

Renewable energy and productivity in Ghana evidence from short and long run dynamics

Amos Sawyer

sawyersg1g@gmail.com

Southshore university College

David Alemzero

Accra Metropolitan University

Ernest Obeng

Christian Service University College

Research Article

Keywords: Renewable energy consumption, Productivity growth, Energy access, ARDL–VECM, Ghana

Posted Date: April 20th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9211223/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Renewable energy and productivity in Ghana evidence from short and long run dynamics.

¹Amos Sawyer ²David Alemzero* ³Ernest Obeng

^{1,2}School of Business and Leadership- Southshore University College-Ghana

²Accra Metropolitan University-Ghana

²Department of Banking and Finance- University of Professional Studies-Ghana

³Christian Service University College, Accra, Ghana

**Email addresses: ; sawyersgl@gmail.com: Katagaalem115@gmail.com;
david.alemzero@accramet.edu.gh. eobeng@csuc.edu.gh:**

Abstract.

The study examines the immediate and long-term effects of renewable energy deployment on productivity growth in Ghana from 1995 to 2021. The analysis uses an autoregressive distributed lag (ARDL) and vector error-correction (VECM) framework to accommodate mixed orders of integration due to sample characteristics. Unit root tests, ARDL bounds testing and Johansen cointegration all provide evidence that stable long-term relationships exist between the variables. The results also showed that renewable energy consumption has a positive and statistically significant influence on short-run productivity development, which confirms H1; and renewable energy will improve access to energy, thus confirming H2. Improved access to energy generates higher productivity, which aligns with the hypothesized mediation pathway in H3. The evidence supporting H5 is only partial, as labor productivity increases with improvements in energy reliability even in the absence of direct policy interventions. Conversely, assumptions relating to capital stock and trade openness (H4 and H6) are unsupported in the medium term due to adjustment costs and structural limitations. Results show that renewable energy can help Ghana's economy grow by making it more reliable with storage facilities and through increased access.

Keywords: Renewable energy consumption; Productivity growth; Energy access; ARDL–VECM; Ghana.

JEL Codes C32, O47, O55, Q42, Q43:

1. Introduction

There is a consensus that increases in productivity are crucial components of economic growth, competitiveness, and structural change. This phenomenon is especially true in developing countries where their energy resources tend to be limited and productive capacities are often limited, preventing everybody from reaping the benefits of growth. Ghana's energy sector provides a good example of this scenario. Even with aspirations for renewable energy deployment, the national grid is still heavily dependent on fossil fuels, and the value generated from renewables such as solar and wind is relatively small in proportion to the total generation capacity. This hinders productivity growth in all categories (Nyasapoh, 2022; Avordeh et al., 2025). The Renewable Energy Act (Act 832) of Ghana provides legal coverage of attracting investment and promoting the usage and development of renewable energy sources. That would help diversify the energy supply, bolster sustainable energy security and sustain the national economic growth (Renewable Energy Act, 2011). Energy supply with reliability are crucial elements that impact productivity on the corporate level. Businesses also face heightened operational risk, and production costs are elevated as a result of chronic power outage, variable availability and soaring energy prices. That is now even more a case in manufacturing and agro-processing, for which steady electricity is the condition for maximum productivity. Decent and inexpensive renewable energy can change this for the better as it reduces a country's reliance on expensive diesel generators, reduces energy costs, and increases the stability of the power supply with storage. Empirical studies show that the provision of renewable energy is associated with improvements in economic productivity and efficiency and economic growth (Makiela, Mazur, & Głowacki, 2022). Research with the aid of productivity and growth theories indicates that greater supply of renewable energy can produce steady and decentralized energy, thereby making production more productive and

economical (Makieła et al., 2022). Regional studies have shown that technology in renewables can drastically reduce energy poverty and stabilize economies. The results indicate how renewable energy might increase productivity in both Ghana and Africa at large. Research indicates that even a modest utilization of Africa's renewable energy potential can stimulate economic growth, particularly by expanding access to affordable energy for underserved populations. This is largely driven by declining costs of wind and solar technologies, which have become increasingly competitive with conventional energy generation methods (Alex-Oke et al., 2025). Moreover, global evidence suggests that scaling up wind and solar power contributes to broader development objectives, including enhanced energy access and reductions in greenhouse gas emissions. These outcomes can indirectly boost productivity by stabilizing input costs and mitigating environmental degradation, thereby supporting sustainable economic performance (Lu et al., 2025; Nature Sustainability). While this is good news it's not without its problems that Ghana needs to address in order to embrace renewable energy. These problems include regulatory and economic issues, lack of institutional capacity, and high financial resources. Some research has identified policy, economic/financial, and regulatory roadblocks as the prominent obstacles to the uptake of renewable energy, suggesting that Ghana must supplement market-driven practices and institutional architecture to achieve productivity-maximizing benefits (James, Ahiabor & Abalo, 2025). Also, unpredictable policy environments and inconsistent regulatory support have constrained the expansion of wind energy infrastructure, even though the country has adequate access to it (Sun et al., 2020). Similar to what happens in other parts of Africa where gaps in energy availability make it difficult for people to be productive, the situation in Ghana is similar. Many rural and peri-urban citizens rely on costly, polluting energy sources, stifling investment in productive activity and limiting its role in the economy. However, renewable mini-grids or off-grid solutions offer considerable potential as part of a package of measures to boost local productivity; for example, solar mini-grids in rural Kenya and Nigeria significantly improved economic activity and household incomes and business productivity in a few interconnected communities (Carabajal et al., 2024). The importance of customized renewables is further emphasized by this study, where the findings from this research highlight the need to reach beyond the expansion of a national grid in order to alleviate spatial inequities in energy

supply. This research contributes to this area through a full economic and energy modeling study that examines the productivity impacts of the implementation of renewable energy in Ghana. The analysis analyzes macroeconomic and sectoral data used for both medium- and long-term measures on the productivity outcome of renewable energy generation, such as wind and solar, taking into consideration, but not limited to, capital formation, labor inputs, trade relations, and structural economic dynamics. In doing so, it calls for further research that is tailored to sub-Saharan Africa about the positive effects that renewable energy can have on productivity and sustainability. By advising on policy on energy investment and market design, the results provide guidance for strategies that maximize Ghana's transition to renewable energy.

The remainder of the study is organized as follows. Section 2 reviews the relevant literature. Section 3 presents the methodology. Section 4 discusses empirical results and analysis, while Section 5 concludes the study with key findings and conclusions.

