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Energy Efficiency Policies and Industrial Growth: Unlocking West Africa's Production Potential

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ABSTRACT

The paper objective is crucial because the study analyzes how energy efficiency policies affect industrial growth in 16 West African countries from 2000 to 2023, therefore addressing the energy challenges and low industrial performance in the region for sustainable growth. The limited research with regard to the interplay of energy efficiency and industrial development in the context of West Africa motivated this study and integrates the endogenous growth theory, focusing on technological innovation, human capital, and resource efficiency. In particular, this study applies several high-tech econometric methods, namely the stochastic frontier and random effects models, to examine the effect of energy intensity, carbon emission intensity, renewable energy efficiency, and energy infrastructure on industrial, manufacturing, and productivity growth. The inefficiency in energy intensity and infrastructure dampens industrial growth. Also, governance quality and urbanization have a positive impact on productivity. The interaction between governance quality and energy policies amplifies productivity but worsens manufacturing growth. Carbon emission efficiency promotes manufacturing but detracts from productivity. This study, therefore, stresses the need for policy interventions that focus on governance improvement, energy infrastructure development, and renewable energy utilization to stimulate industrial growth in West Africa.

Keywords: Energy Efficiency Policies, Industrial Growth, Stochastic Frontier Model, West Africa
JEL Classifications: C21, Q43, L16, N77

1. INTRODUCTION

Energy efficiency plays a critical role in achieving sustainable industrial growth in West Africa in the face of expected significant economic transformation in the region. Energy-intensive industries in West Africa are part and parcel of core economic development within the subregion, but potential industrial growth is still hindered by inefficiencies in energy use (Appiah et al., 2021). According to the International Energy Agency (2023), energy efficiency can be understood as producing more with less energy input; therefore, it is vital not only to reduce industrial energy costs but also to enhance productivity, competitiveness, and sustainability. Energy efficiency policies have been one of the prime factors in unlocking West Africa's full production potential in light of the growing demand for industrial goods and global shifts toward decarbonization (Prempeh, 2024).

The industrial sector contributes around 25% to the region's GDP; its energy consumption is high while energy productivity is low. Apart from that, West Africa is persistently plagued by a shortage of electricity. Much of this inefficiency in the industrial competitiveness of West Africa emanates from its overdependence on fossil fuels to meet the energy needs, leading not just to high industrial energy costs but also environmental degradation (World Bank, 2023). Countries like Nigeria and Ghana, which lead the region in industrial output, have energy deficits characterized by frequent power outages, with operational inefficiencies in infrastructure severely hindering industrial activity (African Development Bank, 2024). In this context, energy efficiency policies become quite instrumental in reducing these inefficiencies, lowering operational costs, and enhancing industrial growth.

Despite the increasing focus on energy efficiency, there are a lot of significant barriers in the industrial sector in West Africa. The defining characteristic of the industry in the region is high energy intensity or large quantities of energy use per unit of output. Take, for instance, the industrial sector of Nigeria, which uses about 12.5 megajoules per dollar of GDP, a quantity far above the world average of 4.5 megajoules per dollar (World Bank, 2023; Djeunankan et al., 2024). This inefficiency results in higher production costs, making the economy less competitive, with its capacity to scale reduced. Further complications are added by the underdeveloped energy infrastructure, supplemented by outdated power plants and widely distributed transmission losses. Distribution and transmission losses top over 20% in Sierra Leone and Liberia, way over the global average of 8%, resulting in huge industrial energy use inefficiencies (International Energy Agency, 2023).

Meanwhile, the significant renewable energy potential of the region remains underutilized. West Africa enjoys favorable solar, hydro, and wind resources that can be employed to radically lower the industrial energy burden and unleash a path of growth that is sustainable. According to International Renewable Energy Agency (2023), there is a potential to achieve over 4,000 terawatt-hours annually from renewable sources, enough to satisfy the energy requirements of its industrial sector. However, the lack of integrated energy policies, poor investment in renewable energy infrastructure, and certain regulatory gaps have stultified the efforts toward the effective implementation of strategies aimed at energy efficiency (Appiah et al., 2021).

Energy efficiency policies hence stand a better chance of retransforming the industrial landscape of West Africa. With advanced energy-saving technologies, revised energy management practices, and improved industrial processes, West African countries can reduce energy consumption for the same capacity of production (Safarzadeh et al., 2020). Besides, these policies can also encourage industrial players to use cleaner and more efficient technologies. These, in turn, can attract foreign investment and promote technological innovation too. For instance, Ghana's Energy Efficiency and Conservation Program has led to the reduction of industrial energy consumption by 12% since 2016, when this program started. Similarly, Nigeria's National Energy Efficiency Action Plan aims to reduce energy use in industrial sectors by 20% by 2030, an ambitious target that underscores the importance of energy efficiency to the nation's industrial policy framework (Aquilas et al., 2024).

The interaction between energy efficiency and industrial growth is complex and multifaceted. Effective energy efficiency policies can reduce energy costs, enhance industrial competitiveness, and improve productivity (Chen et al., 2024). However, this potential comes with requirements: Firstly, the robustness of institutional frameworks; secondly, the level of technological adoption; and thirdly, policy composition in line with the real-life situation of the industrial sector (Wang et al., 2024). Success has been greater in West Africa within countries like Côte d'Ivoire, with better governance and institutional frameworks, where energy efficiency measures have seen industrial energy consumption reduced and competitiveness improved. Conversely, in countries where governance structures are weak, policy enforcement is a serious problem, and the rate of energy efficiency improvement is very slow or even nil (Djeunankan et al., 2024).

Although there is substantial literature on energy efficiency and industrial growth globally, several gaps persist in the West African context. Many studies have focused more broadly on Sub-Saharan Africa (Aboagye and Nketiah-Amponsah, 2016; Appiah et al., 2021) or on energy poverty impacts (Djeunankan et al., 2024), without specific discussions on policy pathways to unlock industrial growth through energy efficiency within West Africa. The existing analytical frameworks, such as the Environmental Kuznets Curve by Prempeh (2024) or energy sustainability functions by Ghobakhloo and Fathi (2021), do not fully incorporate industrial dynamics and regional challenges such as infrastructure deficits, energy poverty, and poor policy enforcement. Therefore, this paper contributes to the literature by analyzing how West Africa can have energy efficiency policies that lead to sustainable industrial growth in the most effective balancing of economic, environmental, and energy demands.

The structure of the paper is as follows: Following this introductory section, the literature review will be based on conceptual frameworks and empirical studies relating to energy efficiency and industrial growth. Specifically, the methodology section shall outline the research design, data sources, model specification, and their analytical techniques. The results section will present findings from the analysis carried out regarding energy efficiency policies and their impact on industrial growth in the region. Finally, the conclusion should give some policy recommendations to help enhance energy efficiency and consequently foster industrial growth in West Africa.

