

Powering Industrial Growth in Kenya: The Role of Renewable Energy Generation in Manufacturing

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ABSTRACT

The growth of renewable energy is viewed as a way to support both decarbonization as well as manufacturing and industrial development, yet available empirical evidence on its sector-specific growth effects in developing economies remains scarce. This study examines the relationship between renewable energy generation and manufacturing output in Kenya using annual data from 1980 to 2023 within an autoregressive distributed lag (ARDL) framework using data from WDI and EIA. Controlling for non-renewable generation, gross capital formation, as well as labour, the bounds testing approach confirms a stable long-run relationship between renewable energy generation and manufacturing sector growth in Kenya. The results indicate that renewable energy generation exerts a positive and statistically significant lagged effect such that a 1% increase in renewable generation increases manufacturing output by approximately 0.099% in the subsequent year. However, non-renewable energy generation displays delayed contractionary effects in the long run, thus suggesting potential structural inefficiencies associated with non-renewable energy sources. Gross capital formation remains the strongest determinant of manufacturing growth, underscoring the importance of complementary investment. The error correction term of -0.763 indicates rapid adjustment toward equilibrium by correcting 76.3% of disequilibrium annually. Diagnostic and stability tests confirm model robustness. The findings suggest that aligning renewable energy expansion with manufacturing and industrial policy can boost manufacturing growth and productivity while supporting long-term energy transition objectives in Kenya and comparable emerging economies.

Keywords: Renewable energy generation; Manufacturing sector growth; Industrial policy; Energy transition; ARDL model; Kenya

INTRODUCTION

Manufacturing and industrialization remain central to Kenya's long-term development strategy, with the sector playing a pivotal role in employment creation, value addition, as well as structural transformation. However, manufacturing growth in Kenya has been modest and volatile, constrained by structural bottlenecks including infrastructure gaps and electricity supply challenges (World Bank, 2020). Reliable and adequate electricity generation is therefore seen as a fundamental requirement for manufacturing and industrial expansion, particularly in energy-intensive manufacturing processes.

Kenya has significantly expanded its renewable energy generation capacity, drawing on geothermal, hydro, wind, as well as solar resources. The country is well recognized as a regional leader in renewable-based electricity generation, with geothermal power forming a stable base-load component of its generation mix (International Energy Agency, 2024). Policy reforms, independent power producer frameworks, as well as sustained public investment, have underpinned this transition. Renewable energy expansion in Kenya has therefore been positioned not only as a climate mitigation strategy but also as an instrument for enhancing energy security and supporting productive sectors of the economy. Despite substantial investments in renewable energy infrastructure, Kenya still faces a gap between total installed electricity capacity and the energy actually generated and utilized, a situation that has important implications for manufacturing and industrial development.

Kenya's electricity system has around 3.3 gigawatts of installed generation capacity, largely anchored in renewable sources such as geothermal, hydro, wind, and solar, with geothermal and hydropower together accounting for nearly half of the portfolio and renewable energy sources supplying approximately 90% of total generation (International Energy Agency, 2024). Recent data affirm that installed capacity stood at approximately 3,192 megawatts, while peak demand reached 2,316 megawatts, thus indicating that not all potential capacity is consistently mobilized to meet demand pressures (Energy and Petroleum Regulatory Authority, 2025). Although the renewable share of generation is high, variability in hydropower due to climatic conditions, transmission constraints, as well as intermittent output from wind and solar mean that actual generation often falls short of installed potential, compelling some industries to heavily depend on backup diesel generators or face power interruptions, thus affecting the smooth running of industrial operations. This capacity–generation mismatch constrains manufacturing growth by increasing production costs, reducing reliability and undermining competitiveness, especially for energy-intensive firms. This highlights the need for policies that improve energy utilization, grid stability and investment in storage and transmission infrastructure in Kenya.

From theory, renewable energy generation capacity influences manufacturing performance through supply reliability, long-run adequacy and cost stability. Adequate generation capacity reduces supply constraints that can disrupt industrial processes and constrain investment. In developing economies, infrastructure expansion activities such as electricity generation have been shown to play a critical enabling role in industrial growth and structural transformation (Calderón & Servén, 2010). Renewable energy generation, particularly geothermal power, may offer additional advantages due to its relatively stable output compared to non-renewable alternatives that are vulnerable to fuel price volatility and import dependency.

