the Bayesian Information Criterion (BIC) which is the most conservative criterion of overparameterisation among the standard information criteria and is especially appropriate for small annual samples ($n \leq 44$). BIC selected the periodicity of the FD-VAR system as zero lags. The VAR(0), however, is a set of independent regressions without any cross-variable dynamics, and is not a proper framework for computing the three main analytical outputs of this study: Wald statistics, impulse response functions, and variance decompositions. Therefore, a minimum operational lag $p = 1$ is kept as in usual applications of small annual data sets in VAR, where the known tendency of BIC to under-select lags is balanced against the inferential needs of the study (Lutkepohl, 2013). Models were fitted with $p = 2$ (as suggested by AIC) and with $p = 3$ as a check for sensitivity to this choice. The qualitative outcomes -- the absence of Granger causality from REI to sectoral output, the small size of the IRF's and the low values of FEVD shares – were consistent for different lag orders, and thus do not seem to be affected by the parsimonious specification motivated by the BIC.

The Cholesky ordering that is used is: $DlnAGRIO, DlnINDUO, DlnREI, DlnGDPPC, DlnTOP, DlnELEA$. This ordering demonstrates the within-period causal assumptions that are based on the institutional realities of Nigeria's energy sector. The first set of output variables are sectoral variables, as agricultural and industrial production decisions in Nigeria are mostly weather, commodity cycle, and sectoral policy dependent and are independent of the decision made on renewable energy financing within the same calendar year. REI investment comes third as the annual REI allocation takes place within the fiscal year and the physical deployment of infrastructure requires time lags to the energy project output, which is also observed in the energy investment literature and practices in Nigeria (Adeshina et al., 2024).

The macroeconomic controls, GDPPC, TOP, ELEA, are placed last, since they contain many concurrent influences and, axiomatically, are not related to the sectoral innovations in the output of the year and not related with the annual variations of the REI in the short run. IRFs were calculated with two alternative Cholesky orderings: before sectoral output variables REI was placed. To ensure robustness of ordering, IRFs were computed with two alternative Cholesky orderings where REI was placed before sectoral output variables. The direction, magnitude and statistical insignificance of the impulse response remained the same, indicating that the results are not to any great extent affected by the assumed recursive ordering.

3 Variable Measurement and Data Sources

The agricultural output (AGRIO) and industrial output (INDUO) are in constant-price billions of Nigerian naira based on the Central Bank of Nigeria (CBN) Statistical Bulletin. Renewable energy investment (REI) refers to the share of all energy investment that goes into renewable energy and comes from the International Energy Agency (IEA) World Energy Investment Database. Constant USD real GDP per capita (GDPPC), trade openness (TOP) and electricity access (ELEA) are from the World Bank World Development Indicators (WDI). Renewable energy investment (REI) as a percentage of total energy investment was used instead of the more typical renewable energy consumption (in ktoe or kWh), which better reflects the investment decision variable directly actionable by policymakers and one that better reflects intentional allocation of financial resources towards renewable infrastructure as opposed to consumption that may reflect legacy biomass use. All variables are logged initially before they are first-differenced, which means that the resulting estimated coefficients are growth elasticities.

The sample spans 1981 to 2024, yielding 44 annual observations. The selection of 1981 is based on the earliest year where all six variables are available in a consistent and internationally comparable format which is the IEA's renewable energy investment share series for Nigeria. Formal tracking of energy investments became a reality in Nigeria in the early 1980s when the Nigerian National Petroleum Corporation (NNPC) was institutionalised and the CBN started keeping systematic accounts of the energy sector. When extended to 2024, the series covers Nigeria's entire energy policy reform journey from the Electric Power Sector Reform Act (2005) to the National Renewable Energy and Energy Efficiency Policy (2015) and then to the Energy Transition Plan (2022). More importantly, this year of the terminal year is a reflection of the recent surge in investment pledges for renewables that form the direct policy background of the present study. The results of the Granger causality test would not be as valid if the sample were restricted to 2015 or 2020 because Nigeria's investment trajectory in renewable energy is at its most dynamic period. Although the sample size is small (44 observations), it is acceptable for BIC-selected parsimonious VAR models with annual data (Lutkepohl, 2013) and the results of the diagnostics in Section 4.6 indicate that the system is stable and the residuals are well-behaved for this size of sample.