2. LITERATURE REVIEW

Energy efficiency policies play a very important role in shaping industrial growth, especially in regions like West Africa, where energy challenges and the need for sustainable industrial growth coexist. The interlinkages between energy use, industrialization, and environmental sustainability have been discussed at length, thereby providing key insights that could inform the design and implementation of policies.

Wesseh and Lin (2017) present a foundational analysis of renewable and nonrenewable energy's impacts on industrial growth in East Africa. Their findings reveal that nonrenewable energy exhibits higher output elasticities and greater technological progress compared to renewable energy. While the study highlights the potential for transitioning toward renewable energy, it underscores the limitations of renewable sources and the necessity for balanced energy policies emphasizing efficiency and diversification. These facts are of vital importance to West African economies, whose energy resource constraints and the push for industrialization require nuanced strategies.

Prempeh (2024) furthers the discussion by examining the interplay between financial development, globalization, renewable energy, and industrialization on environmental degradation in ECOWAS countries. The study confirms an N-shaped Kuznets curve, where renewable energy and financial development mitigate environmental degradation, while globalization and industrialization worsen it using advanced econometric techniques. The policy implications, therefore, are to develop renewable energy, control industrial growth, and ensure sustainable financial development to enhance environmental quality. This is in line with West Africa's need for a balanced approach between industrial growth and ecological preservation.

Adom and Amuakwa-Mensah (2016) examine the conditional impacts of income, trade openness, foreign direct investment (FDI), and industrialization on energy productivity in East African nations. They also found that income and trade openness increase energy productivity while FDI and industrialization decrease it, especially for low-income economies. Their results highlight the need to combine industrial strategies with a growth in income and trade policies to develop energy efficiency. This multi-dimensional aspect of approach is quite relevant in West Africa, where similar forces play out in energy productivity and drive to higher levels of industrialization.

Aboagye and Nketiah-Amponsah (2016) focus on the drivers of energy intensity in Sub-Saharan Africa. They find that it is higher due to the factors of urbanization and industrialization, while trade openness and FDI lower energy intensity. The study emphasizes the role of energy-efficient urban planning and sustainable industrial practices in mitigating energy intensity. For West Africa, where rapid urbanization and industrialization are underway, adopting such practices can significantly reduce energy demand and enhance overall efficiency.

Djeunankan et al. (2024) examine the role of energy poverty in industrialization and find that improved energy access propels industrial growth across African countries. They also note that human capital and income are mediating factors, while reliable and clean energy access is indispensable for industrial growth. This further underlines the need for energy access initiatives by West African policymakers to catalyze broader economic and industrial growth.

According to Appiah et al. (2021), environmental sustainability has been a key issue with which industrialization is grappling. Their analysis of energy use, industrialization, and urbanization in Sub-Saharan Africa brings forth the fact that the contribution of energy use is high in carbon emissions, while the impact of industrialization and urbanization is relatively weak with positive signs. The paper thus calls for energy conservation, technologies that reduce emissions, and strict regulatory frameworks that minimize the environmental cost of industrial growth. Such measures are vital for West Africa to achieve sustainable industrial growth while addressing climate change.

Aquilas et al. (2024) explore the interaction between renewable and nonrenewable energy with regard to implications for environmental sustainability across African countries. The findings reveal that renewable energy reduces adverse environmental effects emanating from industrialization, while nonrenewable energy has a mixed impact that may result in unsustainability in the long term. The study calls for prioritizing renewable energy investments as a strategy toward sustaining industrial growth without compromising environmental resilience-a strategy in line with West Africa's energy and sustainability challenges.

Chen et al. (2024) examine the moderating role of oil prices in the relationship between industrialization and carbon emissions. Their analysis reveals that while industrialization increases emissions, oil price fluctuations and renewable energy adoption mitigate this impact. These findings suggest that encouraging green industries and expanding renewable energy infrastructure can reduce emissions and promote sustainable industrialization. This is particularly relevant for West Africa, where industrialization efforts must be balanced with environmental considerations.

Wang et al. (2024) further investigate the impact of trade openness on carbon emissions, finding that industrial and urban growth increases emissions, while trade openness amplifies this phenomenon. The study identifies that climate-centered regulations and policies are needed to achieve sustainable industrialization. Integration of trade policies with environmental objectives will be critical for West Africa in promoting industrial growth that is compatible with sustainable development.

Technological advancements hold transformative potential for improving energy efficiency in industrial sectors. Ibekwe et al. (2024) highlight the role of innovations such as smart manufacturing and waste heat recovery in reducing energy consumption and emissions while increasing productivity. However, barriers like insufficient incentives and weak collaboration frameworks persist. Strengthening partnerships and fostering regulatory environments to support technological adoption will drive sustainable industrial practices in West Africa.

Safarzadeh et al. (2020) further discuss the global outlook on industrial energy efficiency through reviewing programs and policy instruments in countries such as China, the United States, and Sweden. It indicates that market-based measures, including subsidy programs and energy price reform, have contributed to decreasing energy consumption; however, rebound effects exist, requiring restrictive policies, which raise the effectiveness of energy efficiency programs. These global experiences can serve as useful lessons that West African policymakers might draw on to develop interventions tailored to regional energy-industrial dynamics.

Guo and Yuan (2020) add more value to energy efficiency by analyzing the effects of environmental regulations on China's industrial sector. Their findings indicate that market-based regulations are more effective than command-and-control approaches in improving energy efficiency. This, therefore, brings into perspective a leeway for regulatory reforms in West Africa, where the stimulation of energy efficiency in industry is essential for sustainable growth.

Zakari et al. (2022) discuss how sustainable economic growth, financial development, and green innovation have influenced energy efficiency in Asian and Pacific countries. Their findings indicate that harmonization of economic policies with sustainability enhances energy efficiency. In the same way, Zou (2022) examines the causality between energy consumption and industrial sectors in China and calls for energy-saving measures to lower environmental costs while supporting industrial growth. These studies bring valuable lessons for West Africa on how energy efficiency should be incorporated into industrial strategies.

Ghobakhloo and Fathi (2021) also present the role of digital transformation in energy sustainability by discussing the potential of Industry 4.0 technologies to transform energy production and distribution. Their findings indicate that policies supporting digital innovation enhance energy efficiency and industrial competitiveness. In this vein, leveraging digital transformation becomes an opportunity for West Africa to respond to energy challenges while pushing forward with industrial growth.

Sahoo and Sethi (2020) examine the relationships among energy consumption, industrialization, urbanization, and financial development in the Indian context, drawing parallels from West Africa. According to their results, it was observed that industrialization and urbanization raise the demand for energy, while financial development reduces it. Energy-efficient technologies and public infrastructure development are suggested to tackle the demand for energy at large. These recommendations apply directly to West Africa, given its industrial and urban growth, which is in dire need of sustainable energy strategies.