Despite substantial investments in renewable energy generation, empirical evidence on its sector-specific contribution to manufacturing output in Kenya remains limited. Much of the broader energy–growth literature has focused on aggregate GDP effects or overall electricity supply without isolating renewable energy generation as a distinct production-side determinant (Payne, 2010; Ozturk, 2010). While these studies provide valuable macro-level insights, they offer a limited understanding of how renewable generation translates into industrial output growth at the sectoral level. Thus, the direct relationship between renewable energy generation and manufacturing performance in Kenya remains insufficiently explored.

This gap is particularly significant given Kenya's simultaneous pursuit of manufacturing and industrialization as well as low-carbon energy transition objectives. If renewable energy generation expansion contributes meaningfully to manufacturing output, it strengthens the economic justification for continued investment in clean energy infrastructure beyond environmental considerations. On the other hand, weak or insignificant associations would mean the need for complementary industrial policies to enhance transmission mechanisms between energy infrastructure and productive sectors such as manufacturing.

The research problem addressed in this study is therefore whether the expansion of renewable energy generation in Kenya has contributed to manufacturing sector growth over the long run. Using annual data from 1980 to 2023 within an ARDL framework, this study examines the long-run and short-run relationship between renewable energy generation and manufacturing output while controlling for key production inputs. By providing sector-specific evidence from a renewable-dominant African economy, the study contributes to the energy policy literature and offers insights for policymakers seeking to align renewable energy expansion with sustainable industrial development strategies.

LITERATURE REVIEW

Halicioglu and Ketenci (2018) examined the dynamic interactions among output, renewable and non-renewable energy production, international trade, capital, and labour in the EU-15 countries over the 1980-2015 period. The study employed an extended production function framework in which both renewable and non-renewable energy inputs, alongside international trade, were incorporated as determinants of output. Econometric analysis was conducted using the ARDL framework for individual countries and a panel Generalized Method of Moments (GMM) for the EU-15 as a whole. The ARDL results showed cointegration relationships in 7 of the 15 economies, with Greece, Italy and Portugal showing the most robust production function estimates. Across the panel, the GMM analysis indicated that non-renewable energy had roughly twice the impact on output compared

to renewable energy, although international trade emerged as an important contributor, particularly in Portugal. The study highlights that despite increasing adoption of renewable sources, EU-15 economies remain largely reliant on non-renewable energy sources for production and the relative effects of renewable and non-renewable energy vary significantly across countries. A limitation of the study is that the heterogeneous country effects mean that panel-wide results may not reveal country-specific dynamics and the focus on aggregate output does not isolate sectoral or manufacturing growth specifically. Nevertheless, the research provides valuable empirical evidence on the role of energy generation in shaping long-run economic output, thus offering important insights for energy policy and industrial planning.

Wangare (2015) examined the influence of disaggregated energy production on manufacturing growth in Kenya over the 1979-2009 time period, using World Bank time series data. The study disaggregated energy into hydroelectricity, oil and other renewable sources. The study applied multivariate regression analysis to estimate their contribution to the percentage annual growth of manufacturing. Findings indicate that energy production has a strong positive influence on manufacturing growth, with non-hydro renewable energy contributing the most. The study thus emphasizes the pivotal role of energy in industrial expansion and recommends enhancing renewable energy generation and research coordination. However, the study is limited by its relatively short time span, the exclusion of energy consumption and generation dynamics beyond production, as well as the lack of examination of sector-specific short- and long-term effects using modern cointegration techniques such as ARDL or ECM. This gap motivates the present study, which incorporates both renewable and non-renewable energy generation, manufacturing sector growth and contemporary time series econometric methods to provide a more in-depth understanding of renewable energy generation-manufacturing relationships in Kenya.

Alanne and Saari (2005) conducted a conceptual study in Finland and other Nordic contexts to examine distributed energy generation (DEG) as a pathway toward sustainable development. Using a qualitative, literature-based methodology, the study analyzed political, economic, social, and technological dimensions of regional energy systems, emphasizing the shift from centralized to decentralized energy units located near consumers. Its findings suggest that DEG improves efficiency, reliability and environmental performance. The findings also reveal that societal embedding and stakeholder acceptance are critical for successful implementation. The study highlights the particular potential of DEG in sparsely populated regions and countries with extensive district heating networks. However, the study is limited by its theoretical and descriptive approach, lacking empirical validation or quantitative modeling of system performance, leaving a gap for research that measures the actual economic, social and environmental impacts of DEG in practice.