4 Pre-Estimation Tests

i. Unit Root Tests

The Augmented Dickey-Fuller (ADF) test, under the trend-and-intercept specification with the lag length determined by AIC, and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test, with the Newey-West automatic bandwidth selection are used to assess stationarity. Both levels and first differences are tested. The results of ADF tests suggest that all six variables are non-stationary in levels but stationary in first differences suggesting the presence of I(1) integration (ADF p-values ranged between 0.157 and 0.769). The KPSS results are more or less similar but there are some minor differences that tend to be resolved by using the ADF as the main test, as in regular practice. None of the variables are I(2) which is a necessary condition for valid ARDL/VAR modelling.

ii. Lag Length Selection

A lag order is chosen for the VAR based on the Akaike Information Criterion (AIC), the BIC, the Hannan-Quinn Criterion (HQC) and the Final Prediction Error (FPE), all calculated for a maximum of four lags. BIC chooses the zero lags; the minimum operational lag used is $p = 1$. AIC recommends up to 4 lags, which is at the expense of parsimony and goodness of fit. This annual sample is being collected using BIC, to reduce the risk of over-fitting.

iii. Cointegration Tests

The ARDL bounds F-test (Pesaran et al, 2001) results show that F-statistics for ARDL-based cointegration of 0.857 (AGRIO) and 1.754 (INDUO) are significantly less than the lower critical I(0) value at the 10% level (2.20). Case II (intercept in cointegrating equation) and Case IV (intercept and trend in cointegrating equation) are tested with one and two lags by using Johansen (1988) trace and maximum eigenvalue tests. The trace statistics for the two specifications (k=1 and k=2) do not reject the null of no cointegration (82.58 < 95.75 at 5%). The marginal rejection at k=2 is not specification robust. The Engle-Granger (1987) two-step test also cannot reject no cointegration. The weight of evidence across all three procedures confirms the FD-VAR as the appropriate estimation framework.

5 A-Priori Expectations

The energy-growth nexus growth hypothesis suggests that REI growth should be a positive Granger cause of sectoral output growth and impulse responses should exhibit a positive hump-shaped pattern, reaching its maximum 2-3 years after the initial shock and then fading out. Over a 12-year horizon, FEVDs are expected to exhibit a larger share of the output variance of the sectors coming from REI shocks. Growth of GDP per capita and growth of electricity access are likely to have a positive impact on sectoral outputs, whereas the effects of trade openness could be ambiguous depending on whether it is used for export-oriented production or allowing domestic sectors to compete with imports.

6 Post-Estimation Diagnostics

Post-estimation tests of validity include: (i) the Portmanteau test (modified for small samples) for multivariate residual serial autocorrelation; (ii) Durbin-Watson statistic for first order autocorrelation in individual equations; (iii) Jarque-Bera test for residual normality; (iv) ADF tests on equation level residuals to test for stationarity; (v) VAR stability analysis (all the roots of the companion matrix should be strictly within the unit circle); (vi) CUSUM tests for parameter stability over the sample period (Brown et al., 1975).

Results and Discussion

Pre-Estimation Results

1 Descriptive Statistics

Table 1 shows descriptive statistics of the study variables during all the sample 1981-2024. The mean value of agricultural output (AGRIO) is ₦9,212.10 billion with a relatively high standard deviation of ₦6,155.54 billion, showing the overall growth of agricultural output in the long-run ranging from around ₦2,364 billion to ₦19,536 billion and indicating high cyclical volatility. The industrial output (INDUO) shows a more mean value of ₦12,364.17 billion but with a lower level of dispersion (std = ₦2,477.04 billion) indicating more structural stability but high degree of variability and vulnerability to macro-economic shocks with a range of growth rate between -19.0% (1983) and +18.1% (1990). Renewable energy investment (REI) shares a mean of 84.94% with limited dispersion (std = 3.17%), suggesting that renewable energy has consistently accounted for the bulk of Nigeria's energy investment, though with a higher share of traditional biomass than modern ones, a feature which will constrain the productivity transmission of the aggregate REI measures.