This wide-ranging literature underlines the complex interlinkages between energy policies, industrialization, and sustainability. The findings underline the imperative of balanced energy strategies that give primacy to efficiency, innovation, and environmental resilience. For West Africa, these insights translate into actionable policy recommendations that integrate renewable energy investments, technological advancements, and regulatory reforms to unlock the region's industrial potential while safeguarding its environmental and social assets.

3. METHODOLOGY

3.1. Data and Scope

This study, therefore, attempts to investigate the relationship between energy efficiency policy and industrial growth in West Africa within the period 2000-2023. The 16 member states of ECOWAS[1] have been focused on because of their shared developmental aspirations, energy challenges, and poor industrial performance. The selected countries and periods allow a proper evaluation of how regional and global energy policies have affected industrial performance, ensuring data availability and minimizing issues related to missing or unbalanced datasets. Consequently, Table 1 presents the variables employed for this paper.

1 Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo

These variables (Table 1) were selected from some reputable databases around the world, ensuring their comparability, reliability, and validity. Moreover, they were selected based on their relevance for assessing the impact of energy efficiency on industrial performance. For instance, energy intensity and renewable energy consumption provide direct insight into policy-driven efficiency improvements, while industrial output is a reliable measure of economic progress within the industrial sector. This study encompasses these dimensions in its analysis of how energy efficiency policies unlock West Africas industrial growth potential.

3.2. Theoretical Model

The theoretical basis of this study is based on the endogenous growth theory, especially regarding the emphasis it lays on technological innovation, human capital, and resource efficiency for sustained economic growth. This framework is quite relevant to industrial growth as it integrates the role of energy efficiency and policy interventions. The theory, developed by Romer (1990) and further advanced by Lucas (1988), postulates that growth is usually determined by endogenous factors in the system rather than exogenous shocks.

At the core of this framework is the Cobb-Douglas production function, modified to include energy inputs and policy effects. The classical function $Y = AK^{\alpha} L^{\beta}$, where Y is output, A is technology, K is capital, L is labor, and α and β are output elasticities, is extended to incorporate energy inputs (E) and efficiency-enhancing policies (P). The extended function becomes:

$$Y = AK^{\alpha} L^{\beta} E^{\gamma} P^{\delta} \quad (1)$$

Where γ represents the elasticity of energy input and δ indicates the impact of energy efficiency policies. Since the study is based on the premise that policy interventions significantly moderate the relationship between energy use and industrial output, P has been incorporated. Building on this, the energy-augmented Solow model suggests that improvements in energy efficiency reduce the effective cost of production and raise output. The modified growth equation can be expressed as:

$$\frac{\hat{Y}}{Y} = sA - \left(\delta + n + g\right) + \theta P \quad (2)$$

where s is the savings rate, δ is the depreciation rate, n is population growth, g is technological growth, and θP represents the efficiency-enhancing effects of policy P. This modification explicitly links energy efficiency to long-term industrial growth.

Consequently, the empirical functional model derived from the augmented framework, which emphasizes the integration of energy efficiency variables into the industrial growth model, is represented as:

$$IG_{it} = f(EEF, X, Z)_{it} \quad (3)$$

Where:

Industrial growth: $IG_{it} = f(INDS, MANS, PROD)_{it}$

Energy efficiency: $EEF_{it} = f(EINT, CINT, REN, EINF)_{it}$

Moderating variables: $X_{it} = f(GOVQ, URBN)_{it}$

Control variables: $Z_{it} = f(EUI, ICT, NARR, INFL, EXHR)_{it}$

Table 1: Variable description, definition, measurement, and source

Variable	Description	Definition	Measurement	Sign	Source
Dependent variables: Industrial growth					
INDS	Industry share	Share of industry (including construction) in GDP	Industry value added as % of GDP	Dependent	World Bank
MANS	Manufacturing share	Share of manufacturing value added in GDP	Manufacturing value added as % of GDP	Dependent	World Bank
PROD	Productive capacity index	Composite index measuring productive capacity	Indexed score based on productive resources	Dependent	UNCTAD
Independent variables: Energy efficiency policy					
EINT	Energy intensity	Efficiency of energy usage in economic production	MJ per $2017 PPP GDP/SFA	Negative	World Bank
CINT	Carbon intensity	Emissions associated with GDP	Kg CO2e per constant 2015 US$ of GDP/SFA	Negative	World Bank
REN	Renewable energy share	Proportion of renewable energy in total energy consumption	Renewable energy as % of total final energy consumption/SFA	Positive	World Bank
EINF	Energy infrastructure	Capacity of installed electric power plants	Total net installed capacity (10000/MW)/SFA	Positive	UNSD
Moderating variables					
GOVQ	Governance quality	Effectiveness of governance in policy implementation	Estimate from World Bank Governance Index	Positive	World Bank
URBN	Urbanization development	Proportion of population living in urban areas	Urban population as % of total population	Positive	World Bank
Control variables					
EUI	Economic uncertainty index	Weighted index capturing economic uncertainty	Moving average of the World Uncertainty Index	Negative	EIU (Ahir et al., 2022) AQ3
ICT	Technology adoption	Access to internet technology	Percentage of individuals using the internet	Positive	ITU
NARR	Natural resources	Dependence on natural resource rents	Total natural resource rents as % of GDP	Negative	World Bank
INFL	Inflation rate	Changes in consumer price levels	Annual % change in the consumer price index	Negative	World Bank
EXHR	Exchange rate	Value of local currency relative to the US Dollar	Official exchange rate (local currency/$ US)	Negative	World Bank

Source: Authors' compilations[2]

To address potential moderations, the study introduces interaction terms between energy efficiency policies and governance quality, as well as urbanization, yielding the expanded mathematical model:[2]

$$IG_{it} = \beta_0 + \beta_1 EEF_{it} + \beta_2 X_{it} + \beta_3 Z_{it} + \beta_i (EEF*Z)_{it} + \varepsilon_{it} \quad (4)$$

Equation (4)[3] is consistent with a priori expectations that improved energy efficiency—like lower energy intensity and higher renewable energy consumption—and positive moderating factors such as better governance and urban development to provide support to industrial growth. In light of the theoretical foundation, the model explicitly considers the role of energy efficiency policy as an important determinant for industrial growth while controlling for certain moderating effects.

3.3. Estimation Method

This study uses advanced econometric estimation techniques to rigorously estimate the relationship between energy efficiency policy and industrial growth. First, the stochastic frontier model is applied to extract energy efficiency-related variables, while the random effect model acts as the baseline technique selected by the Hausman & Taylor (1981) test in analyzing the effects of these energy efficiency policies on industrial growth. However, given that T < 25 and N < 25, the first-generation unit root tests, including Levin-Lin-Chu and Im-Pesaran-Shin, were performed to investigate the stationarity of the variables under consideration. These initial steps ensure that the dataset and model specifications are appropriate for the objectives of the study, thus addressing major econometric challenges like spurious regressions and dependence structures.