Allan et al. (2014) examined the economics of distributed energy generation in the United Kingdom using secondary data drawn from existing empirical and theoretical studies on distributed technologies, electricity markets and macroeconomic modeling. Employing a qualitative and critical literature review methodology, the authors synthesize prior research on financial viability, social costs and benefits and economy-wide impacts of distributed generation. The findings reveal that although many studies assess the profitability of specific technologies such as wind and combined heat and power, very few rigorously analyze the pure economic efficiency of distributed generators or their broader macroeconomic effects within the UK energy system, where distributed generation accounted for less than 10% of electricity supply in 2006. The study concludes that stronger economy-wide modeling is necessary to guide public policy. However, its reliance on secondary literature without original quantitative estimation leaves a gap for empirical, country-specific econometric analysis that measures the actual sectoral and macroeconomic growth effects of distributed energy generation, which this study seeks to address

Carley et al. (2017) sought to investigate the global expansion of renewable energy generation by analyzing the effectiveness of policy instruments across 164 countries over the 1990-2010 period. Using an original cross-national panel dataset, the authors employ econometric regression techniques to estimate the impact of feed-in tariffs and renewable portfolio standards on renewable energy growth. The dependent variable is measured in two ways: the percentage share of renewable energy in total electricity generation and the annual increase in renewable energy output. Results from this study indicate that both feed-in tariffs and renewable portfolio standards significantly promote renewable energy market growth and results remain robust under alternative specifications, including models excluding hydropower. However, the study notes inconclusive evidence regarding the potential endogeneity of feed-in tariffs and finds that factors driving short-term increases in

renewable generation differ from those influencing long-term structural transition away from non-renewable energy forms. A key limitation is its macro-level policy focus without sectoral or country-specific dynamic modeling, leaving a gap for studies that examine how renewable energy expansion translates into sectoral growth and structural transformation within individual economies, which the present study addresses.

Magnani and Vaona (2013) sought to examine the regional spillover effects of renewable energy generation on economic growth in Italy using panel data for 20 NUTS2 regions over the period 1997-2007. The study employs a multivariate econometric framework, applying panel unit root and cointegration tests, estimation of the long-run cointegrating vector, as well as the Granger non-causality tests within a panel vector ECM model, with robustness checks using system GMM and alternative energy measures. The findings indicate that renewable energy generation has a positive and statistically significant long-run effect on regional output, supporting the growth hypothesis and suggesting that renewable energy generation alleviates balance-of-payments constraints, reduces exposure to non-renewable energy price volatility and also mitigates environmental externalities, thus fostering environmental sustainability. However, the analysis is limited to one country and a relatively short time span, which restricts generalizability and broader macroeconomic inference. This leaves a gap for cross-country or longer-horizon empirical studies that may seek to quantify the sectoral and structural growth effects of renewable energy generation beyond the Italian regional context, which this study seeks to address.

Vaona (2016) sought to investigate the effect of renewable energy generation on import demand using panel data for 26 countries over different time periods sourced from the World Development Indicators. The study adopts a dynamic import demand framework and employs the system GMM estimator, alongside alternative estimators and robustness checks, to address potential endogeneity and dynamic panel bias. Findings of the study show that renewable energy generation significantly reduces import growth, thus supporting the argument that renewable energy softens balance-of-payments constraints and enhances external sustainability. The findings remain robust across model specifications, including controls for fossil and nuclear energy. However, the study focuses on aggregate imports rather than sectoral trade effects and does not explicitly link reduced imports to sectoral output or structural transformation, thus leaving a gap for research that connects renewable energy generation to sector-specific growth dynamics and broader economic development outcomes, which this study sought to address.