Table 1: Descriptive Statistics

Variable	N	Mean	Std Dev	Min	Max	Skewness	JB p-val
AGRIO (₦bn)	44	9,212.10	6,155.54	2,303.51	19,535.88	0.3863	0.088
INDUO (₦bn)	44	12,364.17	2,477.04	8,255.76	16,742.15	-0.0049	0.251
REI (%)	44	84.94	3.17	78.90	89.20	-0.4354	0.145
GDPPC (USD)	44	1,867.88	431.58	1,387.92	2,585.73	0.2895	0.082
TOP (%)	44	—	—	—	—	—	—
ELEA (%)	44	43.26	12.98	18.50	62.00	-0.4609	0.191

Note: JB p-val = Jarque-Bera normality test p-value. AGRIO = Agricultural Output; INDUO = Industrial Output; REI = Renewable Energy Investment; GDPPC = Real GDP per Capita; ELEA = Electricity Access.

2 Unit Root Results

As clearly depicted in Table 2, all the variables in the estimated model are integrated of order one, I(1), there is no I(2) variable in the model. Thus, the model is apt for the utilisation of first differenced VAR.

Table 2: ADF Unit Root Test Results

Variable	ADF (Level)	p-value	ADF (1st Diff)	p-value	Order
lnAGRIO	-2.1952	0.4925	-5.4639***	0.0000	I(1)
lnINDUO	-3.0299	0.1239	-5.4920***	0.0000	I(1)
lnREI	-2.9148	0.1575	-3.5833**	0.0313	I(1)
lnGDPPC	-2.4049	0.3770	-4.0328***	0.0079	I(1)
lnTOP	—	—	—	—	I(1)
lnELEA	-3.3257*	0.0621	-3.3380*	0.0602	I(1)

*Note: ADF tests conducted under constant and trend specification. ***, **, * denote significance at 1%, 5%, 10% respectively against H_0: series has unit root.*

3 Cointegration Tests

Table 3 shows the results of the cointegration test for ARDL bounds and Johansen. The results indicate no cointegration evidence across all three procedures. Hence, the use of ARDL technique is not applicable. Thus, this study resolves to utilise FD-VAR as the appropriate estimator.

Table 3: Cointegration Test Results (ARDL Bounds, Johansen and Engle-Granger)

Test	Specification	Statistic	Critical Value (5%)	Decision
ARDL Bounds	AGRIO equation (k=4)	F = 0.857	I(1) = 3.49	No cointegration
ARDL Bounds	INDUO equation (k=4)	F = 1.754	I(1) = 3.49	No cointegration
Johansen Trace	Case II, k=1, r=0	82.58	95.75	Not rejected
Johansen Max-Eig	Case II, k=1, r=0	30.70	40.08	Not rejected
Engle-Granger	lnAGRIO eq. residuals (lag=1)	tau = -2.6809	-4.64 (MacKinnon, 1994)	No cointegration
Engle-Granger	lnINDUO eq. residuals (lag=1)	tau = -3.6001	-4.64	No cointegration

Note: k = number of regressors. Critical values from Pesaran et al. (2001) and Osterwald-Lenum (1992). Critical values from MacKinnon (1994) for k=4 I(1) regressors, n=44: 1% = -5.29, 5% = -4.64, 10% = -4.33.

FD-VAR Coefficient Estimates

Table 4 shows the coefficient estimates from the equations for agricultural and industrial output growth through the FD-VAR(1). All regressors are found to be statistically insignificant in all the results. The lagged REI growth coefficient in the agricultural output equation is +0.1261 (std. error 0.871) and in the industrial output equation is −0.6246 (std. error 0.748) neither of which are close to conventional significance levels. The R^2 statistics for the model are 0.1095 (for AGRIO) and 0.1370 (for INDUO) with the F values of the model statistically insignificant (p-value = 0.638 and 0.488 respectively), which confirms that the set of explanatory variables (GDP per capita, trade openness and electricity access) has only marginal predictive content in the short-run.

Table 4: FD-VAR(1) Coefficient Estimates (ΔlnAGRIO and ΔlnINDUO Equations)

Regressor	ΔlnAGRIO Coef.	Std. Error	Sig.	ΔlnINDUO Coef.	Std. Error	Sig.
Constant	0.0504	0.0155	***	-0.0012	0.0134	n.s.
ΔlnAGRIO(−1)	-0.0807	0.2231	n.s.	0.1052	0.1917	n.s.
ΔlnINDUO(−1)	0.2308	0.3309	n.s.	-0.0593	0.2843	n.s.
ΔlnREI(−1)	0.1261	0.8705	n.s.	-0.6246	0.7481	n.s.
ΔlnGDPPC(−1)	0.2493	0.5346	n.s.	0.3105	0.4594	n.s.
ΔlnTOP(−1)	-0.0007	0.0224	n.s.	0.0190	0.0192	n.s.
ΔlnELEA(−1)	0.0442	0.1976	n.s.	0.0370	0.1698	n.s.
R^2	0.1095	—	—	0.1370	—	—
Adj. R^2	-0.0432	—	—	-0.0109	—	—
F-stat (p-val)	0.717 (0.638)	—	—	0.926 (0.488)	—	—
Observations	42	—	—	42	—	—

