Greening the Industrial Agenda: The Role of Renewable Energy Consumption in Accelerating the Growth of Kenya's Manufacturing Sector

Masibayi Peter Situma [1], Obange Nelson[2], Odhiambo Scholastica Achieng[3]

[1]PhD in Economics candidate, Department of Economics, Maseno University, Kenya

[2]Holds a PhD in Economics, A Professor of Economics, Maseno University, Kenya

[3] Holds a PhD in Economics, A Senior Lecturer in the Department Economics, Maseno University, Kenya

DOI: https://doi.org/10.51244/IJRSI.2025.1210000300

Received: 04 November 2025; Accepted: 11 November 2025; Published: 20 November 2025

ABSTRACT

This study aimed to investigate the impact of renewable energy usage on Kenya's manufacturing and industrial sectors. It emphasizes the sector's transition toward green manufacturing and industrial growth. The study made use of annual time series data for the period 1985-2023. It employed the ARDL framework, guided by the AIC criterion and the ECM to capture both short-run and long-run dynamics amongst the variables. The ARDL findings revealed that the use of renewable energy has immediate positive impacts on manufacturing output and productivity. The lagged effects emerge over multiple periods, implying the gradual integration of renewable energies into the production processes. On the other hand, non-renewable energy consumption has delayed negative effects, thus highlighting the shortcomings that come with the usage of non-renewable energies. Labour has a strong positive influence on output, whereas gross capital formation shows a long-lag positive impact. This shows the extended gestation periods of capital-intensive projects. The ECM results confirm that deviations from long-run equilibrium are corrected at a moderately fast rate of about 52% annually. The F-bounds test found the existence of a long-run association between renewable energy consumption and manufacturing and industrial output. These results emphasize the importance of renewable energy uptake, efficient capital deployment and labour utilization in driving sustainable manufacturing and industrial growth in Kenya. This study provides policymakers and industry stakeholders with empirical guidance for aligning energy policy, investment and technological adoption with Kenya's broader objectives for green industrialization. This will ensure countries not only grow economically, but also grow sustainably since renewable energies have the capability of taking care of both the current and future energy needs without fear of depletion, while also ensuring environmental sustainability. This study, therefore, highlights that renewable energy consumption significantly supports Kenya's manufacturing sector growth and recommends aligning industrial energy policy interventions with green growth and sustainability frameworks such as Vision 2030 and SDG 9 by promoting clean energy adoption, energy-efficient technologies and renewable energy integration within industrial value chains so as to enhance competitiveness and low-carbon industrial transformation.

Keywords: renewable energy consumption, manufacturing and industrial activities, greening the industrial growth

INTRODUCTION

The manufacturing and industrial sector is critical in modernization and global competitiveness and contributes approximately 17% of the global GDP. Countries such as China and South Korea have achieved accelerated sectoral growth through manufacturing and industrialization, which depend heavily on affordable and reliable energy. (World Bank, 2021).

The manufacturing and industrial sector in Kenya plays a critical role in accelerating industrial production, employment creation and economic diversification, among others. However, the sector's growth has for some time now been hindered by unreliable and costly energy supply, mainly from non-renewable sources, thereby increasing the costs of production. Given the country's rapid economic expansion and the ever-rising demand for electricity, the integration of renewable energy sources such as hydroelectric power, solar and wind has proved to be a strategic approach to ensure energy security, reduce the skyrocketing production costs and also promote environmentally sustainable manufacturing and industrial development. Despite the investments in renewables, challenges remain in effectively and efficiently translating renewable energy usage into tangible manufacturing and industrial productivity. Changes in infrastructure readiness, capital deployment and the rate of workforce and labour absorption can serve to hinder the sectoral benefits of clean and green energy. Existing literature, such as Oyeleke and Akinlo (2020) in Nigeria and Jeon (2022) across US states, has clearly shown the positive impacts of renewable energy usage on the sectoral output, yet statistics from Kenya, particularly within the manufacturing and industrial sector, remain to be limited. This study sought to bridge this empirical gap.

Kenya's manufacturing and industrial sector continues to face frequent power shortages, load-shedding, high costs of electricity from non-renewable sources and limited integration of renewable energy infrastructure. While the adoption of renewable energy is increasing, its direct contribution to manufacturing sector output, both immediately and lagged, remains to be unknown. The understanding of the sectoral impact of renewable energy usage is important for guiding investment in the country, policy formulation and technological adoption as well as for achieving Kenya's long-term industrial and clean green growth aspirations.

This study sought to examine the short-run effects of renewable energy consumption on manufacturing and industrial sector growth in Kenya and to also provide policy recommendations and interventions for enhancing manufacturing and industrial growth through renewable energy deployment and adoption.

This study sought to provide policymakers, energy investors and industrial stakeholders with evidence-based insights into the important role of renewable energy usage in promoting and accelerating the growth of the manufacturing and industrial sectors in Kenya. By putting figures on both immediate and lagged effects of renewable energy uptake, this study highlights the timing and magnitude of renewable energy interventions that are deemed in the optimization of manufacturing and industrial output. It also supports Kenya's agenda for energy transition, climate mitigation and preservation and middle-income industrialization by showing how renewable energy consumption can stabilize manufacturing and industrial output while at the same time limiting the overdependence on non-renewable energy sources.

Existing studies on energy and manufacturing and industrial growth has largely been focusing on the aggregate performance of the economy. Few studies have labored to explore the sector-specific impacts of renewable energy consumption on Kenya's manufacturing and industrial output using robust econometric techniques such as the ARDL and the ECM. This study fills this gap by providing a comprehensive analysis of both short-run and long-run effects, while incorporating lag structures and ECM dynamics, while controlling for labour and capital inputs and the non-renewable energy consumption.