Cergibozan (2022) investigates the impact of renewable energy sources on energy security risk in 23 OECD countries using annual data over the 1985-2016 period. It employs second-generation panel econometric techniques, including the CIPS panel unit root test, Durbin-Hausman panel cointegration test, Augmented Mean Group (AMG) estimator, as well as the Dumitrescu-Hurlin heterogeneous panel causality tests in order to account for cross-sectional dependence and long-run linkages. Findings indicate that wind, hydroelectricity and total renewable energy significantly reduce energy security risk, whereas biomass and solar sources have no significant effect. Additionally, causality runs from biomass and hydro to energy security, while bidirectional causality exists between industrial production, total energy, economic integration, urbanization and wind energy. This study, however, is from economies with advantaged endowment of energy resources compared to many Sub-Saharan economies, necessitating this research.

Armeanu et al. (2017) examines the impact of renewable energy production on sustainable economic growth in the EU-28 countries over the 2003-2014 period, disaggregating energy by type, including biomass, hydropower, geothermal, wind, as well as solar. Using panel data fixed-effects regressions, FMOLS, DOLS and panel vector error correction model (PVECM) Granger causality tests, the study establishes that overall renewable energy positively influences GDP per capita, with biomass showing the strongest effect, where a 1% increase in primary production of solid biofuels raises GDP per capita by 0.16% and a 1% increase in total renewable energy production raises GDP per capita by 0.05%–0.06%. Hydropower also significantly contributes to growth, while solar and geothermal effects are lower. Causality analysis shows a unidirectional linkage from economic growth to renewable energy production, supporting the conservation hypothesis. The study highlights the policy relevance of enhancing renewable energy production, particularly biomass and hydropower and fills a gap in the literature by providing EU-level, type-specific evidence on renewable energy production rather than consumption.

Dirma et al. (2024) examine the impact of renewable energy development on economic growth across EU-28 countries over the 2003-2014 period using panel data from Eurostat and the World Bank. Employing fixed-effects regression, cointegration tests, FMOLS, DOLS and a panel vector error correction model (PVECM), findings of the study reveal that renewable energy positively influences GDP per capita, with the share of renewable energy in gross final energy consumption showing the strongest effect. Biomass energy, particularly solid biofuels, has the highest impact among renewable types, while hydropower, geothermal, wind and solar energy also contribute positively. The PVECM results indicate a long-run unidirectional causality from economic growth and energy dependence to renewable energy production, supporting the conservation hypothesis. The study highlights that EU countries have not yet met renewable energy targets and recommends enhanced cooperation, joint projects and integrated energy frameworks to improve energy security, reduce fossil fuel dependence and support sustainable growth. This study seeks to replicate this study in developing economies, Kenya, to be specific.

RESEARCH METHODOLOGY

This study makes use of annual data spanning the period 1985 to 2023 to examine the effects of renewable energy generation on manufacturing sector growth in Kenya. This is the period that preceded the major global oil crisis and led to a shift and relooking at renewable energy adoption globally. Non-renewable energy generation, gross capital formation and labour were incorporated as control variables. All data were sourced from reputable secondary databases to ensure accuracy and consistency. Renewable and non-renewable energy generation figures were obtained from the U.S. Energy Information Administration (EIA), while sectoral output, gross capital formation and labour data were extracted from the World Bank’s World Development Indicators (WDI). The selected period allows for the analysis of long-term trends in energy generation, manufacturing and industrial activity as well as structural adjustments in Kenya’s manufacturing sector.

This study is grounded in the Solow-Swan growth model, using a Cobb-Douglas production function to explain the relationship between renewable energy generation and manufacturing sector growth. The basic function expresses manufacturing output as a product of capital and labour inputs, with exponents representing the respective output elasticities while holding technology constant. To improve statistical properties, the function was log-linearized. This transformation stabilizes variance, reduces heteroscedasticity, linearizes exponential growth trends and also allows coefficients to be interpreted as elasticities, representing percentage changes in output in response to changes in inputs (Kothari, 2004; Wooldridge, 2016; Gujarati & Porter, 2009).

Recognizing renewable energy generation as a critical production input, the model incorporates renewable energy generation as a proxy for total factor productivity, reflecting its role in enabling capital and labour to produce output efficiently. Non-renewable energy generation was included as a control variable to capture the influence of conventional energy sources on manufacturing performance, consistent with approaches in previous studies (Al-Ayouty, 2020; Eggoh et al., 2011; Gava et al., 2025).