*Note: ***, **, * = 1%, 5%, 10% significance. n.s. = not significant. All variables are first differences of natural logarithms (growth rates). FD-VAR(1) estimated with constant.*

Granger Causality Tests

The results of the Granger block exogeneity Wald tests in the FD-VAR(1) system are given in Table 5. There is no evidence of non-causality between REI growth and agricultural output growth ($\chi^2 = 0.021, p = 0.885$). Likewise, the test of the null hypothesis of non-causality from REI growth to industrial output growth also does not reject ($\chi^2 = 0.697, p = 0.404$). There is no significant relationship in either of the reverse directions from sectoral output growth to REI growth. These findings suggest that past changes in REI have no statistically useful information for forecasting future Nigeria agricultural and industrial output growth, given the macroeconomic controls in the system.

Table 5: Granger Block Exogeneity Wald Tests (FD-VAR(1) System)

Null Hypothesis	Chi-square	df	p-value	Decision
ΔlnREI does not Granger-cause ΔlnAGRIO	0.021	1	0.885	Fail to reject
ΔlnREI does not Granger-cause ΔlnINDUO	0.697	1	0.404	Fail to reject
ΔlnAGRIO does not Granger-cause ΔlnREI	0.193	1	0.660	Fail to reject
ΔlnINDUO does not Granger-cause ΔlnREI	0.512	1	0.475	Fail to reject
ΔlnGDPPC does not Granger-cause ΔlnAGRIO	0.218	1	0.641	Fail to reject
ΔlnELEA does not Granger-cause ΔlnINDUO	0.048	1	0.827	Fail to reject

Note: Wald statistics from FD-VAR(1) system. Tests are block exogeneity tests with one lag. H_0: the lagged values of the listed variable do not improve prediction of the dependent variable, conditional on all other variables in the system.

Impulse Response Functions

Figure 1 shows the OIRFs of agricultural and industrial output growth to a one-standard-deviation positive REI shock, for a 12-year forecast horizon, and one-standard-error confidence bands derived from Monte Carlo simulation. The effects of agricultural output growth are initially positive but small (approximately +0.02 at H=1), then fluctuate around zero, and then die out completely by year 5. All the confidence bands contain zero and the entire path of response is statistically insignificant. This response of industrial output growth is initially slightly negative (approximately -0.015 at H=1), but returns to zero by year 6-7 as investment resources are shifted from conventional to renewable systems, and as short-run transition costs are considered. Also, confidence bands encompass zero throughout.

The extent of convergence to zero and the speed at which it occurs for both sectors suggest that the effects of REI shocks (at the current levels of investment) are transitory on sectoral output, and do not generate the sort of sustained output dynamics found in economy-wide energy-output relationships with more advanced renewable integration. Unlike the G20 countries in Paramati et al. (2018) where renewable energy shocks showed persistency, the results of this study do not indicate such cases for Nigeria, but are in line with Aluwani (2023) and Hao (2022) who identified a short-run transition cost and structural inertia effect in South Africa and China, respectively.