The stochastic frontier model, via the technical fixed effect (TFE) has been used to quantify the energy efficiency measures, with particular emphasis on variables like energy intensity, carbon intensity, renewable energy consumption, and energy infrastructure. This model is well suited to disentangle efficiency from stochastic noise, allowing identification of latent variables reflecting policy effectiveness. Thus, the production frontier is defined as:

$$Y_{it} = f(EEF_{it}, \beta).exp(-u_{it} + v_{it}) \quad (5)$$

where Y_{it} denotes the observed energy output or an energy efficiency index, EEF_{it} represents the vector of inputs such as energy intensity, carbon intensity, renewable energy consumption, and energy infrastructure, β represents the vector of coefficients, v_{it} is random noise, and u_{it} captures inefficiency. The inefficient

2 UNCTAD: United Nations Conference on Trade and Development, EIU: Economic Intelligence Unit, UNSD: United Nations Statistics Division, ITU: International Telecommunications Union, and WGI: World Bank Governance Indicator. Furthermore, SFA represents the Stochastic Frontier Analysis used in extracting efficiency variables.

3 Refer to Table 1 for all the variable descriptions, definitions, and their sources.

term is extracted and transformed into energy efficiency indicators. Energy intensity, for example, can be calculated as an independent variable in this study through the inverse of the efficiency scores; the energy use becomes nuanced towards output. These are further included in the baseline model to undertake the analysis.

The baseline estimation technique applied in this study is the random effects model, which is preferred after conducting a robust Hausman & Taylor (1981) specification test to choose between the fixed effects and random effects models. The random effects model assumes that unobserved heterogeneity (μ_i) across cross-sectional units is uncorrelated with the explanatory variables (X_{it}), and the efficient estimation can be achieved through the use of both within-and between-entity variations (Westerlund et al., 2016). The random effects specification is given by:

$$Y_{it} = \alpha + X_{it}\beta + \mu_i + \varepsilon_{it} \quad (6)$$

Where Y_{it} denotes the dependent variable, X_{it} represents a vector of covariates, β is the coefficient vector, $\mu_i \sim N(0,\sigma_\mu^2)$ is the random entity-specific effect, and $\varepsilon_i \sim N(0,\sigma_\varepsilon^2)$ is the idiosyncratic error term. The model combines these components to estimate population-level effects while accounting for individual heterogeneity.

To validate the choice of the random effects model, the Hausman test compares FE and RE specifications under the null hypothesis that H_0:Cov(μ_i, X_{it}) = 0. The test statistic is computed as:

$$\chi^2 = \left(\hat{\beta}_{FE} - \hat{\beta}_{RE}\right)' \left[Var\left(\hat{\beta}_{FE}\right) - Var\left(\hat{\beta}_{RE}\right)\right]^{-1} \left(\hat{\beta}_{FE} - \hat{\beta}_{RE}\right) \quad (7)$$

This follows a Chi-square distribution with degrees of freedom equal to the number of regressors. A non-significant result supports the random effects model due to its efficiency and consistency under the null hypothesis.

Considering these, the Hausman test statistic χ^2 with its P-value above the level of significance of $\alpha > 0.05$ supports the choice for the random effect model in this study. This procedure is theoretically sound and is appropriate for dealing with issues of dynamic heterogeneity that may arise among West African countries, ensuring efficient policy appraisal in the framework of the current study.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Results

This section aims to present the empirical relationship existing between energy efficiency policies and industrial growth in West Africa, bringing forth some descriptive metrics with statistical robustness. The summary statistics from Table 2 show high variability of industrial and manufacturing contribution to GDP, while the means are 20.445% and 8.282%, respectively. The Production Capacity Index has a mean value of 27.124, reflecting fair to moderate industrial productivity. Energy intensity (5.690) and carbon emission intensity (0.312) suggest energy use inefficiencies and environmental concerns. Renewable energy consumption, averaging 62.699%, highlights the region's reliance on renewables, while energy infrastructure (mean: 0.103) remains underdeveloped. Economic uncertainty index (0.065) and governance quality (−0.773) reflect macroeconomic and institutional challenges. Technological adoption and urban development, average 11.844% and 42.483%, respectively, signaling uneven modernization. Inflation (5.685%) and exchange rate variations (2.183) indicate economic volatility. What is more, the correlation matrix (Table A1) confirms no severe multicollinearity among the explanatory variables since pairwise correlations remain below critical thresholds (|0.8|). This confirms the statistical soundness of the applied regression models.

The stochastic frontier analysis shown in Table 3 provides critical information about the determinants of technical efficiency in energy intensity, TE_Eint; carbon emission intensity, TE_Cint; renewable energy use, TE_Ren; and energy infrastructure, TE_Einf. The manufacturing share, 0.048, P = 0.022, positively influences energy efficiency in TE_Eint, indicating that a higher manufacturing share increases energy productivity, whereas production capacity, −0.237, P = 0.000, reduces efficiency on account of probable overconsumption. In the case of TE_Cint, manufacturing (0.003, P = 0.018), technological adoption (0.004, P = 0.000), and natural resource rent (0.007, 0.000) enhance carbon

Table 2: Descriptive metrics

Variable	Description	Obs	Mean	Standard Deviation	Min	Max
Inds	Industry share to GDP output	384	20.445	7.240	3.243	44.108
Mans	Manufacturing share to GDP output	384	8.282	4.773	0.000	21.587
Prod	Production capacity index	384	27.124	8.321	9.359	51.109
Eint	Energy intensity	384	5.690	3.252	0.000	16.090
Cint	Carbon emission intensity	384	0.312	0.129	0.000	0.661
Ren	Renewable energy consumption	384	62.699	25.717	0.000	94.400
Einf	Energy infrastructure	384	0.103	0.227	0.000	1.325
Eui	Economic uncertainty index	384	0.065	0.059	0.000	0.297
Govq	Quality of governance	384	−0.773	0.458	−1.806	0.341
Ict	Technological adoption	384	11.844	15.565	0.000	72.102
rbn	Urban development	384	42.483	11.513	16.186	67.982
Narr	Natural resources rent	384	9.773	7.627	0.000	49.206
Infl	Inflation rate	384	5.685	7.098	−3.503	47.643
Exhr	Official exchange rate	384	2.183	0.913	−0.264	3.981

Source: Authors' computations

efficiency, while production capacity (−0.05, P = 0.08), governance quality (−0.029, P = 0.080), urban development (−0.004, P = 0.087), and inflation (−0.002, 0.013) slightly hinder it due to possible regulatory gaps. In TE_Ren, economic uncertainty is found to impair renewable energy efficiency drastically (−15.762, P = 0.000), reflecting policy instability, while all other variables are statistically insignificant. From the TE_Einf model, all significant variables, with the exception of industry share (−0.001, P = 0.000), governance quality (−0.002, P = 0.000), and inflation (−0.001, P = 0.000), have a positive influence on energy infrastructure efficiency: Manufacturing 0.004, P = 0.000; production 0.004, P = 0.000; urban development 0.001, P = 0.000; and technological adoption 0.001, P = 0.000, suggesting technology-driven energy infrastructure development. Natural resource rents are consistently improving efficiency across models at 0.069, P = 0.000, indicating resource-driven investments. Inflation, on the other hand, negatively affects TE_Eint (−0.043, P = 0.000) and TE_Cint (−0.002, P = 0.013), therefore indicating the adverse effects of macroeconomic instability. The estimated standard deviations, σ_u and σ_v, confirm great inefficiency in energy use, while negative variances indicate systemic inefficiencies. Generally, this means that improvement in technological adoption, industrial expansion, and governance reforms can unlock the potential of West Africa's industrial production.