According to this model, the association between the manufacturing sector and renewable energy generation is represented by the general Cobb-Douglas equation 3.1, in which renewable energy generation, non-renewable energy generation, gross capital and labour enter the model as inputs into the economy’s productive processes.

$$Y = AK^\alpha L^{1-\alpha} \dots \dots \dots (3.1)$$

Y being the output,

A represents total factor productivity,

α represents the output elasticity associated with capital (K) and

$(1 - \alpha)$ is the output elasticity of labour(L).

To incorporate renewable energy generation while preserving constant returns to scale, renewable energy does not enter the model as an additional scale input. Instead, renewable energy affects output through total factor productivity by enhancing efficiency, reliability and technological performance of the production process. Accordingly, the production function is augmented as;

$$MAN = A(REG)K^{\alpha}L^{1-\alpha} \dots \dots \dots (3.2)$$

Where REG represents renewable energy generation, MAN is the manufacturing sector output.

The linearized form takes the form;

$$MAN_t = LnA + \alpha_1 Ln(REG_t) + \alpha_2 Ln(NREG_t) + \alpha_3 Ln(GCF_t) + \alpha_4 Ln(L_t) + \varepsilon_t \dots \dots \dots (3.3)$$

The log-linearization ensures that the parameters $\alpha_1, \alpha_2, \alpha_3$ and α_4 can be interpreted as elasticities of output with respect to the respective inputs, thereby making the model both statistically tractable and economically meaningful.

To include temporal dynamics, lags were included. The lags also helped account for the delayed responses as impacts of energy policies and decisions do not occur instantaneously(Granger,1969). The aggregated equation for objective one became;

$$Ln(MAN_t) = LnA + \alpha_1 Ln(REG_t) + \alpha_2 Ln(NREG_t) + \alpha_3 Ln(GCF_t) + \alpha_4 Ln(L_t) + \beta_1 Ln(REG_{t-1}) + \beta_2 Ln(NREG_{t-1}) + \beta_3 Ln(GCF_{t-1}) + \beta_4 Ln(L_{t-1}) + \varepsilon_t \dots \dots \dots (3.4)$$

RESULTS AND DISCUSSION

Descriptive statistics

Table 1: Descriptive Statistics

	MAN(“000000”)	REG(“000000”)	NREG(“000000”)	L(“{000000”)	GCF(“OF_GDP”)
Mean	486735.3	4.914184	1.115578	13.54270	20.09076
Median	424905.7	3.887850	1.022550	12.73076	19.73131
Maximum	848461.0	11.48400	2.785300	23.18485	25.44904
Minimum	227142.4	1.182000	0.102000	5.341202	15.00382
Std. Dev.	178639.4	3.006695	0.813648	5.556273	2.956138
Skewness	0.455448	0.968854	0.360692	0.205444	0.087421
Kurtosis	2.110278	2.740128	1.874294	1.682008	2.157324
Jarque-Bera	2.972451	7.007456	3.277285	3.494208	1.357899
Probability	0.226225	0.030085	0.194244	0.174278	0.507149
Sum	21416353	216.2241	49.08542	595.8787	883.9934
Sum Sq. Dev.	1.37E+12	388.7293	28.46698	1327.503	375.7664
Observations	44	44	44	44	44

Table 4.1 presents a detailed statistical summary of the key variables used in this study, including manufacturing sector output, renewable energy generation, non-renewable energy generation, labour and gross capital

formation. The manufacturing sector’s output averaged Kshs 487 billion, with a standard deviation of Kshs 179 billion, a minimum of Kshs 227 billion and a maximum of Kshs 848 billion. This reflects substantial variability in industrial performance driven by policy reforms, energy access, global demand shocks and domestic operational inefficiencies. The moderate right-skewness of 0.455 and a kurtosis value of 2.11 indicate occasional sharp growth spurts, while the Jarque-Bera probability value of 0.226 confirms approximate normality, emphasizing that manufacturing has generally trended upward, consistent with Kenya’s industrial recovery and expansion of domestic production capacity.