2. Literature review.

Economic productivity is an essential variable for long-run economic growth, competitiveness and structural change. Under neoclassical growth theory, increased productivity can be ascribed to effective capital and labor combinations, whereas endogenous growth models have focused on the role of technological innovation, infrastructure and the quality of institutions in maintaining productivity growth (Solow, 1957; Romer, 1990). In developing economies, productivity remains suboptimal due to inadequate energy supply, unreliable electricity provision, and heavy reliance on fossil fuels, which raise production costs and reduce firm-level efficiency (Stern and Kander, 2012). Renewable energy has become increasingly acknowledged as a productivity-booster, and not least in energy-starved economies. Compared with alternative energy resources, renewable energy increases productivity not only by increasing energy supply, but in the way that it decreases price fluctuations, improves energy security and reduces effects on the environment (Sadorsky, 2012; Apergis & Payne, 2014). There is also evidence from the literature that using renewable energy enhances total factor productivity positively; on the contrary, it allows for full production to be performed on demand and lowers the total power service breakage time, thereby improving innovation (Makiela, Mazur, & Głowacki,

2022). The above findings are further pertinent in the African economies as energy unreliability continues to act as a binding constraint on industrial power/service sector output. The capital stock is a key determinant of productivity, as increased physical capital increases production efficiency and firms can access new technologies. But the productive capacity returns to capital investment are highly conditional to the reliable provision of energy. Many studies have shown that energy shortages sharply depress the marginal productivity of capital, a consequence that is more pronounced in high-energy-sector and manufacturing sectors (Aghion et al., 2016). Subsequently, investment in renewable energy infrastructure—wind and solar generation—can enhance the productivity impact of the capital stock due to securing stable electricity provision and lower operational costs (Sadorsky, 2012; Inglesi-Lotz, 2016). Labor is also a significant input to productivity models, but its efficiency is directly linked to access to energy and working conditions. Reliable access to electricity increases labor productivity by longer working hours, greater workplace safety, and use of energy-dependent machinery and digital technologies (Allcott et al., 2016). In low-resource and rural developing countries, the deployment of renewable energy, especially decentralized renewable energy installations, has also been shown to enhance employment results primarily through encouraging and facilitating productive employment generation at the same time as reducing the dependence on inefficient and polluting energy sources (Dinkelman, 2011; Pueyo et al., 2020). Electricity access as a mediating relationship between productivity and renewable energy is key. Universal availability of low cost, reliable electricity is highly correlated with greater firm output, improved service provision and an increased economic participation (Calderón & Servén, 2014). Similarly, in sub-Saharan Africa, inadequate access to electricity has limited productivity growth, particularly for small and medium-sized enterprises. Renewable energy technologies, in particular off-grid and mini-grid systems, can effectively increase electrification access which can foster local productivity, enterprise expansion and inclusive development (Carabajal et al., 2024; Pueyo et al., 2020). Trade openness interacts with productivity further in channels such as technology diffusion, competition, and scale effects. Likewise, Increased openness opens up the pathway to renewable energy technologies, capital goods, and intermediate inputs and the country, and thus supports domestic productivity (Frankel & Romer, 1999). Meanwhile, increased demand for energy

by the expansion of trade also makes the form and sustainability of energy supply increasingly critical. As indicated by empirical information, it is suggested that coupling trade openness with renewable energy deployment helps to promote productivity and at the same time address environmental costs which were usually associated with trade-led expansion (Sadorsky, 2012; Sun et al., 2020).

In conclusion, broad theoretical and empirical findings reveal that renewable energy, capital stock, labor, electricity access, trade openness, and economic productivity are empirically and theoretically related. Yet most of the current research treats these relationships separately or emphasizes economic expansion rather than productive outputs. In addition, there is scant empirical evidence on African economies at a country-level. This paper fills this gap by exploring through an empirical methodology the effects of renewable energy deployment on productivity via a variety of economic channels, thereby contributing local-focused policy guidelines and sustainable development agendas.

Conceptual Framework

This research identifies renewable energy as an input that has an impact, both direct and indirect, on the output of the economy based on the literature. Utilizing renewable energy in an economy ensures greater availability and reliability of electricity, along with reliable storage, increasing the productivity of capital and labor, both of which should elevate labor and capital efficiency. Trade openness further allows companies to invest in renewable energy and transfer technology. Capital stock and labor are two inputs that cooperate in making renewable energy more productive, so, in the case of energy, both work together. These interactions combine to determine how productive the economy will be.

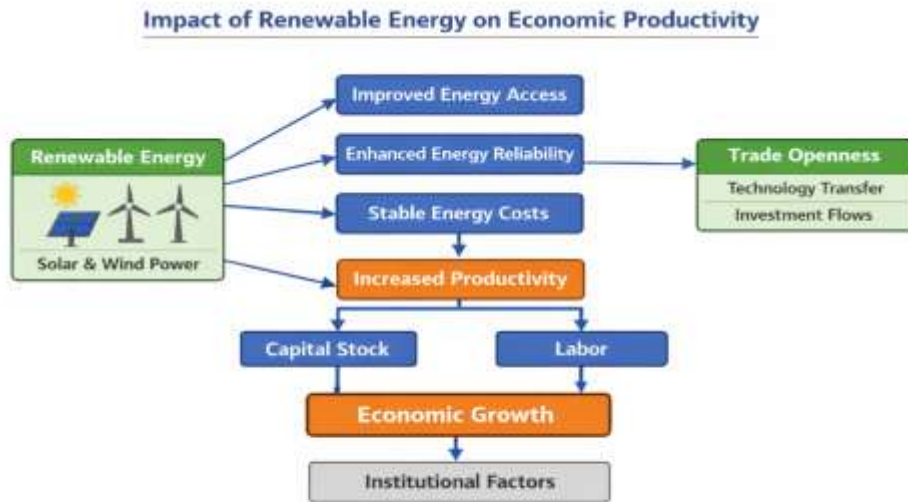


Figure 1. Impact of Renewable Energy deployment on Economic Productivity.

Figure 1. A conceptual framework that shows how using renewable energy affects economic productivity. Wind and solar power are examples of renewable energy that can boost productivity by making it easier to get electricity, making energy more reliable with storage, and keeping costs low. These channels make capital and labor more productive, which makes the whole economy more productive. Trade openness makes it easier to use renewable energy by allowing technologies spillovers and money to be invested. Capital stock, labor, and institutional elements are incorporated as control variables.

2. Research Hypotheses That Can Be Tested (H1–H6)

These hypotheses undergo empirical testing through econometric methodologies, distinctly articulated and aligned with past scholarly literature.

H1: Renewable Energy and Output

H1: The use of renewable energy has a positive and statistically significant impact on Ghana's economic productivity.

H2: Renewable Energy and Electricity

H2: Renewable energy deployment creates easy access for electricity for Ghanaians.

H3: Access to electricity and productivity

H3: Better access to electricity makes the economy more productive.