LITERATURE REVIEW

Consumption of renewable energy is the use of energy generated from natural resources such as sunlight, wind, rain, geothermal and heat, which are renewable and do not suffer from the fear of depletion (Guliyev & Tatoglu, 2023). Several empirical studies exist to explain the relationship between renewable energy consumption and the corresponding growth of the manufacturing, service and agricultural sectors.

Studies that are in consonance with the growth hypothesis within the energy-economic growth framework suggest that renewable energy consumption has a significant positive effect on manufacturing output. An example is the assertion by Obange *et al.* (2013) that examined the influence of renewable energy on manufacturing growth in Kenya. The study found a bi-directional Granger causality between electricity consumption and manufacturing, observed in both short and long-run periods. Using time series data from 1970 to 2010, the study highlighted the existence of a relationship but did not delve into the magnitude or intensity of these effects. In contrast, this study employed advanced analytical methods to not only confirm the presence of such relationships but also to analyze the direction, strength and scale of the impacts and interactions Ototo and Nzai (2022) using annual time series data from 1980-2019 while exploiting the multivariate time series model and incorporating relevant time-series diagnostics, including cointegration test, to examine the short-run and long-run effects of renewable and non-renewable energy consumption on manufacturing sector performance in Kenya, established a feedback positive interaction existing between the usage of renewable energy alternatives and the performance of the manufacturing and industrial sector. However, the study advocates for the exploitation of energy-efficient infrastructure to check energy losses within the value chain. The study, apart from exploiting a less robust analysis technique, did little to establish the magnitudes of the associations. The ARDL methodology that this study exploited was capable of establishing both short-run and long-run magnitudes of the suspected associations.

According to Hoang *et al.* (2020), a study that sought to examine the relationship between renewable energy usage and industrial performance in the United States of America monthly over the 1981-2018 period by employing the Granger-causality test, found that a positive and significant co-movement exists between the usage of renewable energy and industrial performance. The study adopted the usage of fossil-based energy as well as crude oil prices as control variables. *Hoang et al.* (2020), however, did little to establish the magnitudes of the associations. The United States is in a diverse stage of economic advancement and therefore, the study cannot be replicated in Kenya. This body of knowledge sought to clear the ambiguity regarding the sign, direction and magnitudes of the interactions.

Kasae (2014), in its effort to establish energy efficiency in Kenya's manufacturing sector using baseline and current data in Kenya, established that efficiency in the energy value chain possessed a significant influence on manufacturing productivity and growth. The study focused on a sample of 70 manufacturing firms from a total of 735 listed by the Kenya Association of Manufacturers, with a particular emphasis on firms that had previously conducted energy audits. The study utilized regression analysis. This implies that energy consumption led to increased manufacturing growth. However, the study treated energy consumption as an aggregate. According to Kasae (2014), the study is also not definitive as findings from other companies were not in consonance with these results. The study also notes that this finding was inconclusive, as certain companies exhibited weak correlation coefficients for the variables at both baseline and current levels, indicating the necessity for further investigation. This study helped clear the ambiguity, besides also incorporating other sectors of the economy, not just the manufacturing sector.

Onuonga *et al.* (2008), in its quest to determine the existing relationship between the two key parameters, did an econometric assessment to determine the kind of association existing between manufacturing output and energy use in Kenya. The study adopted a trans-logarithmic function to assess total factor specifications involving fuel substitutions. It utilized data from 1970 to 2005. The findings indicated that manufacturing growth was linked to an increased use of various inputs, including different types of energy. However, Onuonga *et al.* (2008) failed to accurately single out the specific effect on the manufacturing sector given the fact that manufacturing activities were being influenced by many other factors in the model. This study not only singled out the specific impacts of renewable energy constructs on the manufacturing sector but also sought to clear the same ambiguity about the agricultural and service sectors of the economy.

Forkuoh and Li (2015) sought to unravel the nexus between electricity insecurity and the growth of small manufacturing and industrial plants in Ghana. It sought to determine the impact attributable to power outages on the effectiveness of the manufacturing plants. It was found that there was a positive relationship between energy efficiency and usage and the growth of the firms. The study also established that the use of backup generators during power outages led to increased costs of production, thereby suppressing production. By the use of mixed methods of study and SPSS output, the study, that solely focused on the Asafo market established that power availability and reliability affected the performance of the manufacturing plants. The study, however, is from an economy with different natural and energy resource endowments compared to Kenya. This study was specific to Kenya and economies with similar resource endowments, economic conditions and political climate as Kenya.

Grainger and Zhang (2017) sought to evaluate the influence of electricity shortages on the operational performance of manufacturing firms in Pakistan. The study employed a cross-sectional regression analysis using firm-level data, where the natural logarithms of firm revenues and value-added were regressed on indices measuring the duration and frequency of electricity shortages, while controlling for labour costs, raw material costs, fixed assets, total electricity costs and sector fixed effects to estimate the impact of power outages on firm productivity. It considered the performance of 4,500 firms for the period 2010-2011. Electricity shortages were measured as the number of hours that the power blackouts lasted. The study established that a 10% rise in the number of outage hours led to a 0.14% decline in firms' revenues and a 0.36% decline in value-added. This implied that it positively influenced manufacturing output and growth. However, the study ignored the intensity of the associations. This study aided in not only determining the presence but will also help determine the sign, direction and intensities of the associations.

Bowden and Payne (2010) conducted a study focusing on the United States, utilizing time-series data from 1949 to 2006. It made use of the Toda-Yamamoto approach to explore the relationship between renewable energy consumption and economic growth. Their long-run causality tests indicated no Granger causality between commercial and industrial renewable energy consumption and real GDP. However, bidirectional Granger causality was found between commercial and residential non-renewable energy consumption and real GDP. Additionally, the results showed unidirectional causality from residential renewable energy consumption and industrial non-renewable energy consumption to real GDP. A key limitation of this study is its exclusive focus on the United States, which may restrict the applicability of the findings to other regions with differing energy frameworks. This study sought to bridge this geographical barrier.