Renewable energy generation recorded a mean of 4,914,184 kilowatt-hours, with a standard deviation of 3,006,695, a minimum value of 1,182,000 and a maximum of 11,484,000 kilowatt-hours. This demonstrates significant variability aligned with the scaling up of hydro, geothermal and wind projects. The positive skewness value of 0.969 and a Jarque-Bera probability value of 0.030 reflect recent rapid growth in renewable alternatives, thus justifying log-transformation and highlighting Kenya’s strategic push toward sustainable energy diversification. Non-renewable generation averaged 1,115,578 kilowatt-hours, with a standard deviation of 813,648, a range from 102,000 to 2,785,300 and a skewness value of 0.361 alongside a J-B probability of 0.194. This illustrates its historical role as a fallback energy source during periods of insufficient renewable capacity. Labour averaged 13,542,697, varying from 5,341,202 to 23,184,849, with a standard deviation of 5,556,273, skewness of 0.205 and a J-B probability of 0.174, indicating steady demographic growth that has continuously bolstered the workforce for manufacturing and domestic market development.

Gross capital formation, measured as a share of GDP, averaged 20.09%, with a standard deviation of 2.956%, a minimum of 15.00382%, a maximum value of 25.44904%, a skewness value of 0.087 and a J-B probability value of 0.507. This signals consistent and stable investment conducive to infrastructure and industrial expansion. These descriptive statistics capture Kenya’s structural transformation and gradual industrialization

Correlation Results

Table 2: Correlation Analysis

Sample: 1980 2023					
Correlation					
Probability	MAN	REG	NREG	L	GCF____OF_GDP_
MAN	1.000000				

REG	0.965234	1.000000			
	0.0000	-----			
NREG	0.538932	0.353163	1.000000		
	0.0002	0.0187	-----		
L	0.984473	0.924895	0.645110	1.000000	
	0.0000	0.0000	0.0000	-----	
GCF %GDP	-0.179764	-0.139183	-0.228289	-0.198752	1.000000
	0.2430	0.3676	0.1361	0.1959	-----

To examine the strength and direction of linkages among the study variables, a Pearson correlation analysis was conducted, as shown in Table 4.2, covering manufacturing sector outputs and renewable energy generation,

alongside control variables: non-renewable energy generation, labour and gross capital formation over the 1980-2023 period. This was based on 44 observations. Correlation coefficients range from negative one to positive one, where values near positive one indicate strong positive relationships, values near negative one indicate strong negative relationships, while values near zero suggest little or no linear association.

Renewable energy generation demonstrates a strong association with manufacturing output at 0.965. This indicates that growth in renewable energy aligns with manufacturing and industrial expansion. On the other hand, non-renewable energy generation exhibits a moderately weaker correlation with manufacturing at 0.539, reflecting Kenya’s gradual transition from non-renewable-based energy sources to cleaner energy systems within industrial processes. Labour input maintains very strong positive correlations with both manufacturing, emphasizing its central role in driving manufacturing sector growth. On the other hand, gross capital formation shows generally weak negative correlations with manufacturing at -0.180, indicating that capital investment has not consistently aligned with manufacturing sector performance and that industrial growth in Kenya remains largely labour-intensive.

Labour continues to show a strong positive correlation with renewable energy generation, whereas gross capital formation remains weakly and negatively correlated with renewable energy generation at -0.139. These patterns suggest that energy and manufacturing sector expansion during the study period has been driven more by operational growth and labour input rather than by large-scale capital investment.

All variables were transformed into natural logarithms to stabilize variance, improve normality, and to also facilitate elasticity-based interpretations within the Cobb–Douglas production framework. Lagged explanatory variables were included to capture delayed sectoral responses and reduce contemporaneous correlation (Gujarati & Porter, 2009). Despite some pairwise correlations approaching 0.90, the ARDL and ECM frameworks, which incorporated lagged values of explanatory variables, reduced correlations below conventional thresholds and mitigated multicollinearity concerns as per the assertions of Wooldridge (2016). The observed co-movement among energy indicators reflects genuine structural and policy linkages rather than statistical bias, thus aligning with the literature that notes strong correlations among renewable and non-renewable energy variables while preserving analytical relevance. Short-run dynamics were captured through first differences in the ECM, while long-run equilibrium was maintained via lagged level terms in the ARDL. This ensured reliable estimation despite the presence of high pairwise correlations.