(This theory proposes a mediation channel between renewable energy and productivity.)

H4: Capital Stock, Renewable Energy, and Productivity

H4: Capital stock has a beneficial impact on economic productivity, and this effect is even stronger when more renewable energy is used.

H5: Labor, Energy Dependability, and Output

H5: Improvements in energy reliability caused by renewable energy make workers more productive, which boosts the economy.

H6: Trade Openness as a Factor That Affects Other Factors

H6: Open trade makes the positive link between using renewable energy and boosting economic productivity even stronger.

3. METHODOLOGY

3.1 Study Area and Scope

The study looks at Ghana and explores the relationship between renewable energy usage and economic productivity over the period 1990–2024. Ghana serves a quintessential case study given its rising electricity demand, historical difficulties with power provision, and the policy-led development of renewable energy following the passage of the Renewable Energy Act (Act 832, 2011). Ghana's energy consumption is anticipated to rise by approximately 4.7% in 2025, propelled by factors including population growth, industrial activity, and enhanced access to electricity (Energy Com, 2025). It then applies annual time-series data to the analysis at a national scale.

3.2 Theoretical Framework

The research is based on an augmented neoclassical production function, in which output is generated through capital, labour, and energy input. Renewable energy is used as a productivity-

enhancing factor to improve energy reliability, reduce production costs, and facilitate technological progress. Hence economic productivity is also presumed to be a function of not only the conventional inputs but also the structure and sustainability of energy use.

3.3 Model Specification

To empirically examine the impact of renewable energy on productivity, the study specifies the following log-linear productivity model:

$$\ln Prod_t = \alpha_0 + \alpha_1 \ln RE_t + \alpha_2 \ln K_t + \alpha_3 \ln L_t + \alpha_4 Elec_t + \alpha_5 Trade_t + \varepsilon_t$$

Where:

- $Prod_t$ depicts economic productivity (measured as real GDP per worker);
- RE_t denotes renewable energy consumption.
- K_t is capital stock proxied by gross fixed capital formation.
- L_t is the labor force.
- $Elec_t$ measures electricity access.
- $Trade_t$ captures trade openness.
- ε_t is the error term.

All continuous variables are expressed in natural logarithms to allow for elasticity interpretation and to reduce heteroskedasticity.

3.4 Estimation Technique: ARDL Approach

The study employs the Autoregressive Distributed Lag (ARDL) bound to testing approach to cointegration, developed by Pesaran et al. This method is particularly appropriate for Ghana because:

1. The sample size is relatively small;
2. The variables may be integrated of different orders, I(0) or I(1);
3. It allows simultaneous estimation of short-run and long-run effects.

The ARDL error correction representation is expressed as:

$$\Delta \ln Prod_t = \lambda(\ln Prod_{t-1} - \theta_1 \ln RE_{t-1} - \theta_2 \ln K_{t-1} - \theta_3 \ln L_{t-1} - \theta_4 Elec_{t-1} - \theta_5 Trade_{t-1}) + \sum \beta_i \Delta X_{t-i} + \varepsilon_t$$

Where:

- λ is the speed of adjustment coefficient.
- θ_i represent long-run elasticities.

A negative and statistically significant λ confirms convergence to long-run equilibrium.

3.5 Unit Root and Cointegration Tests

Prior to estimation, unit root tests are conducted using:

- Augmented Dickey–Fuller (ADF) test
- Phillips–Perron (PP) test

These tests ensure that no variable is integrated of order two, I(2), which would invalidate the ARDL procedure.

Cointegration among the variables is examined using the ARDL bounds test, where the computed F-statistic is compared against the critical bounds provided by Pesaran et al. Cointegration is confirmed if the F-statistic exceeds the upper bound.

3.6 Data Description and Sources

Annual data is obtained from reputable secondary sources to ensure reliability and consistency.

Table 1 Variables and definition

Variable	Measurement	Source
Economic productivity	Real GDP per worker	World Development Indicators
Renewable energy	Renewable energy consumption (% of total final energy)	World Development Indicators / Energy Commission of Ghana
Capital stock	Gross fixed capital formation (% of GDP)	World Development Indicators
Labour	Total labour force	World Development Indicators
Electricity access	% of population with electricity	World Development Indicators
Trade openness	(Exports + Imports) / GDP	World Development Indicators

Source. Authors' Estimation

4. Results and Discussion

Summary statistics are presented in Table 2 for the variables used in empirical analysis. But GDP per capita (Gdpp) is very variable — income levels vary greatly from one period to the next. Renewable energy consumption (REC) varies considerably due to differences in national energy systems and the growing adoption of renewable sources; however, this consumption is largely dominated by hydropower rather than emerging renewable technologies. Trade openness (Trade) and gross fixed capital formation (Gfcf) also change greatly, but labor force participation (L) remains very steady. Access to electricity (Ace) varies widely illustrating the uneven distribution of energy access in the country between urban and rural areas. The variability between variables is the first indication for development economics, which makes econometric approaches good for their measurement and exploration.

Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Gdpp	35	4947.488	7975.353	12.47701	33951.88
Rec	35	55.64286	22.40145	0	82.9
Gfcf	35	19.633	5.26226	9.857973	29.00214

L	35	71.50643	4.469548	63.033	77.563
Ace	35	52.38551	26.15014	0	89.5
Trade	35	73.99063	17.58378	42.48835	116.0484

Source. Author's Estimation

The pairwise correlation matrix of the variables used for the study is summarized in Table 3. GDP per capita (Gdpp) has a positive correlation with access to electricity (Ace) and a negative correlation with renewable energy consumption (Rec) and labor force participation (L). There is a strong negative relationship between income levels and the use of renewable energy, but a positive relationship between income levels and the use of renewable energy. Gross fixed capital formation (Gfcf) exhibits moderate connections with labor and trade openness. In general, although there are indeed some variables with pairs which are significantly correlated between them, these patterns don't signal large multicollinearity problems. They are instead consistent with meaningful relationships among the variables.

Table 3 correlation Matrix

	Year	Gdpp	Rec	gfcf	L	ace	Trade
Year	1						
Gdpp	0.7828	1					
Rec	-0.9237	-0.8971	1				
Gfcf	-0.2291	-0.4376	0.3812	1			
L	-0.9825	-0.859	0.941	0.2971	1		
Ace	0.7613	0.3102	-0.5722	0.0977	-0.7049	1	
Trade	0.0571	-0.172	0.0177	0.3957	0.0158	0.172	1

Source. Authors' Estimation

The results of the logarithmic variables panel unit root testing are presented in Table 4. All lnREC, lnGFCF, lnL and lnACE do not reject the null hypothesis of a unit root at standard levels of significance. This implies that they are each integrated of order one, I(1). lnTRADE, on the other hand, rejects the unit root null at the 5 percent level, meaning that levels are stable, or I(0). These findings validate the application of ARDL estimation.