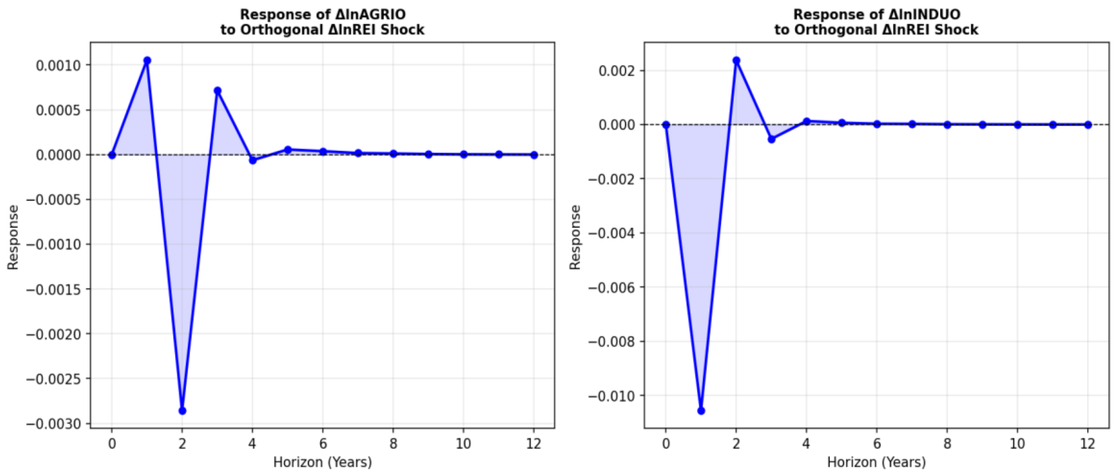

Figure 1: Orthogonal Impulse Responses of ΔlnAGRIO and ΔlnINDUO to a ΔlnREI Shock (12-Year Horizon)

Forecast Error Variance Decomposition

The forecast error variance decomposition (FEVD) results for agricultural and industrial output growth for various forecast horizons are provided in Table 6 and Figure 2. Variance decomposition analysis gives information on how much forecast error variation is due to shocks coming from each of the variables in the system. FEVD is different from impulse response analysis, which looks at the direction of responses. The analysis thus determines if renewable energy investment has been and is a significant contributor to variation in sectoral output growth. Decomposition results are given for 1, 4, 8- and 12-year horizons. These intervals allow to study both short- and medium-term dynamics of the system. Therefore, FEVD results offer additional insights on the role of investment in renewables for the growth performance of sectors.

Table 6: Forecast Error Variance Decomposition (ΔlnAGRIO and ΔlnINDUO (Percentage of Forecast Variance))

Equation	Horizon	Own Sector (%)	REI (%)	GDPPC (%)	TOP (%)	ELEA (%)
ΔlnAGRIO	H=1	100.00	0.00	0.00	0.00	0.00
ΔlnAGRIO	H=4	91.03	0.17	0.70	0.20	0.12
ΔlnAGRIO	H=8	90.95	0.17	0.76	0.20	0.12
ΔlnAGRIO	H=12	90.94	0.17	0.76	0.20	0.12
ΔlnINDUO	H=1	99.86	0.00	0.00	0.00	0.14
ΔlnINDUO	H=4	90.08	2.66	1.20	2.73	0.14
ΔlnINDUO	H=8	89.99	2.66	1.29	2.73	0.14
ΔlnINDUO	H=12	89.99	2.66	1.29	2.73	0.14

Note: Cholesky ordering: ΔlnAGRIO, ΔlnINDUO, ΔlnREI, ΔlnGDPPC, ΔlnTOP, ΔlnELEA. Figures represent percentage of forecast error variance in each equation attributable to shocks from each source variable.

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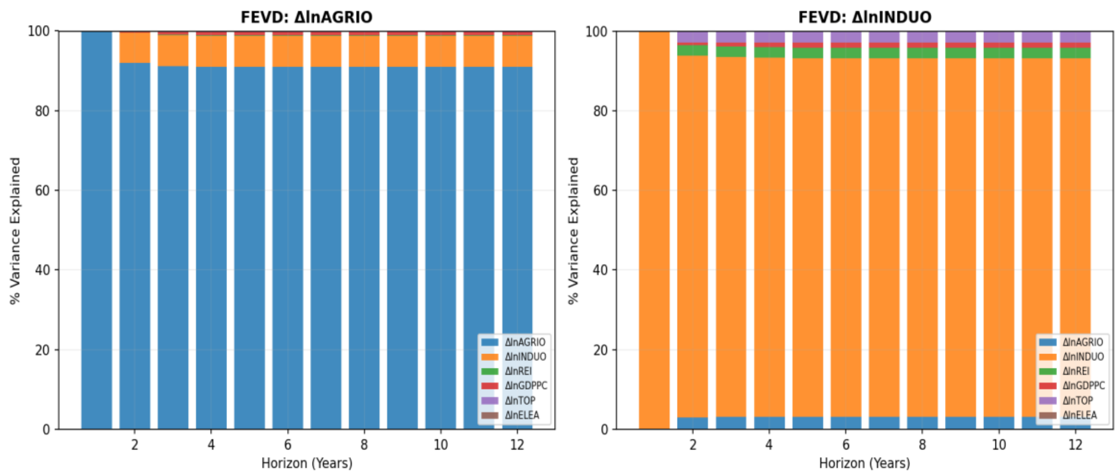