Table 3: Stochastic frontier result for technical efficiency

Variable	*TE_Eint*	*TE_Cint*	*TE_Ren*	*TE_Einf*
Inds	0.006	−0.001	0.044	−0.001***
	(0.731)	(0.192)	(0.924)	(0.000)
Mans	0.048**	0.003**	−0.074	0.004***
	(0.022)	(0.018)	(0.822)	(0.000)
Prod	−0.237***	−0.005**	−0.229	0.004***
	(0.000)	(0.008)	(0.966)	(0.000)
Eui	−0.030	−0.001	−15.762***	0.002***
	(0.977)	(0.984)	(0.000)	(0.000)
Govq	−0.234	−0.029*	−0.095	−0.002***
	(0.323)	(0.080)	(0.999)	(0.000)
Ict	0.030***	0.004***	−0.045	0.001***
	(0.000)	(0.000)	(0.877)	(0.000)
Urbn	−0.011	−0.004*	−0.570	0.001***
	(0.720)	(0.087)	(0.820)	(0.000)
Narr	0.069***	0.007***	−0.085	0.001***
	(0.000)	(0.000)	(0.959)	(0.000)
Infl	−0.043***	−0.002**	0.082	−0.001***
	(0.000)	(0.013)	(0.639)	(0.000)
Exhr	−0.166	0.001	1.951	0.018***
	(0.464)	(0.887)	(0.935)	(0.000)
σ_U	0.081	−6.216***	4.637***	−5.311***
	(0.621)	(0.000)	(0.000)	(0.000)
σ_V	−0.753***	−5.676***	−25.441	−34.062
	(0.000)	(0.000)	(0.988)	(0.616)
α	11.981***	0.725***	91.733*	−0.226***
	(0.000)	(0.000)	(0.081)	(0.000)
N	384	384	384	384

TE_{Eint}=Energy intensity efficiency, TE_{Cint}=Carbon emission intensity efficiency, TE_{Ren}=Renewable energy efficiency, and TE_{Einf}=Energy infrastructure efficiency. Furthermore, P-values are in parentheses - *** denotes 1% significant level, ** implies 5% significant level, and * is the 10% significant level

Energy efficiency statistics as depicted in Table 4 indicate large variations in technical efficiency across dimensions. The average technical efficiency of energy intensity is 0.507 with moderate dispersion (Standard Deviation = 0.197), indicating that energy can be considerably optimized. Carbon intensity technical efficiency averages 0.957 with minimal variability (Std. Dev. = 0.030), reflecting high carbon management efficiency. On the contrary, renewable energy efficiency, TE_{Ren}, is low and averaged 0.117 with high variability, Std. Dev. = 0.253, which indicates weak renewable adoption. Energy infrastructure efficiency, TE_{Einf}, is well-established at an average of 0.939 with Std. Dev. = 0.094, depicting certain disparities. These results underline areas for targeted energy policy reforms necessary for the increase of industrial productivity in West Africa.

The energy efficiency correlation matrix in Table 5 shows that energy intensity efficiency is strongly and positively correlated with carbon intensity efficiency (0.577), suggesting improvement in energy management that went along with reduced carbon emissions. However, renewable energy efficiency exhibited a weak association with energy intensity efficiency (0.125) and carbon intensity efficiency (−0.008); this suggests limited integration in the energy systems. Similarly, energy infrastructure efficiency provides negligible correlations with other measures of efficiency, especially for energy intensity efficiency (0.047) and −0.043 for carbon intensity efficiency, which implies that in infrastructure development, it follows a different path.

The analysis of average technical energy efficiency indices across West African countries as depicts in Table 6 reveals substantial disparities in performance. For energy intensity efficiency, Cape Verde is leading with 0.573, while Sierra Leone records the lowest, 0.403, thus showing different energy optimization capabilities. Carbon intensity efficiency is generally high, averaging 0.957, with Guinea leading at 0.965 and Benin at 0.932, indicating effective emissions control in most countries. The renewable energy efficiency is low, averaging 0.117, with Niger at the highest, 0.236, and Benin at the lowest, 0.043, indicating a very limited integration of renewable energy. Energy infrastructure efficiency is robust, averaging 0.939, with Niger ranking highest at 0.99 and Nigeria performing weakest at 0.695, indicating disparity in infrastructure.

The stationarity tests in Table 7 indicate mixed integration orders across variables. According to the Im-Pesaran-Shin test, most of the variables, including Inds, Mans, Prod, TE_Eint, TE_Cint,

Table 4: Energy efficiency statistics

Variable	Description	Obs	Mean	Standard Deviation	Min	Max
TE_Eint	Technical efficiency of energy intensity	384	0.507	0.197	0.000	0.889
TE_Cint	Technical efficiency for carbon intensity	384	0.957	0.030	0.703	0.989
TE_Ren	Technical efficiency for renewable energy	384	0.117	0.253	0.000	1.000
TE_Einf	Technical efficiency for energy infrastructure	384	0.939	0.094	0.265	1.000

Source: Authors' computations

TE_Einf, Narr, and Exhr, are integrated of order one, I(1), after differencing, while others like TE_Ren, Eui, Govq, Ict, Infl, and Urbn are stationary at levels, I(0). The Levin-Lin-Chu test largely corroborates these findings, though there is some inconsistency from TE_Ren and TE_Cint. It reveals mix confirmation of level and first-difference stationarity, hence model estimations that are compatible with both orders of integration were considered, such as random effects models, for sound estimation and policy inference.