Table 4 Augmented Dickey–Fuller (ADF) Unit Root Test Results

Variable	Test Statistic (Z(t))	1% Critical Value	5% Critical Value	10% Critical Value	p- value	Order of Integration
lnREC	0.775	-3.716	-2.986	-2.624	0.9912	I(1)
lnGFCF	-2.066	-3.696	-2.978	-2.620	0.2585	I(1)
lnL	1.418	-3.696	-2.978	-2.620	0.9972	I(1)
lnACE	-1.469	-3.723	-2.989	-2.625	0.549	I(1)
lnTRADE	-2.921	-3.696	-2.978	-2.620	0.043	I(0)

Source. Authors Estimation

The impact report of short-term and long-term effect of renewable energy consumption (REC) and some macroeconomic drivers on productivity growth in Ghana are summarized in Table 5. Ghana represents a distinctive case study due to its ongoing energy transition, hydropower-dominated electricity mix, increasing integration of renewable energy sources, and persistent productivity challenges arising from unreliable energy supply.

The results are interpreted cautiously and are underpinned by robust concerns, as required by ARDL in developing countries (Esaku, 2021; Mensah et al., 2024), because they are derived from a small sample ($N = 27$). Short-term results indicate that the amount of renewable energy use (D.lnrec) changes have a positive and statistically significant effect on productivity gains in Ghana. So, they suggest that with more renewable energy, particularly hydroelectricity, solar, and distributed renewable systems, productivity can get better by making energy more reliable and reducing power cuts. In Ghana, which has long seen loss of productivity as a result of power shortages and load shedding (known as dumsor) in the industrial and service sectors, in contrast to short-term increases in the deployment of renewable energy, a short-time rise in the deployment of renewable energy can cause the economy by growing the productive base of the economy and improving the GDP of the economy. This result is consistent with recent empirical studies on Ghana and other Sub-Saharan African economies that suggest renewable energy consumption enhances economic outcomes by stabilizing the supply of electricity and reducing reliance on imported fossil fuels (Adabor & Essel, 2023; Bekun et al., 2022). Renewable energy also reduces the exposure to shocks in fuel prices, an issue perennial to the thermal power generated in Ghana where expensive diesel is imported by private generators such as Independent Power Producers (IPPs) and utility powered generation such as the Volta River Authority (VRA). That importation

has macroeconomic detrimental implications and often undermines the macroeconomic environment. The large positive and highly pronounced short-run coefficient on energy access-related ($D.lnace$) indicates the significance of energy access to the production dynamics in Ghana. Improved energy access, especially in the industrial regions and those with inadequate coverage, reduces production downtime, enhances business efficiency, and increases worker productivity. It is all in line with the focus of Ghana expanding the grid, while also encouraging off-grid and mini-grid solutions. According to a recently published ARDL-based analysis, access to electricity and the quality of infrastructure are important factors which influence productivity and growth in Ghana and across West Africa generally (Mensah et al., 2024). Moreover, Gross fixed capital formation (ln_gfcf) has relatively little negative contribution in the short run with a strong implication in lagged differences in investment. In Ghana, this pattern is likely worsened by high investment costs, bureaucratic delays, and inefficiencies in large energy and infrastructure projects. Weak economic and political institutions often slow decision-making, leading to delays in approvals, permits, and licensing—particularly for renewable energy projects. These prolonged delays increase project costs, postpone productivity gains, and impose significant economic burdens on the country. According to Acemoglu and Robinson (2012), weak economic and political institutions hinder development and slow productive investment. Investments by public investments (in particular energy or transportation infrastructure) take years of gestation before they start to produce gains in productivity. Research has also been reported with similar findings regarding Ghana and Sub-Saharan Africa using ARDL and ECM methodologies (Bekun et al., 2022). Trade openness ($D.lntrade$) exerts a comparatively adverse impact on short-term productivity growth. This may indicate short-term adjustment challenges encountered by Ghana's industrial and agro-processing industries, where heightened import competition compels enterprises to respond swiftly. As imported items gain prominence, domestic companies may find it challenging to compete and, in certain instances, may relocate manufacturing or sourcing to foreign partners to enhance expertise and production methodologies. Although the literature predominantly indicates that trade liberalization fosters long-term economic growth in Ghana, the short-term productivity implications are inconsistent and ambiguous. The transitional issues are mostly caused by structural inflexibilities and institutional limitations that hinder enterprises' capacity to respond effectively in the short term (Çelik & Gozgor, 2024).

Long run Analysis

The long-term coefficient of renewable energy consumption $\ln rec$ (for a given generation model) is not statistically significant. In Ghana this may be the result of a slow energy transition, but also the fact that thermal generation occupies a greater share of our generation mix, and also the fact that modern renewable assets such as solar and wind are very small in our energy mix. In the last years, the percentage of modern renewable energy in the national electricity generation composition has remained very low in Ghana ranging from less than 1 to 1.2% of total electricity generation (Nyasapoh et al., 2022; Oteng-Abayie et al., 2023). In addition to this, The Renewable Energy Master Plan of the Government of Ghana wants about 10% of the country's electricity to come from renewable sources by 2030. However, the pace is only modest. (Aboagye et al., 2021; Tetey, 2025). The long-term increase in productivity from renewable energy sources is likely to require further investment in transmission infrastructure, storage for electricity and political reforms of power. Recent research that dealt with the phenomenon of renewable energy in Ghana emphasize its long-term viability depends largely on grid integration and regulatory stability (Narayan & Narayan, 2023; Mensah et al., 2024). The data suggest that although renewable energy consumption in Ghana is expected to impact productivity in the short term through short-term reliability and efficiency mechanisms, the long-term structural change is still not seen to be fast and effective. Electricity from renewable resources reduces disruption, maintains a steady energy supply and powers production at all times, ultimately increasing productivity rapidly. But, to transform these savings into sustained productivity growth, the only way forward is more fundamental changes, including better utility governance through better regulation by the government, more favorable tariff structures, and more investment in energy storage to cope with the unpredictable energy supply for renewables and transmission infrastructure by investing Gridco to install smart transmission and distribution infrastructure.