While seeking to establish the nexus between renewable energy use and export performance of manufacturing firms in India between 2011 and 2021, Das and Mahalik (2023), using both the system dynamic and panel estimation and fixed effects with Driscoll and Kraay standard errors so as to control for cross-sectional independence, established that a positive impact between renewable energy consumption and manufacturing productivity in India. This study, despite attempting to establish and aggregate the renewable energy consumption effects at the sectoral level, is from an economy at a different economic stage compared to Kenya, hence this study had to be conducted.

Zhang and Ma (2023), in China, while seeking to establish the impact of energy consumption structure transformation on total firms' factor productivity using data for the period 2010-2019, found that promotion of the use of this energy source boosted growth of the sector. The study, though, is from a more advanced stage of economic development.

RESEARCH METHODOLOGY

For the manufacturing sector growth, this study adopted the correlational research design and employed the pragmatist research philosophy to use the Solow Swan growth model, the Cobb-Douglas framework to unearth the relationship between renewable energy consumption and manufacturing sector growth in Kenya. Nonrenewable energy consumption, gross capital formation and labour, L, were incorporated as control variables.

The basic Cobb-Douglas function was linearized by logging and therefore the results were interpreted as percentages and elasticities.

$$Ln(MAN_t) = LnA + \alpha_1 Ln(REC_t) + \alpha_2 Ln(NREC_t) + \alpha_3 Ln(K_t) + \alpha_4 Ln(L_t) + \beta_1 Ln(REC_{t-1}) + \beta_2 Ln(NREC_{t-1}) + \beta_3 Ln(K_{t-1}) + \beta_4 Ln(L_{t-1}) + \varepsilon_t \ldots\ldots \text{(3.1)}$$

Where $LnMAN_t$ is the log of manufacturing output, at time t, $Ln(REC_t)$ is the logged renewable energy consumption at time t, $Ln(NREC_t)$ is logged non-renewable energy consumption at time t, $Ln(K_t)$ is logged capital at time t, $Ln(L_t)$ is logged labour at time t, $Ln(REC_{t-1})$ is lagged renewable energy

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue X October 2025

consumption, $Ln(NREC_{t-1})$ is lagged non-renewable energy consumption, $Ln(K_{t-1})$ is lagged capital, $Ln(L_{t-1})$ is lagged labour ε_t is the error term while LnA is logged total factor productivity.

RESULTS AND DISCUSSION

Descriptive Statistics

Table 4:1 -Descriptive Statistics

	MAN (”000000”)	REC	NREC (“000000”)	L (“{000000”)	GCF (“OF_GDP”) (K)
Mean	486735.3	19791.70	0.137666	13.54270	20.09076
Median	424905.7	16115.00	0.117500	12.73076	19.73131
Maximum	848461.0	46600.00	0.242000	23.18485	25.44904
Minimum	227142.4	6000.000	0.072000	5.341202	15.00382
Std. Dev.	178639.4	10732.72	0.057575	5.556273	2.956138
Skewness	0.455448	0.900081	0.577631(	0.205444	0.087421
Kurtosis	2.110278	2.769333	1.841721	1.682008	2.157324
Jarque-Bera	2.972451	6.038611	4.906443	3.494208	1.357899
Probability	0.226225	0.048835	0.086016	0.174278	0.507149
Sum	21416353	870835.0	6.057312	595.8787	883.9934
Sum Sq. Dev.	1.37E+12	4.95E+09	0.142540	1327.503	375.7664
Observations	44	44	44	44	44

(Source: Author,2025)

Table 4:1 presents the descriptive statistics for the variables used in the study. It covers manufacturing outputs, renewable energy indicators, gross capital formation and labour. Each variable is interpreted based on its statistical characteristics and put in the right Kenyan context.

The average output of the manufacturing sector, measured in constant Kenyan shillings, stood at Kshs 487 billion over the study period. The sector exhibited a standard deviation of Kshs 179 billion, with values ranging between Kshs 227 billion and Kshs 848 billion. This substantial spread reflects the sector's fluctuating performance, likely influenced by industrial policy changes, access to electricity, global economic shifts and internal inefficiencies. The moderate right-skewness value of 0.455 and near-normal kurtosis value of 2.11 support the conclusion that manufacturing output has generally trended upward with occasional sharp increases. The J-B probability of 0.226 confirms the data’s

normality. These trends make sense since Kenya’s manufacturing growth has been uneven, shaped by policy reforms, energy costs and changing global demand. The overall upward trajectory reflects gradual industrial recovery and expanding domestic production capacity.

Renewable energy consumption recorded an average of 19791.70 kilowatt-hours, with a standard deviation of 10732.72. The consumption ranged from 6000- 46600 kilowatt-hours, reflecting the country’s gradual transition to green energy. The right-skewness of 0.900 and moderate kurtosis of 2.77 imply a growth pattern where most of the observations are concentrated in earlier, lower-consumption years, with sharp increases in later periods. The J-B probability of 0.048 confirms the distribution is marginally non-normal, supporting the choice to log transform this variable in regression analyses. This trend is economically consistent with Kenya’s growing investment in renewable energy projects, particularly geothermal and hydropower, which have steadily expanded capacity and boosted consumption as part of the national shift toward sustainable energy use.

Non-renewable energy consumption showed a higher average of 137666.2 kilowatt-hours and a standard deviation of 57575.04, with values ranging from 72000-242000. This steady growth corresponds with rising transport and industrial demands for non-renewable energies. The right-skewed distribution of 0.578 and mild departure from normality, with a J-B probability of 0.086, indicate a consistent upward trend punctuated by years of accelerated consumption. This pattern is expected as Kenya's transport and manufacturing sectors still heavily depend on fossil fuels, leading to sustained growth in non-renewable energy use despite ongoing efforts to expand cleaner alternatives.