The analysis in Table 8 shows the differential impacts of energy efficiency policy on industrial growth across three West African sectors. In the industrial sector (Inds), efficiency in energy intensity negatively influences industrial growth, with a coefficient of −2.982, significant at the 5% level, indicating that higher energy intensity reduces productivity in industry. However, efficiencies in carbon intensity and renewable energy show no significant impact on industrial output growth, while efficiency in energy infrastructure is insignificant despite its negative coefficient (−3.627). Governance quality significantly reduces industrial output at the 10% level, while natural resource rents positively influence it at the 1% level. In the manufacturing sector (Mans), energy infrastructure significantly reduces manufacturing growth with a coefficient of −7.802, signaling infrastructural inefficiencies. Also, the use of ICT negatively influences manufacturing output growth at the 10% level, while other variables do not show any significant effect on manufacturing output. In the case of productivity sectors (Prod), energy infrastructure again exerts a significant negative impact (−7.202, $P < 0.01$), reflecting persistent infrastructure bottlenecks. Governance quality and urbanization show strong positive effects of 1.913 and 0.053, respectively,

Table 5: Energy efficiency correlation matrix

Variable	TE_Eint	TE_Cint	TE_Ren	TE_Einf
TE_Eint	1.000			
TE_Cint	0.577	1.000		
TE_Ren	0.125	−0.008	1.000	
TE_Einf	0.047	−0.043	−0.002	1.000

Source: Authors' computations

Table 6: Average technical energy efficiency index in West Africa

ID	Country	TE_Eint		TE_Cint		TE_Ren		TE_Einf	
		Value	Rank	Value	Rank	Value	Rank	Value	Rank
1	Benin	0.470	14	0.932	16	0.043	16	0.98	3
2	Burkina Faso	0.482	13	0.956	12	0.147	3	0.98	2
3	Cape Verde	0.573	1	0.961	8	0.141	6	0.96	10
4	Cote d'Ivoire	0.520	7	0.964	3	0.068	12	0.97	7
5	Gambia	0.569	2	0.963	5	0.058	14	0.97	8
6	Ghana	0.540	3	0.961	7	0.057	15	0.82	15
7	Guinea	0.540	4	0.965	1	0.143	5	0.95	13
8	Guinea Bissau	0.524	6	0.962	6	0.144	4	0.98	4
9	Liberia	0.430	15	0.946	15	0.122	8	0.95	12
10	Mali	0.517	9	0.959	9	0.084	11	0.98	5
11	Mauritania	0.500	11	0.950	14	0.137	7	0.97	6
12	Niger	0.529	5	0.964	4	0.236	1	0.99	1
13	Nigeria	0.507	10	0.957	11	0.221	2	0.69	16
14	Senegal	0.518	8	0.958	10	0.091	10	0.96	9
15	Sierra Leone	0.403	16	0.964	2	0.061	13	0.95	11
16	Togo	0.485	12	0.954	13	0.121	9	0.92	14
	Average	0.507		0.957		0.117		0.939	
	Minimum	0.403		0.932		0.043		0.695	
	Maximum	0.573		0.965		0.236		0.985	

Source: Authors' computations

Table 7: Stationarity tests

Variable	Im-Pesaran-Shin			Levin-Lin-Chu		
	Level	1st Diff.	Order	Level	1st Diff.	Order
Inds	−0.910	−10.430***	I (1)	−2.118**	−10.325***	I (0)
Mans	1.333	−7.287***	I (1)	−0.960	−5.744***	I (1)
Prod	1.862	−10.434***	I (1)	−1.918**	−10.298***	I (0)
TE_Eint	−1.149	−8.851***	I (1)	0.418	−2.232***	I (1)
TE_Cint	1.645	−7.704***	I (1)	3.625	1.413	Nil
TE_Ren	−22.401***	−28.499***	I (0)	110.136	52.770	Nil
TE_Einf	−0.519	−5.599***	I (1)	−1.104	3.036	Nil
Eui	−3.577***	−14.039***	I (0)	−3.692***	−12.090***	I (0)
Govq	−12.638***	−16.969***	I (0)	−11.362***	−5.476***	I (0)
Ict	−2.818**	1.044	I (0)	−1.462**	35.514	I (0)
Urbn	−0.032	3.402	Nil	−17.066***	4.856	I (0)
Narr	1.482	−9.666***	I (1)	4.237	−7.371***	I (1)
Infl	−6.113***	−15.140***	I (0)	−3.915***	−11.965***	I (0)
Exhr	1.276	−5.204***	I (1)	1.014	−4.554***	I (1)

*** denotes 1% significant level, ** implies 5% significant level, and * is the 10% significant level both at $P < 0.01$, suggesting these factors enhance productivity. Moreover, technological adoption, or ICT, and natural resource rent are positively contributing (0.624 and 0.075, correspondingly, both at $P < 0.01$), thus underlining their transformative role in enhancing productivity.

Table 8: Effect of energy efficiency policies on industrial growth in West Africa

Variable	*Inds*	*Mans*	*Prod*
TE_Eint	−2.982**	−0.793	0.864
	(0.019)	(0.420)	(0.280)
TE_Cint	7.369	3.391	0.698
	(0.389)	(0.608)	(0.897)
TE_Ren	−1.143	0.102	−0.695
	(0.146)	(0.867)	(0.161)
TE_Einf	−3.627	−7.802**	−7.202**
	(0.286)	(0.003)	(0.001)
Govq	−1.531**	−0.208	1.913***
	(0.054)	(0.728)	(0.000)
Urbn	0.017	0.010	0.053***
	(0.381)	(0.490)	(0.000)
Eui	4.641	−2.352	4.419*
	(0.218)	(0.417)	(0.062)
Ict	0.017	−0.086*	0.624***
	(0.810)	(0.080)	(0.000)
Narr	0.108**	0.017	0.075***
	(0.004)	(0.545)	(0.001)
Infl	−0.017	0.034	−0.025
	(0.643)	(0.231)	(0.274)
Exhr	0.109	0.456	−0.202
	(0.825)	(0.218)	(0.507)
C	14.838	14.917**	6.773
	(0.140)	(0.048)	(0.274)
σ_e	3.737	2.868	2.284
ρ	0.828	0.618	0.666
rmse	3.711	2.875	2.342
N	384	384	384

P-values are in parentheses - *** denotes 1% significant level, ** implies 5% significant level, and * is the 10% significant level

Table 9 presents the results as a function of the moderating role of governance quality and urban development in the relationship between energy efficiency policies and industrial growth in West Africa. Specifically, under governance quality, energy efficiency significantly reduces manufacturing growth, with a coefficient of −7.626, while it positively influences productivity, with a coefficient of 8.893. The interaction term between efficient energy and governance quality further amplifies the positive effect on productivity by 10.061 while exacerbating the negative effect on manufacturing by −9.836. Carbon emission efficiency positively influences manufacturing growth by 33.356 but negatively affects productivity by −36.712, while the interaction between carbon emission efficiency and governance quality further strengthens such effects. The interaction coefficients of renewable energy efficiency and governance quality show that renewable energy efficiency constantly displays negative effects on industrial output and productivity but became less deleterious when governance was strong, with a −3.911 value for industrial output and −4.314 for productivity, respectively. Energy infrastructure is mainly insignificant under governance quality, even though interaction between energy infrastructure efficiency and governance quality enhances productivity to 18.453.