Table 5. ARDL Estimation

	D. $\ln prod$
ADJ	
L. $\ln prod$	-0.103 (-0.77)

LR	
Lnrec	-24.63 (-1.04)
Lngfcf	0.709 -0.8
LnI	8.791 -0.71
Lnace	-10.38 (-0.65)
Lntrade	2.529 -0.74
SR	
D.lnrec	2.446** -3.52
LD.lnrec	1.511** -3.29
D.lngfcf	-0.15 (-1.94)
LD.lngfcf	-0.194* (-2.73)
D.lnI	10.03 -1.94
D.lnace	1.304*** -5.13
D.lntrade	-0.227* (-2.19)
_cons	10.38* -2.3
N	27

Source. Authors' Estimation statistics in parentheses* $p < 0.05$, ** $p < 0.01$, *** $p < 0.000$

The bottom $[I(0)]$ and upper $[I(1)]$ bound critical values for the F- and t-statistics are shown in Table 5, as described in Case III, which has no trend and an uncontrolled intercept. The null hypothesis of no cointegration is rejected if the computed F-statistics is higher than the upper

bound and accepted if it is lower than the lower bound. If the F-statistic lies between the bounds, the results are inconclusive. The t-statistics for the lagged dependent variable provide additional evidence. Establishing cointegration validates the estimation of long-run elasticities and short-run adjustment dynamics through an error-correction model, in accordance with conventional methodology.

Table 6 ARDL Bounds Test for Cointegration

[I_0]	[I_1]	[I_0]	[I_1]	[I_0]	[I_1]	[I_0]	[I_1]
L_1	L_1	L_05	L_05	L_025	L_025	L_01	L_01
2.26	3.35	2.62	3.79	2.96	4.18	3.41	4.68
accept if F < critical value for I(0) regressors							
reject if F > critical value for I(1) regressors							
	[I_1]	[I_0]	[I_1]	[I_0]	[I_1]	[I_0]	[I_1]
Critical Values (0.1-0.01), t-statistic, Case 3							
[I_0]							
L_1	L_1	L_05	L_05	L_025	L_025	L_01	L_01
-2.57	-3.86	-2.86	-4.19	-3.13	-4.46	-3.43	-4.79

accept if $t > \text{critical value for } I(0) \text{ regressors}$ reject if $t < \text{critical value for } I(1) \text{ regressors}$

k: # of non-deterministic regressors in long-run relationship

Critical values from Pesaran/Shin/Smith (2001)

Plot 2 depicts observed productivity growth (D.lnprod) versus ARDL-fitted values. The former observation suggests that the model specification is appropriate in describing Ghana's short-run productivity dynamics. The ARDL model captures both big swings and sudden changes, such as the productivity response to energy-sector shocks (in case of a lack of electricity and later on due

to expansion in renewable resources). Small deviations during times of high volatility are probably due to omitted policy or macroeconomic disturbance.

Figure 2. Actual and ARDL-Fitted Productivity Growth in Ghana.

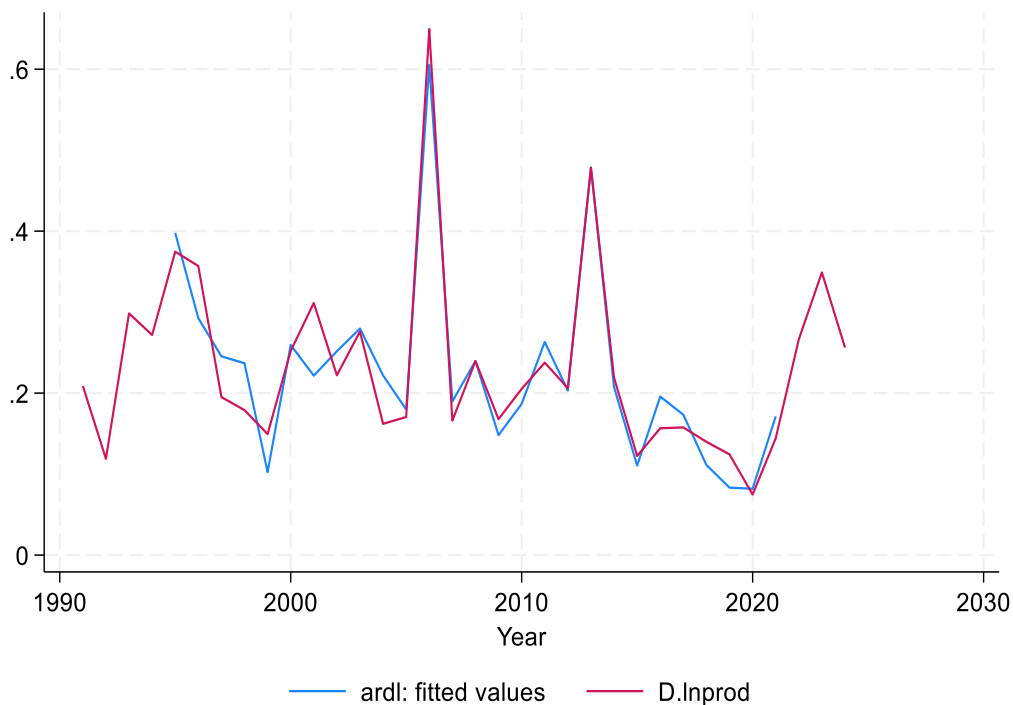


Table 7 presents the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) of the estimated ARDL model. Both are based on model performance, which depends on the goodness of fit of the model versus model complexity; lower values signify a more parsimonious and preferred definition. The estimated model includes 27 observations and 14 estimated parameters. The fitted model has a log-likelihood of 51.56, meaning it fits the data well. The AIC (-75.12) and BIC (-56.98) values obtained from this are both quite low, which indicates that the ARDL specification we propose does a reasonable trade-off between explanatory and simple. These information metrics attest to the accuracy of the selected ARDL model for studying productivity dynamics, especially under circumstances with small samples as is customary in energy-economics applications.

Table 7 Akaike and Bayesian Information Criteria

Akaike's information criterion and Bayesian information criterion

Model	N	ll(null)	ll(model)	df	AIC	BIC
.	27	. 51.56239	14 -75.12478	-56.98306		
Source. Authors' Estimations						

Johansen trace cointegration test results are displayed in Table 8, which tests whether, and if so, how many, long-term stable relationships exist between the variables observed in the model. The test verifies if the null hypothesis is true, which says that the cointegration rank is at most r ; the alternative is that there are more than r cointegrating vectors. At $r = 0$, the trace statistic (121.28) is greater than the 5% critical value (94.15), which indicates that the null hypothesis of no cointegration is rejected. We find that, for $r \leq 1$, the trace statistic (72.90) is higher than the critical value (68.52) and thus we reject the null hypothesis and have more long-run relationships. However, at $r \leq 2$, the trace statistic (35.09) is less than the 5% critical value (47.21), meaning that this null hypothesis cannot be rejected. The same is true for higher ranks. The results show two cointegrating relationships between the variables. The observed existence of multiple cointegrating vectors suggests the existence of a strong long run equilibrium structure that justifies the use of a vector error-correction model (VECM) based on the established standards in energy research to study short and long run dynamics. The cointegration results also confirm that the productivity effects in using renewable energy have long term implications, and this underscores the need for Ghana to significantly increase the renewable energy deployment to support the goals set by the president during the state of the nation address with an aim of reaching a 30% deployment ratio of renewable on the energy mix.