Labour showed a mean of 13542697 with a standard deviation of 5556273. The population grew from 5341202 to 23184849, nearly quadrupling over the study period. The low skewness of 0.205 and normal distribution, as indicated by a J-B probability of 0.174, reflects steady demographic growth, a crucial determinant of labour supply in the economy. This pattern can be explained by the fact that Kenya's steady population growth has continuously expanded the labour force, providing a vital foundation for sectoral productivity and domestic market development.

Gross capital formation, expressed as a percentage of GDP, averaged 20.09076%, with a standard deviation of 2.956138%. The values ranged between 15.00382% -25.44904%, indicating sustained investment efforts. The very low skewness value of 0.087 and strong normality, with a J-B probability of 0.507, suggest a stable macroeconomic environment that is conducive to infrastructure development and industrial growth. This outcome can be justified by the fact that consistent gross capital formation reflects Kenya's ongoing commitment to infrastructure expansion and industrial investment, which underpin long-term growth and structural transformation.

The descriptive statistics align with Kenya's historical trajectory of structural transformation, increasing investment in renewable energy, demographic expansion and shifting sectoral contributions to GDP. The presence of skewness and kurtosis in most energy variables confirms the appropriateness of log transformations to normalize the data for sound econometric modeling. This overall pattern is economically sound as it captures Kenya's gradual evolution toward a more diversified and energy-driven economy, where renewable investments, population growth and sectoral shifts collectively shape the country's development path.

Stationarity Test Results: The Augmented Dickey-Fuller (ADF)

Table 4:2-ADF Results

Null hypothesis: Variable has a unit root Lag length: Automatic based on AIC, maximum lags of 10

	ADF		
	Level	First Difference	CONCLUSION
Variable	Trend & Intercept	Trend & Intercept	
MAN	-0.478092 (0.9809)	-5.886987 (0.0001)	I (1)
REC	-2.148084 (0.5053)	-5.148163 (0.0008)	I (1)
NREC	-2.591905 (0.2858)	-6.793060 (0.0000)	I (1)
L	-3.558792 (0.0494)	-2.925557 (0.1665)	I (0)
GCF____OF_GDP	-2.754643 (0.2212)	-5.703648 (0.0002)	I (1)

(Source: Author, 2025)

Table 4.2 shows the results of the ADF stationarity test. In order to ensure the validity of time series regression

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue X October 2025

analysis, particularly in ARDL modelling, it is important to test the stationarity properties of the variables under study. The ADF test was exploited to examine whether each variable contains a unit root, implying nonstationarity or whether it is stationary either at level or if it becomes stationary after first differencing. The test was conducted using the trend and intercept specification, with lag length automatically selected based on the AIC and a maximum lag of 10.

The results reveal that the dependent variable, that is, manufacturing output is non-stationary at level but become stationary after first differencing, thus integrated of order one. The same trend is observed for the energy variables: renewable energy consumption and non-renewable energy consumption, all of which are stationary at first difference and therefore also classified as I (1). In contrast, labour is found to be stationary at level, implying it is integrated of order zero. This means labour does not require differencing to achieve stationarity. Gross capital formation is both non-stationary at level but become stationary after first differencing, confirming that they are also I(1) variables.

The combination of variables with mixed orders of integration, that is, I(0) and I(1), satisfies the fundamental requirement for using the ARDL bounds testing approach, which allows for such a mix as long as none of the variables is integrated of order two, I(2). Since none of the variables is I(2), the dataset is appropriate for ARDL modelling and further cointegration analysis can proceed confidently using the bounds testing procedure.

Lag Length Determination

The ARDL model automatically selected the lag lengths using the Akaike Information Criterion which is known in helping strike a good balance between having a well-fitting model and keeping it simple.

ARDL Analysis.

Table 4:3-Influence of renewable energy consumption on the growth of the manufacturing sector in Kenya, ARDL Results

Dependent Variable: MAN				
Method: ARDL				
Date: 07/08/25 Time: 18:14				
Sample (adjusted): 1985 2023				
Included observations: 39 after adjustments				
Maximum dependent lags: 1 (Automatic selection)				
Model selection method: Akaike info criterion (AIC)				
Dynamic regressors (5 lags, automatic): REC NREC L GCF				
Fixed regressors: C				
Number of models evalulated: 1296				
Selected Model: ARDL(1, 4, 1, 0, 5)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
MAN(-1)	0.477181	0.122378	3.899221	0.0007
REC	0.071733	0.022235	3.226129	0.0037
REC(-1)	0.018555	0.022932	0.809136	0.4267
REC(-2)	0.023068	0.025104	0.918899	0.3677
REC(-3)	0.044265	0.026708	1.657385	0.1110
REC(-4)	0.063231	0.025846	2.446420	0.0225
NREC	-0.038739	0.063556	-0.609526	0.5482
NREC(-1)	-0.113673	0.054764	-2.075683	0.0493
L	0.353834	0.097750	3.619785	0.0014
GCF	0.044694	0.033286	1.342713	0.1925

GCF(-1)	0.031500	0.038064	0.827551	0.4164
GCF(-2)	0.026983	0.037754	0.714721	0.4820
GCF(-3)	0.011272	0.037699	0.298990	0.7676
GCF(-4)	-0.043225	0.035015	-1.234466	0.2295
GCF(-5)	0.074039	0.035920	2.061231	0.0508
C	7.482671	1.826004	4.097839	0.0004
R-squared	0.998049	Mean dependent var		26.92435
Adjusted R-squared	0.996777	S.D. dependent var		0.316000
S.E. of regression	0.017940	Akaike info criterion		-4.911122
Sum squared resid	0.007402	Schwarz criterion		-4.228635
Log likelihood	111.7669	Hannan-Quinn criter.		-4.666251
F-statistic	784.4624	Durbin-Watson stat		2.358324
Prob(F-statistic)	0.000000			
*Note: p-values and any subsequent tests do not account for model selection.				