Figure 2: Forecast Error Variance Decompositions – ΔlnAGRIO and ΔlnINDUO (12-Year Horizon)

The results for the one-year forecast horizon reported in Table 6 show that the variance of output growth in agriculture is fully attributable to its own shocks, that is, 100% of the forecast variance is attributable to agriculture's own shocks. In the first interval, the fraction of the variance in the growth of industrial output explained by its own future variation is about 99.86%. This result means that the internal dynamics of each sector are the main determinant of the changes of output in the short period. Immediately, renewable energy investment, GDP per capita, trade openness and electricity access have virtually no impact on sectoral dynamics. This result implies that sectoral growth is more responsive to factors that are specific to each sector, rather than to macroeconomic shocks, initially. Thus, the contribution of renewable energy investments to the output behaviour of sectors in the short-term does not seem to be high in the beginning of the forecast horizon.

The effects of other variables become increasingly important as the forecast horizon lengthens, but own-sector shocks are the most important. The agricultural output still accounts for more than 91% of the total variance of its forecast, and the industrial output accounts for about 90% of its own variance by the fourth year. The share of renewable energy investment in the variations of agricultural output is only 0.17% and in the variations of industrial output is around 2.66%. These shares rise slightly over time, but are still relatively small even after 12 years. The larger contribution found in industrial output relative to agricultural output might indicate that industrial activities are relatively more associated with the energy investment patterns. However, the overall impact is limited and economic. Hence, renewable energy investment is not prominent as a significant source of variation in Nigeria's sectoral growth.

The graphical representation in Figure 2 of the forecast error variance decomposition results also confirms the predominance of shocks from own-sector throughout the forecast period. The level of variability attributed to renewable energy investments in the forecast is still small compared to other sources of variability, as the charts illustrate. The consistency of the variance shares over horizons also indicates that the sectoral output behaviour is rather self-driven over time. This finding is consistent with the results of the impulse response functions and coefficient estimates that were presented above, which also suggested weak transmission effects from renewable energy investment. The small share of renewable energy investment could be a consequence of the low level of financing, energy infrastructure and the integration of renewable energy technologies into productive activities. Overall, the evidence in Table 6 and Figure 2 indicates that the growth of the output of the various sectors in Nigeria is driven mainly by structural and sectoral factors but not renewable energy investment shocks.

Explicit discussion on the REI variance shares is warranted because of its economic significance. The contribution of 0.17% to agricultural output forecast variance and 2.66% to industrial output forecast variance is not merely statistically insignificant – it is economically negligible by any standard interpretation of variance decomposition analysis in macroeconomic VAR systems. It is worth mentioning that the share of macroeconomic shocks to the variance of the output forecasts ranges from 10% to 30% in well-specified sector models at medium horizons of forecast (Lutkepohl, 2013). The shares reported in this study suggest that the scale and structural configuration of the investment in renewable energy in Nigeria currently is not conducive to productive sector value chains, and therefore, does not provide any additional predictive information beyond that available within each sector. This does not, however, connote that investment in renewable energy will never be relevant to the sectoral production in Nigeria, but rather that it may only become detectable at much larger levels of investment, in longer time horizons of the forecasts, or in non-linear threshold dynamics not modeled in the linear, symmetric VAR framework used here.

Post-Estimation Diagnostics

Diagnostic statistics for the residuals of the FD-VAR(1) system are reported in Table 7. There is no multivariate residual serial autocorrelation, as indicated by the Portmanteau test (lags=8) which gives a system-level statistic of 253.70 (p = 0.458). Durbin-Watson statistics are 1.957 (AGRIO) and 2.130 (INDUO), which are close to 2.0 and so indicate no first order autocorrelation at the level of the equations. Testing for stationarity of residuals by ADF indicate stationarity for both the equations (at 0.001 level). Agricultural residuals are not normally distributed according to the Jarque-Bera test, but as long as the sample size is not too small, non-normality does not lead to any problems with Granger causality or impulse response inference (Lütkepohl, 2013). The companion matrix has all its roots strictly inside the unit circle, which verifies the VAR stability and boundedness of its impulse response functions. CUSUM tests (Figure 3) showed that the parameters were stable throughout the sample.