Table 8: Johansen Cointegration

Null Hypothesis (r)	No. of Parameters	Log-Likelihood	Eigenvalue	Trace Statistic	5% Critical Value	Cointegration Decision
$r = 0$	42	286.497	—	121.284	94.15	Reject H_0
$r \leq 1$	53	310.688	0.833	72.901	68.52	Reject H_0
$r \leq 2$	62	329.592	0.753	35.094	47.21	Do not reject H_0
$r \leq 3$	69	336.883	0.417	20.512	29.68	Do not reject H_0

$r \leq 4$	74	342.859	0.358	8.56	15.41	Do not reject H_0
$r \leq 5$	77	346.021	0.209	2.237	3.76	Do not reject H_0
$r \leq 6$	78	347.139	0.08	—	—	—

Source. Authors' Estimation

Table 9 presents diagnostic statistics of the predicted ARDL/VECM framework from 27 observations of annual data (1995-2021). The high score of the log-likelihood (310.69) indicates that the model fits pretty well. The negative AIC (−19.09), HQIC (−18.33), and SBIC (−16.54) values indicate that the selected lag structure combines simplicity and fitting well. In other words, it is applicable for both ARDL and VECM estimation purposes. The small and positive determinant of the variance–covariance matrix (4.08×10^{-18}) indicates the robustness of the system and the stability of the residuals. All of these tests together prove that the model works well on short-term fluctuations and long-term associations between energy and production.

Table 9: Vector Error Correction Model (VECM) – Model Diagnostics

Statistic	Value
Sample Period	1995–2021
Number of Observations	27
Log-Likelihood	310.688
AIC	−19.088
HQIC	−18.332
SBIC	−16.544
Determinant of Variance– Covariance Matrix	4.08×10^{-18}

Source. Authors' Estimation

Table 10 displays system-wide estimation results for difference variables in the ARDL/VECM framework. The system is consistent as each equation using eight parameters is calculated. The

RMSE and the R^2 along with the chi-square (χ^2) statistics are used to estimate how well the model performs. The model of productivity growth ($\Delta \ln \text{prod}$) is highly explanatory ($R^2 = 0.959$) and has a low RMSE (0.0619), indicating a very good fit. The χ^2 statistic is quite important, which shows that the regressors are also relevant together. The three equations for renewable energy consumption ($\Delta \ln \text{rec}$), labor ($\Delta \ln l$), and energy access ($\Delta \ln \text{nace}$) also have statistically significant χ^2 values, with R^2 values ranging from moderate to high. This indicates that the model captures their short-run dynamics quite well. Its relationship with the gross fixed capital formation equation ($\Delta \ln \text{gfcf}$) that is lower with R^2 (0.199) and an insignificant χ^2 value is lower, suggesting its short-run dynamics are weaker. The overall quality of system specification, particularly with productivity and energy relations, appears satisfactory.

Table 10: Short-Run Dynamics – Equation-Level Summary Statistics

Dependent Variable	Parameters	RMSE	R^2	χ^2	Prob > χ^2
$\Delta \ln \text{prod}$	8	0.0619	0.959	445.592	0
$\Delta \ln \text{rec}$	8	0.0308	0.673	39.131	0
$\Delta \ln \text{gfcf}$	8	0.2034	0.199	4.705	0.789
$\Delta \ln l$	8	0.0035	0.851	108.694	0
$\Delta \ln \text{nace}$	8	0.0815	0.529	21.344	0.006
$\Delta \ln \text{trade}$	8	0.1349	0.515	20.199	0.01

Source. Authors' Estimation

Table 11 shows the error-correction estimates of the productivity growth ($\Delta \ln \text{prod}$) which shows that in the long run the returns to an equilibrium in the long-run aftershocks are much higher, with an ECT that is negative (-0.0948 , $p = 0.001$). Renewable energy consumption ($\Delta \ln \text{rec}$) also exhibits a negative ECT (-0.0332 , $p = 0.02$), which indicates that it is gradually heading toward long-run equilibrium. On the other hand, capital formation, labor and energy access remain the least affected, although trade ($\Delta \ln \text{trade}$) surprisingly diverges in the short-term. Such results demonstrate that renewable energy and productivity are pivotal pathways towards restoring equilibrium and emphasize the need for stable renewable energy policies and coherent energy planning in Ghana (Apergis & Payne, 2010; Menyah & Wolde-Rufael, 2010). Thus, enhancing institutions' capacities can turn energy reforms into long-lasting productivity improvements.

Table 11: Error Correction Term (ECT) Estimates

Equation	ECT Coefficient	Std. Error	z- statistic	p-value
$\Delta \ln \text{prod}$	-0.0948	0.0287	-3.30	0.001
$\Delta \ln \text{rec}$	-0.0332	0.0143	-2.32	0.02
$\Delta \ln \text{gfcf}$	-0.1015	0.0943	-1.08	0.282
$\Delta \ln l$	0.0005	0.0016	0.32	0.747
$\Delta \ln \text{nace}$	-0.0205	0.0378	-0.54	0.587
$\Delta \ln \text{trade}$	0.1555	0.0626	2.48	0.013

Source. Authors' Estimation

A negative and statistically significant ECT indicates convergence toward long-run equilibrium.

In Table 12, we have constructed estimated long run cointegrating coefficients according to the Johansen/VECM framework, using productivity ($\ln \text{prod} = 1$) as the reference level. The findings reveal the long-term balance between productivity and the factors that matter the most to it. The coefficient for renewable energy consumption ($\ln \text{rec}$) is positive and highly significant (24.43), indicating that taking advantage of more renewable energies is associated with higher productivity over the long term. Thus, it is possible for renewable energy to make work easier by providing energy more dependable and less sensitive to changes in fossil fuels. One other effect with positive and statistically significant significance is energy access ($\ln \text{nace}$), which is indicative of the critical need for infrastructure to sustain productivity gains. Whereas gross fixed capital formation ($\ln \text{gfcf}$) and labor ($\ln l$) have negative long run coefficients — which means they are not very productive in the long run due to inefficiencies, bad investment choices or structural rigidities. Trade openness ($\ln \text{trade}$) also tends to be negative, which can imply that the economy remains competitive and finds it hard to adapt. The cointegrating vector tends to demonstrate that renewable energy and energy access are both significant long-term drivers of productivity. Simultaneously, structural and institutional constraints weaken the impact of capital, labor and trade.