(Source: Author, 2025)

The ARDL model in Table 4:3 for the manufacturing sector was estimated using 39 adjusted observations from 1985 to 2023, guided by the AIC Criterion which selected the optimal lag structure as ARDL (1, 4, 1, 0, 5). This model includes one lag of manufacturing output, four lags of renewable energy consumption, one lag of nonrenewable consumption, no lag of labour and five lags of gross capital formation.

The lag of manufacturing output, MAN(-1), has a coefficient of 0.477181, a standard error of 0.122378, a tstatistic of 3.899221 and a p-value of 0.0007. This result is statistically significant at the 1% level. It implies that a 1% increase in manufacturing output in the previous period leads to a 0.477% increase in the current period, suggesting strong inertia or momentum in the sector. The positive and significant influence of past output reflects stable production cycles, possibly due to continuous industrial processes, capital stock persistence and learning effects in Kenya's manufacturing firms.

Renewable energy consumption has five lags in the model. The contemporaneous value of REC has a coefficient of 0.071733, a standard error of 0.022235, a t-statistic of 3.226129 and a p-value of 0.0037. This coefficient is statistically significant at the 1% level and indicates that a 1% increase in renewable energy consumption in the current year leads to a 0.071% increase in manufacturing output. This confirms that renewable energy sources such as hydropower, solar and biomass provide an effective, reliable energy input for industrial processes in the short term.

The first lag, REC (-1), has a coefficient of 0.018555, a standard error of 0.022932, a t-statistic of 0.809136 and a p-value of 0.4267. This is statistically insignificant, meaning that the immediate past year's renewable energy consumption does not significantly influence current manufacturing output. Similarly, REC (-2) has a coefficient of 0.023068, a t-statistic of 0.918899 and a p-value of 0.3677, which is also insignificant. The third lag, REC (3), has a coefficient of 0.044265, a t-statistic of 1.657385 and a p-value of 0.1110, which remains statistically insignificant at the 10% level. However, REC (-4), the fourth lag of renewable energy consumption, has a coefficient of 0.063231, a standard error of 0.025846, a t-statistic of 2.446420 and a p-value of 0.0225. This is statistically significant at the 5% level, indicating that a 1% increase in renewable energy consumption four years ago increases current manufacturing output by 0.063%. This lagged effect implies that some forms of renewable infrastructure or industrial adaptation to clean energy require time to mature and integrate effectively into production.

Non-renewable energy consumption also appears in two lags. The contemporaneous value has a coefficient of 0.038739, a standard error of 0.063556, a t-statistic of -0.609526 and a p-value of 0.5482, indicating no statistically significant influence. However, the lagged value, NREC(-1), has a coefficient of -0.113673, standard error of 0.054764, a t-statistic of -2.075683 and a p-value of 0.0493. This is statistically significant at the 5%

level and suggests that a 1% increase in non-renewable energy consumption in the previous year reduces current manufacturing output by 0.113%. This negative impact may reflect inefficiencies or environmental costs associated with fossil fuels, including frequent power interruptions, maintenance downtime or emissions-related regulatory pressure. It also supports the shift toward cleaner energy for industrial use in Kenya.

Labour enters the model without lags and has a coefficient of 0.353834, a standard error of 0.097750, a t-statistic of 3.619785 and a p-value of 0.0014. This is statistically significant at the 1% level and indicates that a 1% increase in labour input leads to a 0.353% increase in manufacturing output. The result affirms the labourintensive nature of Kenyan manufacturing and industrial activities, particularly in small and medium enterprises where manual operations still dominate. It also indicates high responsiveness of output to workforce expansion in the short to medium term.

Gross capital formation appears through six terms. The contemporaneous effect has a coefficient of 0.044694, a standard error of 0.033286, a t-statistic of 1.342713 and a p-value of 0.1925, which is statistically insignificant. The first four lags, GCF (-1) to GCF (-4), are all statistically insignificant with respective coefficients of 0.031500, 0.026983, 0.011272 and -0.043225 and corresponding p-values above 0.2. However, the fifth lag, GCF (-5), is statistically significant at the 5% level, with a coefficient of 0.074039, a standard error of 0.035920, a t-statistic of 2.061231 and a p-value of 0.0508. This indicates that a 1% increase in gross capital formation five years ago leads to a 0.074% increase in manufacturing output today. This long gestation lag suggests that capital projects such as plant expansion; machinery investment or infrastructure upgrades may take years to fully impact industrial sector growth.

The constant term is 7.482671, with standard error of 1.826004, a t-statistic of 4.097839 and a p-value of 0.0004, which is statistically significant. It represents the base level of manufacturing output when all other variables are at neutral levels.

The model diagnostic statistics confirm strong performance. The R-squared is 0.998049, indicating that 99.80% of the variation in manufacturing output is explained by the model. The adjusted R-squared is 0.996777. The Fstatistic is 784.4624 with a p-value of 0.000000, confirming joint significance. The D-W statistic is 2.358324, indicating no autocorrelation. The standard error of regression is 0.017940, suggesting very low residual error.

The ARDL results confirm that renewable energy consumption has both immediate and lagged positive effects on manufacturing output. Labour also contributes strongly, while non-renewable energy exerts a delayed but negative influence. Gross capital formation has a long-lag positive effect. The findings align with the expectation that clean, accessible energy and workforce expansion are vital to manufacturing and industrial growth in Kenya, while fossil energy may increasingly constrain output through operational inefficiencies or rising costs.