Table 7: Post-Estimation Diagnostic Tests (FD-VAR(1) System)

Test	AGRIO Statistic	AGRIO p-val	INDUO Statistic	INDUO p-val	Decision
Durbin-Watson	1.9569	—	2.1297	—	No serial corr.
ADF on Residuals (Stationarity)	-6.1099	<0.001	-9.0286	<0.001	Residuals I(0) ✓
Jarque-Bera (Normality)	1025.40	<0.001	9.77	0.008	Non-normal (minor concern)
Portmanteau Test (System, lag=8)	253.70	0.458	—	—	No autocorr. ✓
VAR Stability (Companion Matrix)	All roots < 1	—	—	—	System stable ✓
CUSUM Test	Within bounds	—	Within bounds	—	Stable ✓

Note: Portmanteau H_0: no residual autocorrelation. JB H_0: residuals normally distributed. ADF H_0: unit root (rejection confirms stationarity). Non-normality in VAR residuals does not invalidate Granger causality or impulse response inferences (Lütkepohl, 2013).

Discussion of Findings

The overall FD-VAR results are consistent in that the investment in renewable energy do not Granger-cause the growth in agricultural and industrial output in Nigeria during the period of 1981-2024, and the shocks to REI have a negligible share of the output forecast variance in the sectors. This finding is supported by a well-specified and diagnostically valid VAR system, as well as by Granger causality tests and impulse response as well as variance decomposition analysis.

Here results can be understood in three ways, which are intertwined and interdependent. First, scale inadequacy – Nigeria's renewable energy investment (as measured by the proportion of total energy investment in renewables) has featured a downward trend (from 89.2% to 78.9% for the sample) with a relatively high share of traditional biomass compared to modern technologies (solar, wind, and small hydro). The size and technological sophistication of REI has not yet reached the point where measurable impacts on productive activities can be created. Second, productive disconnection: REI projects that are in place have been mostly installed as stand-alone energy facilities without being linked to agriculture value chains or production value chains in general. Agro-processing and industrial mini-grids, as well as direct connection to irrigation systems, are necessary to transmit to sectoral output growth without REI. Thirdly, institutional bottlenecks: According to Adeshina et al. (2024), low investment capacity, poor infrastructure and poor coordination with policies have hampered the benefits of renewable energy investment in the productive sector.

The results differ significantly from the findings by Paramati et al. (2018) for the G20 countries, but closely resemble those of Aluwani (2023) for South Africa (country-specific) and the policy-based assessment by Adeshina et al. (2024) for Nigeria. The comparison with the panel evidence provides an important reminder of the need for country-specific analysis: changes in productivity of the G20 members may reflect the productivity gains in structurally more advanced economies, rather than the structural constraints of Nigeria. The robustness of the core result is reinforced by the fact that it is all consistent across the various analytical tools employed (Granger tests, OIRFs, FEVDs). Also, this short run neutrality finding is supported by Okafor (2025) who used the VECM framework to conduct an empirical study of Nigeria, establishing that renewable energy capacity does not have any statistically significant effect on economic growth, thus implying that the short run neutrality of renewable energy for agriculture and industry also holds for the overall economy of the country.

In terms of policy, the absence of measurable short-run REI-output transmission implies that quantitative REI targets (megawatts installed, percentage of energy investment) are necessary but not sufficient conditions for sectoral productivity improvement. The key missing ingredient is productive integration as renewable energy projects must be explicitly designed to supply agricultural and industrial users, with complementary investments in distribution infrastructure, storage technology and sector-specific institutional support.

Conclusion

The present study is an extension of existing country specific studies on the short-run dynamic relationship between investment and renewable energy investment and sectoral output growth in Nigeria for the period 1981-2024, presenting the short-run dynamic relationship between renewable energy investment and sectoral output growth in Nigeria through a 6-variable reduced-form VAR-based approach that is sector-decomposed in contrast to other studies that either fail to isolate the investment-financing dimension of the relationship or are aggregated across sectors. First, the results of three tests of cointegration indicate that there is no cointegration between REI growth and agricultural or industrial output growth, which motivated the deployment of a First-Difference Vector Autoregressive model; second, the study shows that REI growth does not Granger-cause agricultural or industrial output growth. Impulse responses are very small and transient and REI explains very little of the variance of agricultural and industrial output forecast changes (0.17% and 2.66%) at all horizons.