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

Table 4.3. 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)
REG	-0.932019 (0.9427)	-5.267663 (0.0005)	I (1)
NREG	-1.190329	-5.343954	I (1)

	(0.8983)	(0.0005)	
L	-3.558792 (0.0494)	-2.925557 (0.1665)	I (0)
GCF___OF_GDP	-2.754643 (0.2212)	-5.703648 (0.0002)	I (1)

To ensure the suitability of the time series data for econometric analysis and to prevent spurious regression results, the stationarity of the variables was tested using the ADF as shown in Table 4.3, considering both levels and first differences under trend and intercept specifications. Establishing the integration properties of the variables is critical, as correlations among non-stationary series can lead to misleading inference if not properly addressed.

The results show that manufacturing output is non-stationary at level but becomes stationary after first differencing. This implies it is integrated of order one. Renewable energy generation and non-renewable energy generation follow the same pattern, being non-stationary at level yet attaining stationarity after first differencing, thereby confirming their integration of order one. Gross capital formation also exhibits non-stationarity at level but achieves stationarity after first differencing. This is consistent with I(1) behaviour. Labour, however, is stationary at level and does not significantly change after differencing, demonstrating it is integrated of order zero.

This mixed order of integration, with most variables being I(1) and labour being I(0), makes the ARDL bounds testing technique suitable for the analysis. Unlike conventional cointegration techniques, such as Johansen or Engle-Granger, which require all variables to share the same order of integration, the ARDL approach accommodates a combination of I(0) and I(1) series. This flexibility allows for robust estimation of both short-run dynamics and long-run equilibrium relationships. Moreover, the ARDL framework allows the inclusion of lagged explanatory variables, which capture delayed sectoral responses to changes in renewable energy generation and gross capital formation, while also mitigating potential endogeneity and omitted variable bias.

Given these unit root findings, the use of ARDL is well justified. It provides an approach for modelling dynamic interactions among manufacturing output, renewable and non-renewable energy generation, labour, as well as gross capital formation, supporting consistent inference for both immediate adjustments and long-term growth paths. This methodology is appropriate in the Kenyan context, where sectoral growth and energy transitions are shaped by both rapid operational changes and gradual structural adjustments over time.

Lag Length Determination

Lag lengths were automatically selected within the ARDL framework using the AIC, which balances model fit and parsimony. EViews determined the optimal lags, which were retained for both short- and long-run estimations to capture essential dynamics efficiently. These determined lag lengths are reported with the ARDL results.

Auto-Regressive Distributed Lag Model (ARDL) Analysis

Table 4.4 ARDL Results

Dependent Variable: MAN			
Method: ARDL			
Date: 07/08/25 Time: 17:09			

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): REG NREG L GCF				
Fixed regressors: C				
Number of models evaluated: 1296				
Selected Model: ARDL(1, 1, 3, 5, 4)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
MAN(-1)	0.236928	0.114199	2.074692	0.0511
REG	0.009095	0.023392	0.388815	0.7015
REG(-1)	0.099105	0.024560	4.035220	0.0006
NREG	-0.011076	0.010260	-1.079560	0.2932
NREG(-1)	0.006091	0.009698	0.628099	0.5370
NREG(-2)	-0.001986	0.008944	-0.222025	0.8265
NREG(-3)	-0.038145	0.009239	-4.128832	0.0005
L	0.360737	0.505481	0.713651	0.4837
L(-1)	0.049129	0.982096	0.050025	0.9606
L(-2)	-0.396599	1.039082	-0.381682	0.7067
L(-3)	0.928318	1.177919	0.788100	0.4399
L(-4)	-1.563348	1.129358	-1.384280	0.1815
L(-5)	1.178193	0.559214	2.106874	0.0480
GCF	0.131822	0.029315	4.496756	0.0002
GCF(-1)	0.033429	0.030884	1.082406	0.2920
GCF(-2)	0.023253	0.031415	0.740193	0.4678
GCF(-3)	0.045071	0.033188	1.358052	0.1896
GCF(-4)	-0.092972	0.029911	-3.108304	0.0055
C	10.00686	1.577071	6.345215	0.0000

R-squared	0.998939	Mean dependent var	26.92435
Adjusted R-squared	0.997984	S.D. dependent var	0.316000
S.E. of regression	0.014188	Akaike info criterion	-5.366371
Sum squared resid	0.004026	Schwarz criterion	-4.555918
Log likelihood	123.6442	Hannan-Quinn criter.	-5.075587
F-statistic	1046.181	Durbin-Watson stat	1.624827
Prob(F-statistic)	0.000000		
*Note: p-values and any subsequent tests do not account for model selection.			