4.5 ARDL Error Correction Regression

Table 4:4-Influence of renewable energy consumption on the growth of the manufacturing sector in Kenya, ARDL Error Correction Regression

ARDL Error Correction Regression				
Dependent Variable: D(MAN)				
Selected Model: ARDL(1, 4, 1, 0, 5)				
Case 3: Unrestricted Constant and No Trend				
Date: 07/08/25 Time: 18:14				
Sample: 1980 2023				
Included observations: 39				
ECM Regression				
Case 3: Unrestricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	7.482671	1.233094	6.068208	0.0000

D(REC)	0.071733	0.018564	3.864042	0.0008
D(REC(-1))	-0.130564	0.036179	-3.608797	0.0015
D(REC(-2))	-0.107496	0.029731	-3.615589	0.0015
D(REC(-3))	-0.063231	0.023039	-2.744507	0.0115
D(NREC)	-0.038739	0.048272	-0.802509	0.4305
D(GCF)	0.044694	0.025189	1.774357	0.0892
D(GCF(-1))	-0.069070	0.035721	-1.933606	0.0656
D(GCF(-2))	-0.042086	0.033949	-1.239710	0.2276
D(GCF(-3))	-0.030815	0.028673	-1.074695	0.2937
D(GCF(-4))	-0.074039	0.028380	-2.608823	0.0157
CointEq(-1)*	-0.522819	0.086396	-6.051399	0.0000
R-squared	0.721779	Mean dependent var		0.030105
Adjusted R-squared	0.608429	S.D. dependent var		0.026461
S.E. of regression	0.016558	Akaike info criterion		-5.116250
Sum squared resid	0.007402	Schwarz criterion		-4.604385
Log likelihood	111.7669	Hannan-Quinn criter.		-4.932597
F-statistic	6.367735	Durbin-Watson stat		2.358324
Prob(F-statistic)	0.000044			
* p-value incompatible with t-Bounds distribution.				

(Source: Author, 2025)

The ECM model in Table 4.4 estimates the short-run dynamics of how renewable and non-renewable energy consumption affect manufacturing output, while also capturing the sector's speed of adjustment toward long-run equilibrium. This ECM is derived from the ARDL (1, 4, 1, 0, 5) model and includes 39 adjusted annual observations.

The constant term is 7.482671, with a standard error of 1.233094, a t-statistic of 6.068208 and a p-value of 0.0000. This value is statistically significant and reflects the baseline level of manufacturing output in the absence of shocks from the independent variables.

The change in renewable energy consumption, D(REC), shows a short-run coefficient of 0.071733, a standard error of 0.018564, a t-statistic of 3.864042 and a p-value of 0.0008. This coefficient is statistically significant at the 1% level and implies that a 1% increase in renewable energy consumption in the current period leads to a 0.072% increase in manufacturing output. This strong immediate response reflects the ability of renewable energy inputs to power production lines, run machinery and stabilize energy availability, particularly in regions with frequent grid interruptions or expensive fossil energy.

The first lag of renewable energy consumption, D(REC(-1), has a coefficient of -0.130564, a standard error of 0.036179, a t-statistic of -3.608797 and a p-value of 0.0015. This is statistically significant at the 1% level and indicates that a 1% increase in renewable energy consumption in the previous period reduces current manufacturing output by 0.131%. Similarly, D(REC(-2) is also negative and significant, with a coefficient of 0.107496, a standard error of 0.029731, a t-statistic of -3.615589 and a p-value of 0.0015. These negative lagged effects suggest that while renewable energy drives immediate gains, excessive or unstable consumption patterns may reduce efficiency in subsequent periods, possibly due to adjustment costs or the delayed impact of system inefficiencies. The third lag, D(REC(-3), is also significant, with a coefficient of -0.063231, a standard error of 0.023039, a t-statistic of -2.744507 and a p-value of 0.0115. This further supports the presence of short-run volatility in how renewable energy affects manufacturing, where initial gains are followed by dampening effects in later periods.

Turning to non-renewable energy consumption, the contemporaneous change D(NREC) has a coefficient of

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue X October 2025

0.038739, a standard error of 0.048272, a t-statistic of -0.802509 and a p-value of 0.4305. This is statistically insignificant, indicating that current fluctuations in non-renewable energy consumption do not have a reliable short-run impact on manufacturing output.

Gross capital formation also displays mixed short-run effects. The contemporaneous change D(GCF) records a coefficient of 0.044694, a standard error of 0.025189, a t-statistic of 1.774357 and a p-value of 0.0892. This result is weakly significant at the 10% level, suggesting that new investments can support manufacturing output, albeit with limited immediate strength. The first lag, D(GCF(-1), has a coefficient of -0.069070, a standard error of 0.035721, a t-statistic of -1.933606 and a p-value of 0.0656, which is marginally insignificant at the 5% level but points toward possible delayed negative effects. Subsequent lags D(GCF(-2) and D(GCF(-3) remain insignificant, with coefficients of -0.042086, a p-value of 0.2276 and a coefficient of -0.030815 with a p-value of 0.2937, respectively. By the fourth lag, D(GCF(-4) becomes statistically significant, with a coefficient of 0.074039, a standard error of 0.028380, a t-statistic of -2.608823 and a p-value of 0.0157. This negative effect implies that gross capital formation undertaken four years earlier exerts a drag on current manufacturing output, possibly due to depreciation, misallocation or inefficiencies in capital use.

The ECM term, CointEq (-1), has a coefficient of -0.522819, a standard error of 0.086396, a t-statistic of 6.051399 and a p-value of 0.0000. This is statistically significant at the 1% level and reflects the speed at which short-run deviations from the long-run equilibrium are corrected. The coefficient of -0.522819 indicates that approximately 52.28% of the gap between the current level of manufacturing output and its long-run equilibrium level is corrected within one year. It means that after a shock, just over half of the adjustment back to long-term growth happens within a single period. This moderately fast correction speed is indicative of the manufacturing sector's structured processes and its ability to respond to energy or capital shocks through systematic realignment.

Model diagnostics affirm the statistical strength of the ECM. The R-squared is 0.721779 and the adjusted Rsquared is 0.608429, meaning that about 72% of the short-run variation in manufacturing output is explained by the included variables. The F-statistic is 6.367735 with a p-value of 0.000044, confirming joint significance of the regressors. The standard error of regression is 0.016558, while the D-W statistic of 2.358324 suggests no concern for serial correlation.