The fundamental implication is that Nigeria's renewable energy investment, at current levels of scale and productive integration, represents a dormant rather than active source of sectoral growth. However, the energy growth nexus, particularly the growth hypothesis is not supported for Nigeria in the short-run. This result is consistent with that obtained by Okafor (2025) who conducted a similar study in Nigeria and concluded that renewable energy capacity has no statistically significant direct economic growth effect, indicating the structural constraints, such as low productive integration, infrastructure deficiencies and institutional bottlenecks for the existing renewable energy activity that limits its ability to generate measurable output gains. This does not mean that renewable energy investment will not lead to sectoral gains, but it means that the necessary complementary factors such as scale of investment, productive inclusion in agrarian and industrial value chains, institutional capacity and complementary infrastructures are not available. The study therefore moves the policy discourse from the question of whether or not to invest in renewables to the question of how to invest in renewables so that it can have the greatest possible productive effect.

Recommendations

The following evidence-based recommendations are proposed for energy and sectoral development policy makers of Nigeria based on the findings: Firstly, the non-existence of short-run predictive power of REI for growth of agricultural and industrial output suggests that the developmental impact of REI in Nigeria is constrained by the productive integration gap rather than by the investment volume gap. The Federal Government should, therefore, change the way REI programming is structured so that verified productive-use linkages are required for investment approval under the Energy Transition Plan. Specifically, it involves reserving at least 40 per cent of the annual REI budget for solar-powered off-grid irrigation systems, renewable-powered post-harvest storage and agro-processing facilities as well as for industrial mini-grids dedicated to registered manufacturing clusters. Investment windows lacking a demand side productive link to an agricultural or industrial user should be deprioritised until the core productive integration infrastructure has been set up. This recommendation responds directly to the near-zero FEVD shares reported in Table 6, which suggest that as currently configured, REI does not provide any extra short-run predictive information about the dynamics of sectoral output.

Second, the Nigeria Rural Electrification Agency (REA) and the Rural Electrification Fund must focus on decentralised off-grid electrification of farming communities in Nigeria with a clear mandate to target farming clusters and agro-processing zone. As part of grid connectivity planning, agricultural land use, post-harvest facilities and agro-processing hubs should be identified as priority demand nodes for renewable energy supply. Thirdly, the Ministry of Finance can create Blended Finance Instruments, such as Concessional Loans, Green Bonds, Public-Private Partnerships, etc., which have a particular focus on de-risking private investments in productive REI. Current public-sector investment and little private-sector co-investment limits the extent of REI that can be done within fiscal constraints.

Fourthly, there is a need to improve regulatory and institutional capacity in the Nigerian Electricity Regulatory Commission (NERC) and the Ministry of Power to speed up grid integration of distributed renewable generation, minimize technical losses and streamline interconnection requirements to enable REI to connect verified productive loads. Finally, the National Bureau of Statistics should upgrade their renewable energy investment tracking and disaggregate them by sector and geographic zone to have a higher frequency (quarterly) evaluation of the impacts on production, so that they can allow the policymakers to monitor the short-run impacts and adjust programming in real time.

Limitations of the Study

Some limitations of the current study are recognised. First, the use of annual data restricts the study to detecting causality at the annual frequency; energy-output transmission mechanisms that operate at quarterly or monthly frequencies – such as seasonal agricultural energy demand or industrial production cycles – are not captured in the FD-VAR system. Second, the reduced-form VAR does not identify structural shocks, meaning that the Granger causality results represent predictive, but not necessarily structural causal relationships; identification of structural renewable energy shocks as in Aiyetan et al. (2021) by applying sign restrictions to an SVAR would offer a complementary and more causally interpretable analysis. Third, the linear symmetric VAR specification fails to capture non-linear or asymmetric energy-output relationship; the literature on asymmetric causality indicates that the negative REI shocks could have larger and more persistent effects on output than shocks of the same magnitude but of opposite sign (Hatemi-J & Uddin, 2012).

In the Nigerian Agriculture, specifically Adeleye et al. (2021) show that non-renewable energy is the major determinants of agricultural productivities with a long-run effect of about 5.38 per unit, while renewable energy's effect on agricultural output is negligible, indicating that the symmetric linear VAR model is appropriate for the current state of the relation between renewable energy and agriculture, but may underestimate the potential of renewables in the future as they become more productive. Fourth, the REI variable only accounts for the financial allocation of resources, rather than the productive use of deployed resources in the form of renewable capacity (megawatts used for agriculture or industry). Future studies should incorporate a direct measure of productive-use renewable capacity rather than an investment share metric.

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