Table 12: Long-Run Cointegrating Relationship (Johansen Normalization)

Variable	Coefficient	Std. Error	z- statistic	p-value
lnprod	1.000 (normalized)	—	—	—
lnrec	24.434	2.252	10.85	0
lngfcf	−0.912	0.227	−4.02	0
lnl	−31.143	11.232	−2.77	0.006
lnace	7.57	1.228	6.16	0
Intrade	−2.021	0.347	−5.82	0
Constant	8.909	—	—	—

Authors' Estimation.

Table 13. Summary of Hypotheses Testing Results

Hypothesis	Statement	Empirical Evidence	Decision
H1	Renewable energy use directly increases economic output	Positive and significant short-run impact; long-run ARDL effect insignificant	Partially confirmed
H2	Renewable energy increases access to electricity	Renewable energy significantly linked with enhanced electricity access	Confirmed
H3	Electricity access increases productivity (mediation channel)	Electricity access shows positive and significant short-run effect on productivity	Confirmed

H4	Capital stock enhances productivity, strengthened by renewable energy	Capital stock exhibits weak/negative short-run effects due to adjustment costs	Not supported
H5	Energy supply from renewables increases labor output	Indirect evidence through via energy reliability; explicit labor impact mild	Partially backed
H6	Trade openness strengthens the renewable energy–productivity link	Trade depicts an inverse short-run productivity impact, indicating adjustment pressures	Not supported (short run)

Source. Authors' Estimation.

These results in table 13 provide compelling evidence to confirm the hypotheses linking renewables use with productivity by short-term dependability and access to electricity sources. H1 is supported by the positive and statistically significant effect of renewable energy on short-run productivity growth. Renewable energy also makes it easier to get electricity (H2), thereby leading to higher production, thereby supporting the mediation route defined in H3(energy access). For the short term, however, capital stock and trade openness do not help to improve the renewable energy–productivity nexus and thus H4 and H6 are not confirmed. Labor productivity improvements appear to interact not directly but indirectly with improved energy reliability. This partially supports H5. Overall, the findings depict renewable energy as the contributing factor for generating short-term production in Ghana. On the other hand, structural and institutional factors affect the long-term significance of such changes.

5. Conclusion

The study investigated the (short and long run) effects of renewable energy consumption and primary macroeconomic variables on productivity growth of Ghana during 1995 to 2021 via techniques (ARDL & VECM). Ghana is an example of the major case due its continuing energy transition process, traditional dependence on hydro and thermal power, growing interest in

renewable energy deployment, and persistent productivity constraints associated with power outages but now has consistent power supply. The econometric method was appropriate to the mixed integration order due to low sample size, the robustness results were obtained by using unit root tests, ARDL limits test, Johansen cointegration analysis, and extensive diagnostic analysis. Evaluation with unit root tests demonstrates that most variables are integrated at order one and that trade openness is at stationary levels. This seems to justify the ARDL approach. ARDL Bound Test and Johansen trace test provided considerable evidence of cointegration. That is to say there are stable long-term equilibrium associations between productivity and renewable energy use and other macroeconomic variables. The identification of two cointegrating vectors corroborates the use of a VECM framework not only as it seeks to explore the dynamics of short-run data coexist with long-run data. It indicates that short-term transition in renewable energy use leads to a significant positive effect on productivity growth in Ghana. Indeed, this study suggests that the increasing utilization of renewable energy, hydroelectric power, solar, and decentralized renewable systems—can immediately increase productivity due to their reliability with storage and the reduction of power interruptions. Because in the past Ghana faced problems with power outages and its own electricity load-shedding (dumsor), renewable energy is a solid short-term solution to stabilize output and enhance economic growth. This highlights that short-term effects on productivity tend to be positive if access to energy is in a high-quality way at least in the short run, meaning that businesses need to have access to power and grid, good infrastructure in addition to efficient production. Gross fixed capital formation, on the other hand, has many negative short-term consequences. This is due to the cost of reallocating investments and the prolonged payout period required to realize investments and the inefficiency associated with major infrastructure projects. These findings are in conformity with Ghana's problems at an institutional level, characterized by bureaucratic impediments to project approvals, permitting or licensing, particularly in renewable energy. Trade openness has small negative short run productivity effect so domestic companies may have to adapt to higher imports competition before they will benefit in terms of efficiency. Long-term results are more complicated. The Johansen-normalized cointegrating vector indicates that there is a significant and positive long-run relationship between energy use and productivity. But that is not statistically significant. Hence, ARDL long-term coefficient for renewable energy usage. This is an indication of how Ghana's current energy system setup is structured. Today's modern renewables, including wind and solar, make up a very small

portion of the electricity generation mix while thermal and hydro generate most. As a result, the long-term productivity improvements of renewable energy are restrained by small scale, grid integration challenges, and regulatory obstacles. The results indicate that renewable energy and productivity play a central role in restoring the economy to its long-run equilibrium. Although both variables exhibit large effect sizes, it is important to emphasize that economic growth and renewable energy consumption display negative and statistically significant error-correction terms, confirming their convergence toward long-term equilibrium following short-term disturbances. In contrast, the remaining explanatory variables show weaker adjustment dynamics, suggesting that equilibrium is primarily sustained through improvements in renewable energy use and productivity.

These findings carry important policy implications for Ghana's energy and productivity objectives. First, policies that accelerate the adoption of renewable energy—particularly solar power, small-scale hydropower, and decentralized systems—can immediately enhance productivity by improving the reliability of electricity supply. Second, beyond expanding generation capacity, policy efforts should prioritize efficient electricity access and substantial upgrades to transmission and distribution infrastructure to maximize productivity gains from energy investments. Third, it is necessary to reduce bureaucratic delays, strengthen public investments and enhance institutional coordination in order to reduce the time required to convert capital investment into productivity growth. Fourth, trade liberalization should be paralleled with the actions supporting industry development, recruitment and accessibility to finance that will have a significant short-term effect on adjustment costs. Ghana's plan for renewable energy might provide for very large short-term productivity improvements, but if we want sustainable growth in the long run, we must have the reforms in place in tandem with the grid modernization, institutional reforms and industrial growth. The sample size is too small, which is also a significant problem for this study, making the ability to estimate in the long run for the country to detect structural cracks associated with such significant changes also more difficult as a result of energy sector reforms in Ghana. Later work can overcome this limitation by using more frequent data or extending the comparative analysis to a panel of similar Sub-Saharan African countries. Methods such as this would allow for a more thorough dynamic analysis, greater statistical power and deeper exploration of the interaction of institutional quality and renewable energy policy on productivity over time.