The ECM results indicate that renewable energy consumption exerts both immediate positive and delayed negative effects on manufacturing output, reflecting short-run efficiency gains followed by adjustment costs. Non-renewable energy consumption has no significant immediate effect, underscoring its diminishing role in supporting industrial expansion. Gross capital formation shows weak contemporaneous support but reveals negative lagged effects, pointing to inefficiencies in long-term capital utilization. The moderately fast speed of adjustment confirms that manufacturing responds systematically to shocks, with steady convergence back to its long-run growth path, ensuring resilience and stability in the sector.

F-Bounds Test

Table 4:5-Influence of renewable energy consumption on the growth of the manufacturing sector in Kenya, -Bounds Test

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	6.238867	10%	2.45	3.52
K	4	5%	2.86	4.01
		2.5%	3.25	4.49
		1%	3.74	5.06

(Source: Author, 2025)

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue X October 2025

The ARDL bounds test in Table 4:36 yields an F-statistic of 6.238867, which exceeds the upper bound critical value at the 5% level of 4.01 and even the 1% level of 5.06. This confirms the existence of a long-run equilibrium relationship between manufacturing output and the regressors, including renewable energy consumption. The null hypothesis of no cointegration is therefore rejected.

Post Diagnostic Tests

Test for Normality

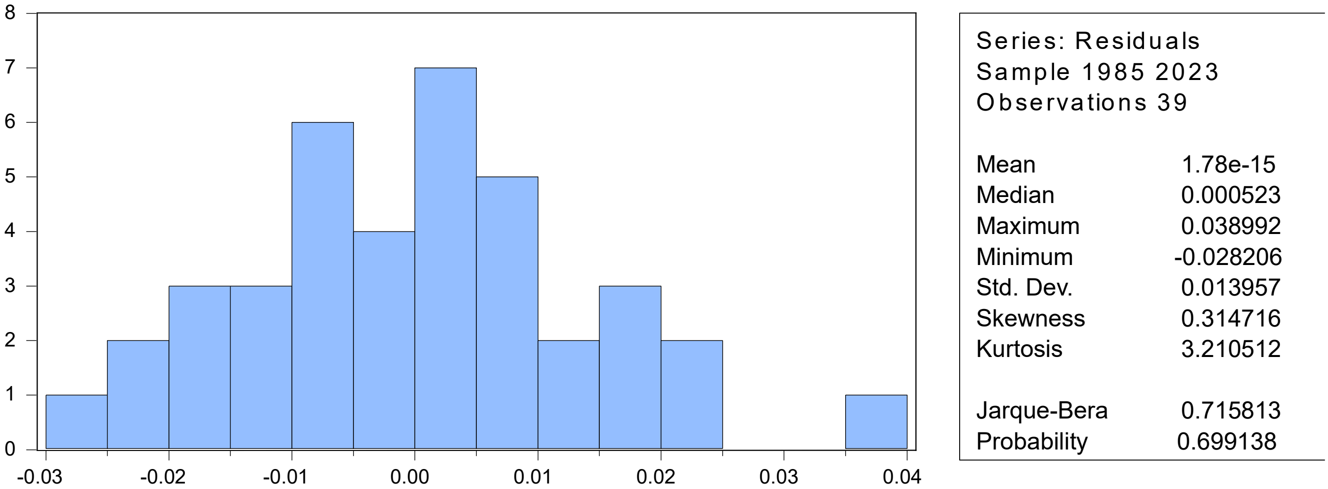

Figure 4:1-Influence of renewable energy consumption on the growth of the manufacturing sector in Kenya, J-B Stability Test

(Source; Author,2025)

As per the results in Figure 4:1, residuals pass the J-B test with a p-value of 0.699138, indicating normal distribution.

Test for Serial Correlation

Table 4:5-Influence of renewable energy consumption on the growth of the manufacturing sector in Kenya, Breusch-Godfrey Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	1.654110	Prob. F(2,21)	0.2152
Obs*R-squared	5.307694	Prob. Chi-Square(2)	0.0704

(Source: Author, 2025)

The Breusch-Godfrey LM test in table 4:5 yields an F-statistic of 1.654110 and a p-value of 0.2152, which is statistically insignificant. Thus, there is no evidence of serial correlation in the residuals, confirming that the model's assumptions are valid.

Test for Heteroskedasticity

Table 4:6-Influence of renewable energy consumption on the growth of the manufacturing sector in Kenya, Heteroskedasticity test: Breusch-Pagan-Godfrey

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	0.616681	Prob. F (15,23)	0.8319

Obs*R-squared	11.18623	Prob. Chi-Square (15)	0.7393
Scaled explained SS	4.300047	Prob. Chi-Square (15)	0.9966

(Source: Author, 2025)

The Breusch-Pagan-Godfrey test in Table 4:6 shows an F-statistic of 0.616681 and a p-value of 0.8319 and an Observed R-squared value of 11.18623 with a p-value of 0.7393, both of which are highly insignificant. This indicates homoskedasticity, a desirable property showing that the variance of errors is constant across observations.

4.5.6 Cumulative Sum of Recursive Residuals (CUSUM) Stability Test

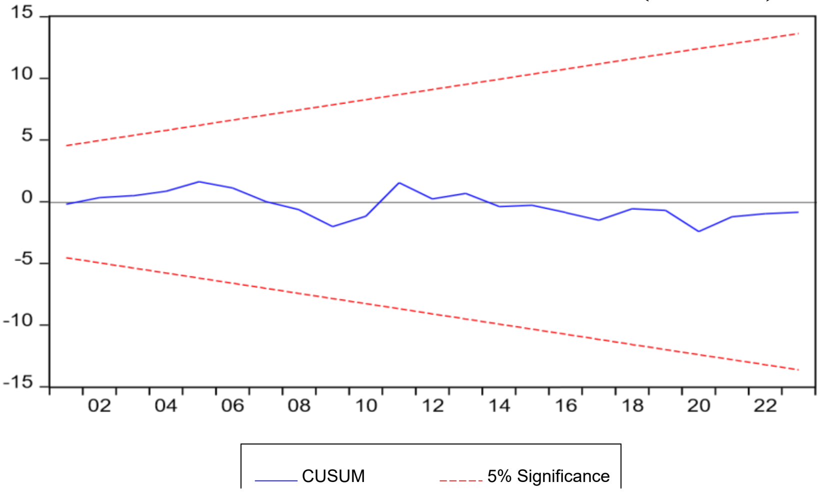

Figure 4:2-Influence of renewable energy consumption on the growth of the manufacturing sector in Kenya, CUSUM Stability Test