Urban development brings various dynamics. Energy intensity affects the growth of all sectors positively (9.630, 8.391, and 8.493, respectively) for the industrial, manufacturing, and productive sectors, though with significant interaction

Table 9: Moderating roles of governance quality and urban development on energy efficiency policies in influencing industrial growth in West Africa

Variable	Governance quality			Urban development			
	Inds	Mans	Prod	Variable	Inds	Mans	Prod
TE_Eint	−1.812	−7.626***	8.893***	TE_Eint	9.630*	8.391**	8.493**
	(0.463)	(0.000)	(0.000)		(0.066)	(0.033)	(0.010)
Govq	35.622**	−51.001***	33.218**	Urbn	0.397	−3.097***	−0.202
	(0.034)	(0.000)	(0.051)		(0.700)	(0.000)	(0.754)
TE_Eint*Govq	1.983	−9.836***	10.061***	TE_Eint*Urbn	−0.295**	−0.189**	−0.197**
	(0.468)	(0.000)	(0.000)		(0.010)	(0.029)	(0.006)
TE_Cint	−16.133	33.356***	−36.712**	TE_Cint	17.880	−135.218***	−17.481
	(0.189)	(0.000)	(0.003)		(0.725)	(0.000)	(0.582)
TE_Cint*Govq	−45.170**	51.626***	−57.459**	TE_Cint*Urbn	−0.195	2.921***	0.458
	(0.006)	(0.000)	(0.001)		(0.853)	(0.000)	(0.486)
TE_Ren	−4.151**	0.951	−4.238**	TE_Ren	−7.378**	−0.356	−5.258**
	(0.006)	(0.403)	(0.005)		(0.006)	(0.860)	(0.002)
TE_Ren*Govq	−3.911**	1.203	−4.314**	TE_Ren*Urbn	0.155**	0.000	0.119**
	(0.013)	(0.316)	(0.007)		(0.014)	(0.992)	(0.003)
TE_Einf	1.424	−4.261	6.118	TE_Einf	1.890	−25.675**	−35.680***
	(0.801)	(0.318)	(0.287)		(0.897)	(0.018)	(0.000)
TE_Einf*Govq	5.421	6.853	18.453**	TE_Einf*Urbn	0.049	0.383*	0.637**
	(0.405)	(0.163)	(0.005)		(0.869)	(0.086)	(0.001)
C	34.384**	−15.798*	52.554***	C	−3.757	159.283***	42.034
	(0.006)	(0.094)	(0.000)		(0.940)	(0.000)	(0.178)
σ_e	3.689	2.791	3.737	σ_e	3.774	2.822	2.306
P	0.689	0.539	0.721	ρ	0.796	0.732	0.816
rmse	3.723	2.825	3.779	rmse	3.728	2.804	2.327
N	384	384	384	N	384	384	384

P-values are in parentheses - *** denotes 1% significant level, ** implies 5% significant level, and * is the 10% significant level terms, governance quality shows significant negative effects: −0.295 on industrial, −0.189 on manufacturing, and −0.197 on productivity. Carbon emission efficiency positively influences the manufacturing growth of 135.218, and its interaction with governance quality yields a similar significant positive effect with manufacturing growth of 2.921. While renewable energy efficiency detracts from industrial growth by −7.378% and productivity by −5.258%, urbanization cushions the effect, as the interaction between renewable energy efficiency and urban development is 0.155 and 0.119, respectively, for both sectors. Energy infrastructure negatively influences manufacturing and productivity at −25.675% and −35.680%, respectively, but the interaction of energy infrastructure with the quality of governance positively and significantly dampens these impacts to 0.383 and 0.637, improving both sectors' outcomes.

4.2. Discussion

The analysis underscores the complex relationship between energy efficiency policies and the moderating roles of governance quality and urban development in shaping industrial growth in West Africa. Energy intensity, which measures the efficiency of energy use in production processes, negatively impacts industrial growth. This result highlights the structural inefficiencies within the industrial sector, were outdated technologies and suboptimal energy management hinder productivity. Such inefficiencies are characteristic of developing economies like those in West Africa, where industrial processes rely heavily on energy-intensive methods (Adom and Amuakwa-Mensah, 2016). Addressing this requires modernization of industrial systems and adopting energy-efficient practices, as seen in other developing regions that have successfully transitioned to more sustainable industrial growth pathways.

Governance quality plays a pivotal role in moderating the effects of energy efficiency policies. While good governance magnifies the benefits of efficient energy use for productivity, it also enhances the negative influence of inefficiencies in the use of energy on the growth of manufacturing. The dichotomy is thus instructive of the challenges that face the enforcement of policy and the institutional weaknesses pervasive across West Africa. Good governance structures are important to guarantee that policies on energy are not just well-designed but implemented and monitored in a way to achieve full benefit. Studies like Wang et al. (2024) indicate that good governance reduces the risks of energy inefficiency while unlocking potential growth opportunities in industrial sectors.

Urban development is another important moderator in the relationship between energy efficiency and industrial outcomes. Urban agglomerations, as hubs of economic activity, have the potential to provide infrastructural and institutional support to energy efficiency and industrial growth. However, the findings suggest that the benefits of urban development are unevenly spread, with limited positive effects on manufacturing but a more pronounced role in enhancing productivity. This uneven distribution reflects the fragmented nature of urban planning and the varying capacity of cities to support industrial expansion (Zakari et al., 2022). Strategic urban development integrated with industrial policy goals is central to unlocking the full potentials of urbanization in the region.

The energy infrastructure inefficiencies, as recorded, form critical bottlenecks facing West African economies. Bad energy infrastructure also has impacts on manufacturing and productivity-a sign of underinvestment that has been chronic in the sector. Where there is no credible and reliable energy system to support it, industries cannot achieve meaningful scale and quality of production toward sustainable growth. This agrees with Appiah et al. (2021), who found that one of the major deterrents to industrialization in Sub-Saharan Africa is inadequate energy infrastructure. It is, therefore, imperative that policymakers ensure investment in energy infrastructure, including renewable energy systems, to lay a strong foundation for industrial growth.

Finally, the positive effects of technological adoption and natural resource rents on productivity provide a silver lining. Technology adoption, particularly in renewable energy and ICT, offers transformative potential to leapfrog traditional industrialization barriers. Furthermore, effective management of natural resource rents can provide the capital needed to finance industrial development. These findings suggest that West African economies can achieve a sustainable industrialization trajectory by leveraging their resource wealth and investing in technology and energy efficiency measures (Prempeh, 2024).

5. CONCLUSION AND POLICY IMPLICATION

The nexus of energy efficiency policy and industrial growth has been explored in West Africa within the framework of endogenous growth theory, with emphasis on the role of technology, governance, and urban development between 2000 and 2023. Using advanced econometric techniques like the stochastic frontier model and random effect estimation, the analysis found that energy infrastructure inefficiencies, carbon emission intensity, and weak energy management significantly hinder industrial and manufacturing growth, while governance quality and urban development enhance productivity. The interaction terms of governance and urban development proved to be very important, as they increase positive impacts on productivity but also unmask policy failures in energy intensity and infrastructure. These findings underline the critical need for a balanced energy policy framework combining technological innovation, governance reforms, and urban development strategies to stimulate sustainable industrial growth across the region.