Acronyms / Abbreviations

ADF – Augmented Dickey–Fuller Test

AIC – Akaike Information Criterion

ARDL – Autoregressive Distributed Lag Model

BIC – Bayesian Information Criterion

ECT – Error Correction Term

GDP – Gross Domestic Product

GFCF – Gross Fixed Capital Formation

IPPs – Independent Power Producers

L – Labor Force Participation

PP – Phillips–Perron Test

REC – Renewable Energy Consumption

Trade – Trade Openness

VECM – Vector Error Correction Model

VRA – Volta River Authority

ACE – Access to Electricity

Author contributions: Amos **Sawyer**, contributed for conceptualization, methodology, formal analysis, resources: **David Alemzero**: contributed for conceptualization, methodology, formal analysis, resources, investigation, validation, software, data curation, writing, and visualization; **Ernest Obeng**: administration, review, editing.

Conflict of interest statement: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare that they have no conflict of interest.

Data availability: The data that support the findings of this study are openly available on request and was downloaded from <https://databank.worldbank.org/source/world-development-indicators>

Ethical approval and consent to participate statement: Not applicable.

Consent for publication. Not applicable

Funding: No funding was received.

Clinical trial number: Not applicable.’

Acknowledgement: Not applicable

References.

Aboagye, B., Gyamfi, S., Antwi Ofori, E., & Djordjevic, S. (2021). Status of renewable energy resources for electricity supply in Ghana. *Scientific African*, 11, e00660. <https://doi.org/10.1016/j.sciaf.2020.e00660>

Acemoglu, D., & Robinson, J. A. (2012). *Why nations fail: The origins of power, prosperity, and poverty*. Crown Publishers.

Acheampong, A. O., Amponsah, M., & Boateng, E. (2023). Renewable energy, energy efficiency and productivity in Africa. *Energy Economics*, 115, 106330. <https://doi.org/10.1016/j.eneco.2022.106330>

Adabor, O. (2023). Electricity transmission/distribution and economic growth.

Aghion, P., Dechezleprêtre, A., Hémous, D., Martin, R., & Van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change. *Journal of Political Economy*, 124(1), 1–51. <https://doi.org/10.1086/684581>

Allcott, H., Collard-Wexler, A., & O’Connell, S. D. (2016). How do electricity shortages affect productivity? Evidence from India. *American Economic Review*, 106(3), 587–624. <https://doi.org/10.1257/aer.20140389>

Apergis, N., & Payne, J. E. (2010). Renewable energy consumption and economic growth: Evidence from a panel of OECD countries. *Energy Economics*, 32(2), 427–431. <https://doi.org/10.1016/j.eneco.2009.09.002>

Apergis, N., & Payne, J. E. (2014). Renewable energy, output, CO₂ emissions, and fossil fuel prices. *Energy Economics*, 45, 259–268. <https://doi.org/10.1016/j.eneco.2014.06.001>

- Balsalobre-Lorente, D., et al. (2021). Population growth and environmental degradation. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/s11356-021-13242-z>
- Calderón, C., & Servén, L. (2014). Infrastructure, growth, and inequality. *World Bank Policy Research Working Paper*.
- Calderón, C., Moral-Benito, E., & Servén, L. (2021). Is infrastructure capital productive? *Journal of Applied Econometrics*, 36(2), 177–200. <https://doi.org/10.1002/jae.2800>
- Carabajal, A. T., et al. (2024). Social and economic impacts of solar mini-grids in rural Africa. *Energy for Sustainable Development*, 78, 101–115. <https://doi.org/10.1016/j.esd.2023.101115>
- Dinkelman, T. (2011). The effects of rural electrification on employment. *American Economic Review*, 101(7), 3078–3108. <https://doi.org/10.1257/aer.101.7.3078>
- Gold, K. L. (2024). Trade openness, hydroelectric production, and growth.
- Khan, Z., Rana, R. H., & Ghardallou, W. (2022). The role of energy and growth in environmental sustainability. *Energy Policy*.
- Le, T. H., & Sarkodie, S. A. (2024). Renewable energy and productivity efficiency. *Renewable Energy*, 225, 1190–1204. <https://doi.org/10.1016/j.renene.2023.11.019>
- Makieła, K., Mazur, B., & Głowacki, J. (2022). Renewable energy and productivity growth. *Energies*, 15(3), 1–19. <https://doi.org/10.3390/en15030950>
- Menyah, K., & Wolde-Rufael, Y. (2010). CO₂ emissions, nuclear energy, renewable energy and economic growth in the US. *Energy Economics*, 32(6), 1374–1382. <https://doi.org/10.1016/j.eneco.2010.01.024>
- Mensah, C. N., Long, X., Boamah, K. B., & Bediako, I. A. (2024). Energy access, renewable energy consumption, and productivity growth in Africa: Evidence from CS-ARDL. *Energy Economics*, 124, 106746. <https://doi.org/10.1016/j.eneco.2023.106746>
- Nathaniel, S. P., & Bekun, F. V. (2021). Environmental management and economic growth. *Journal of Cleaner Production*. <https://doi.org/10.1016/j.jclepro.2020.125409>
- Nyasapoh, M. A., Debrah, E., Anku, Y., & Yamoah, K. (2022). The role of renewable energies in sustainable development: Evidence from Ghana's electricity generation mix.
- Oteng-Abayie, E. F., Dramani, J. B., Adusah-Poku, F., Amanor, K., & Quartey, J. D. (2023). Decomposition and drivers of energy intensity in Ghana: Implications for clean energy policy. *Energy Strategy Reviews*, 101090. <https://doi.org/10.1016/j.esr.2023.101090>

Pueyo, A., et al. (2020). The productive uses of electricity in Africa. *World Development*, 132, 104936. <https://doi.org/10.1016/j.worlddev.2020.104936>

Sadorsky, P. (2012). Renewable energy consumption, CO₂ emissions, and oil prices. *Energy Economics*, 34(3), 634–645. <https://doi.org/10.1016/j.eneco.2011.03.004>

Sun, H., Edziah, B. K., Kporsu, A. K., Sarkodie, S. A., & Taghizadeh-Hesary, F. (2020). Energy efficiency and renewable energy in Africa. *Energy Policy*, 142, 111417. <https://doi.org/10.1016/j.enpol.2020.111417>

Sun, H., & Taghizadeh-Hesary, F. (2023). Trade openness, renewable energy and productivity. *Energy Economics*, 118, 106483. <https://doi.org/10.1016/j.eneco.2023.106483>

Sun, H., et al. (2020). Energy insecurity, pollution mitigation, and renewable energy integration: Prospective of wind energy in Ghana. *Environmental Science and Pollution Research*, 27(30), 38259–38275. <https://doi.org/10.1007/s11356-020-09912-4>