(Source: Author, 2025)

As per Figure 4:2, the stability plot lies within the 5% critical bounds, indicating structural stability in the model. Therefore, Manufacturing sector output is positively influenced by renewable energy consumption in both short and long runs, while non-renewable sources appear to suppress growth. The model is statistically sound, passes all diagnostic checks and supports the integration of green energy into Kenya's manufacturing development policy.

CONCLUSION AND POLICY IMPLICATIONS

In the manufacturing sector, renewable energy consumption delivers an immediate and statistically significant positive effect on output, suggesting that renewables can quickly support industrial activities such as machinery operation and energy stabilization. However, lagged coefficients turn negative, reflecting possible adjustment costs, inefficiencies in integration or over-reliance on unstable renewable inputs. This volatility highlights the transitional challenges of embedding renewable energy into industrial production chains. Non-renewable energy consumption, on the other hand, has no significant short-run impact, pointing to its reduced importance for immediate manufacturing growth. Gross capital formation provides limited contemporaneous benefits but eventually generates contractionary effects at longer lags, underscoring inefficiencies in capital absorption and project alignment. The adjustment speed of just over 52% annually confirms that manufacturing absorbs shocks at a moderately fast pace, balancing initial energy gains with subsequent corrections.

Therefore, the findings of this study explicitly align with Kenya's Vision 2030 and SDG 9 by emphasizing renewable energy as a driver of sustainable industrialization and green manufacturing. Policy interventions should focus on incentivizing clean energy adoption in industrial zones, supporting technology transfer for energy-efficient production and also integrating renewable energy infrastructure into manufacturing value chains. Linking these strategies to global green growth frameworks will enhance the sector's competitiveness while advancing Kenya's transition toward low-carbon industrial development. This study, therefore, calls for interventions aimed at increasing renewable energy uptake, for instance, through measures such as removing taxes on renewable energy consumption and adopting the carbon tax policy so as to increase the uptake of renewables. This will not only ensure sustainability, but also ensure environmental preservation.

LIMITATIONS OF THE STUDY

Data aggregation is still a key problem. Total renewable energy consumption is still aggregated hence making policy intervention to specific renewable energy sources cumbersome. This is because there exists a lot of renewable energies from sources such as solar that are generated and consumed by firms on-site without the data being captured anywhere in the national statistics. Efforts should be made by the ministry of energy to streamline and regulate the ballooning adoption of energy infrastructure such as solar so that their impact on the ground is correctly captured.

AREAS FOR FURTHER RESEARCH

There is need objectively disaggregate renewable energy consumption into their smaller sources for more informing policy interventions. This will be after serious investments into capturing real data at the firm-level.

REFERENCES

1. Bowden, N., & Payne, J. E. (2010). Sectoral analysis of the causal relationship between renewable and non-renewable energy consumption and real output in the US. Energy Sources, Part B: Economics, Planning, and Policy, 5(4), 400-408.
2. Das, K. C., & Mahalik, M. K. (2023). Renewable energy use and export performance of manufacturing firms: Panel evidence from six industries in India. Energy Economics, 125, 106894.
3. Grainger, C. A., & Zhang, F. (2017). The impact of electricity shortages on firm productivity: Evidence from Pakistan. World Bank Policy Research Working Paper (No. 8130). World Bank.
4. Guliyev., & Yerdelen Tatoglu, F. (2023). The relationship between renewable energy and economic growth in European countries: Evidence from panel data model with sharp and smooth changes. Renewable Energy Focus,46, 185-196. https://doi/10.1016/j.ref.2023.05.004
5. Forkuoh, S. K., & Li, Y. (2015). Electricity power insecurity and growth of small manufacturing firms: A case study of the cold store operators in the Asafo market area of the Kumasi metro in Ghana. Open Journal of Business and Management, 3(3), 312–322.
6. Hoang, T. H. V., Shahzad, H. J. S., & Czudaj, R. L. (2020). Renewable energy consumption and industrial production: A disaggregated time-frequency analysis for the U.S. Energy Economics, 85, 104433. https://doi.org/10.1016/j.eneco.2019.06.018
7. Jeon, H. (2022). Renewable versus non-renewable: The role of electricity generation to economic growth. The Electricity Journal, 35(6), 107140.
8. Kasae, P. (2014). Energy efficiency and operational performance of manufacturing firms in Kenya. Journals in Business & Management, 2(3), 15–24.
9. Obange, N., Siringi, E. M., & Mukras, M. S. (2013). Causality between disaggregated energy consumption and manufacturing growth in Kenya: An empirical approach.
10. Onuonga, S. M., Etyang, M., & Mwabu, G. (2008). The demand for energy in the Kenyan manufacturing sector. The Journal of Energy and Development, 34(1/2), 265–276.
11. Ototo, E. G., & Nzai, C. (2021). Energy consumption and performance of the manufacturing sector in Kenya.
12. Oyeleke, O. J., & Akinlo, T. (2020). Energy generation and economic growth: empirical evidence from Nigeria. Environment, Development and Sustainability, 22(8), 7177-7191.
13. World Bank. (2021). World development report 2021: Data for better lives.
14. Zhang, Z., & Ma, Y. (2023). The impact of energy consumption structure transformation on firms' total factor productivity: evidence from China. Environmental Science and Pollution Research, 30(31), 7695076968.