The policymakers need to focus on improving energy infrastructure with targeted investments in renewable energy and modern energy technologies in order to address the energy-related persistent challenges that the industrial growth of West Africa is beset with. Good governance institutions should be established in order to bring transparency into policy, reduce regulatory bottlenecks, and increase accountability. Moreover, integrating urban development into the industrial strategy can facilitate increased industrial productivity through economies of scale and reduce energy inefficiencies. Collaboration within ECOWAS will contribute to regional energy market integration for shared infrastructure and sustainable industrial development among its member states.

REFERENCES

Aboagye, S., Nketiah-Amponsah, E. (2016), The implication of economic growth, industrialization and urbanization on energy intensity in Sub-Saharan Africa. Journal of Applied Economics and Business Research, 6(4), 297-311.

Adom, P.K., Amuakwa-Mensah, F. (2016), What drives the energy saving role of FDI and industrialization in East Africa? Renewable and Sustainable Energy Reviews, 65, 925-942.

African Development Bank. (2024), African Economic Outlook 2024. Available from: https://www.afdb.org/sites/default/files/2024/06/06/aeo_2024_-_chapter_2.pdf

Ahir, H., Bloom, N., & Furceri, D. (2022), The world uncertainty index (No. w29763). National bureau of economic research. Available from: http://www.nber.org/papers/w29763

Appiah, M., Li, F., Korankye, B. (2021), Modeling the linkages among CO_2 emission, energy consumption, and industrialization in sub-Saharan African (SSA) countries. Environmental Science and Pollution Research, 28, 38506-38521.

Aquilas, N.A., Ngangnchi, F.H., Mbella, M.E. (2024), Industrialization and environmental sustainability in Africa: The moderating effects of renewable and non-renewable energy consumption. Heliyon, 10(4), e25681.

Chen, J., Wu, W., Nguea, S.M. (2024), Combining the effects of industrialization and oil prices on CO_2 emissions: What role do renewable energy, urbanization and financial crisis play? Sustainable Development, 5(2). DOI: https://doi.org/10.1002/sd.3264

Djeunankan, R., Tadadjeu, S., Kamguia, B. (2024), Linking energy poverty and industrialization: Empirical evidence from African countries. Energy, 292, 130374.

Ghobakhloo, M., Fathi, M. (2021), Industry 4.0 and opportunities for energy sustainability. Journal of Cleaner Production, 295, 126427.

Guo, R., Yuan, Y. (2020), Different types of environmental regulations and heterogeneous influence on energy efficiency in the industrial sector: Evidence from Chinese provincial data. Energy Policy, 145, 111747.

Hausman, J.A., Taylor, W.E. (1981), Panel data and unobservable individual effects. Econometrica: Journal of the Econometric Society, 49, 1377-1398.

Ibekwe, K.I., Umoh, A.A., Nwokediegwu, Z.Q.S., Etukudoh, E.A., Ilojianya, V.I., Adefemi, A. (2024), Energy efficiency in industrial sectors: A review of technologies and policy measures. Engineering Science and Technology Journal, 5(1), 169-184.

International Energy Agency. (2023), World Energy Outlook 2023. Available from: https://www.iea.org/reports/world-energy-outlook-2023

International Renewable Energy Agency. (2023), World Energy Transition Outlook 2023. Available from: https://www.irena.org/digital-report/world-energy-transitions-outlook-2023

Lucas, R.E. Jr. (1988), On the mechanics of economic development. Journal of Monetary Economics, 22(1), 3-42.

Pesaran, M.H. (2015), Testing weak cross-sectional dependence in large panels. Econometric Reviews, 34(6-10), 1089-1117.

Prempeh, K.B. (2024), The role of economic growth, financial development, globalization, renewable energy and industrialization in reducing environmental degradation in the economic community of West African States. Cogent Economics and Finance, 12(1), 2308675.

Romer, P.M. (1990), Endogenous technological change. Journal of Political Economy, 98(5, Part 2), S71-S102.

Safarzadeh, S., Rasti-Barzoki, M., Hejazi, S.R. (2020), A review of optimal energy policy instruments on industrial energy efficiency programs, rebound effects, and government policies. Energy Policy, 139, 111342.

Sahoo, M., Sethi, N. (2020), Impact of industrialization, urbanization, and financial development on energy consumption: Empirical evidence from India. Journal of Public Affairs, 20(3), e2089.

Wang, J., Zhang, Y., Twum, A.K., Agyemang, A.O. (2024), Realizing sustainable development goals in sub‐Saharan Africa: The role of industrialization on consumption‐based carbon emission. Sustainable Development, 32(3), 2666-2677.

Wesseh, P.K. Jr., Lin, B. (2017), Is renewable energy a model for powering Eastern African countries transition to industrialization and urbanization? Renewable and Sustainable Energy Reviews, 75, 909-917.

Westerlund, J., Hosseinkouchack, M., Solberger, M. (2016), The local power of the CADF and CIPS panel unit root tests. Econometric Reviews, 35(5), 845-870.

World Bank. (2023), Global Economic Prospects. Available from: https://www.worldbank.org/en/publication/global-economic-prospects

Zakari, A., Khan, I., Tan, D., Alvarado, R., Dagar, V. (2022), Energy efficiency and sustainable development goals (SDGs). Energy, 239, 122365.

Zou, G. (2022), The relationships between energy consumption and key industrial sector growth in China. Energy Reports, 8, 924-935.

APPENDIX

Table A1: Correlation matrix

Var	Inds	Mans	Prod	Eint	Cint	Ren	Einf	Eui	Govq	Ict	Urbn	Narr	Infl	Exhr
Inds	1.00													
Mans	0.38	1.00												
Prod	0.18	0.08	1.00											
Eint	−0.26	−0.19	−0.45	1.00										
Cint	0.10	0.22	0.38	0.15	1.00									
Ren	−0.21	−0.14	−0.68	0.77	−0.17	1.00								
Einf	0.27	0.16	0.11	0.01	−0.03	0.13	1.00							
Eui	0.13	0.06	0.01	0.03	−0.10	0.06	0.23	1.00						
Govq	0.14	0.26	0.50	−0.59	0.21	−0.55	−0.03	−0.18	1.00					
Ict	0.03	−0.01	0.61	−0.27	0.34	−0.36	0.21	0.15	0.25	1.00				
Urbn	−0.16	−0.16	0.76	−0.26	0.35	−0.53	0.14	−0.03	0.24	0.53	1.00			
Narr	0.02	−0.26	0.12	0.39	0.22	0.22	0.02	−0.07	−0.16	−0.14	0.06	1.00		
Infl	0.13	−0.06	0.02	−0.05	−0.13	−0.03	0.29	0.16	0.00	0.01	0.14	0.10	1.00	
Exhr	0.11	0.33	−0.15	0.19	0.02	0.22	−0.07	0.17	−0.16	−0.06	−0.39	−0.09	−0.34	1.00

Source: Authors' computation