The ARDL model in Table 4.4 was estimated to examine the long-run interactions between renewable energy generation and manufacturing sector growth in Kenya using 39 annual observations from 1985 to 2023. The optimal lag structure, as determined by the AIC, included one lag for manufacturing output besides lags of one, three, five and four for renewable energy generation, non-renewable energy generation, labour and gross capital formation, respectively.

The first lag of manufacturing output has a coefficient of 0.236928, implying that approximately 23.7% of the previous year's output contributes to the current level of output. This serves to demonstrate moderate inertia in manufacturing sector output over time, with the effect being marginally significant at the five percent level. Renewable energy generation in the current period has a negligible and statistically insignificant effect of 0.009095. However, the first lag of renewable energy generation is positive and significant at 0.099105. This implies that a 1% increase in renewable energy generation in the previous year raises current manufacturing output by approximately 0.099%, *ceteris paribus*.

Non-renewable energy generation exhibits a delayed effect. The contemporaneous impact is negative at -0.011076 and statistically insignificant. The first and second lags are also insignificant. The third lag, however, shows a significant negative effect of -0.038145, suggesting that a 1% increase in non-renewable generation reduces manufacturing output by 0.038% three years on. This delayed contractionary effect may reflect rising production inefficiencies or environmental costs associated with non-renewable energy forms of energy.

Labour enters the model with five lags. The immediate and intermediate effects up to the fourth lag are positive but statistically insignificant. The fifth lag is positive and significant at 1.178193. This indicates that a 1% increase in labour five years earlier leads to an estimated 1.178% increase in manufacturing sector output. This highlights the delayed but substantial contribution of human capital to manufacturing and industrial growth.

Gross capital formation has an immediate positive effect of 0.131822, showing that a 1% increase in gross capital formation is associated with a 0.132% rise in manufacturing sector output in the same year. However, the fourth lag has a negative effect of -0.092972, thereby suggesting that past capital investments may eventually introduce structural inefficiencies or diminishing returns, particularly when investments are poorly targeted or become obsolete.

The model constant is 10.00686. This reflects the baseline level of manufacturing output when all other variables are neutral. The ARDL findings demonstrate that renewable and non-renewable energy, labour and gross capital formation exert both immediate and lagged effects on manufacturing sector growth. Renewable energy generation and gross capital formation have sustained positive impacts, while non-renewable energy generation shows delayed contractionary impacts. Labour contributes meaningfully over time, emphasizing the importance of long-term human capital investment. These findings are consistent with economic theory and provide guidance for policies on energy mix optimization, labour absorption and efficient capital allocation in the manufacturing sector.

The model diagnostics confirm an excellent fit. The R-squared of 0.998939 implies that about 99.89% of the variation in manufacturing sector output is explained by the model, while the adjusted R-squared of 0.997984 accounts for the number of regressors. The F-statistic value of 1046.181 confirms the joint significance of the explanatory variables. The Durbin-Watson statistic of 1.624827 suggests no autocorrelation in the residuals, thus reinforcing the reliability of the model estimates.

4.5.2 ARDL Error Correction Regression

Table 4.5. ARDL Error Correction Regression

ARDL Error Correction Regression				
Dependent Variable: D(MAN)				
Selected Model: ARDL(1, 1, 3, 5, 4)				
Case 3: Unrestricted Constant and No Trend				
Date: 07/08/25 Time: 17:09				
Sample: 1980 2023				
Included observations: 39				
ECM Regression				
Case 3: Unrestricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	10.00686	1.069879	9.353262	0.0000
D(REG)	0.009095	0.017386	0.523144	0.6066
D(NREG)	-0.011076	0.006890	-1.607626	0.1236
D(NREG(-1))	0.040130	0.008067	4.974518	0.0001
D(NREG(-2))	0.038145	0.007846	4.861442	0.0001
D(L)	0.360737	0.383273	0.941200	0.3578
D(L(-1))	-0.146565	0.531847	-0.275576	0.7857
D(L(-2))	-0.543164	0.541103	-1.003808	0.3275
D(L(-3))	0.385154	0.635599	0.605970	0.5514
D(L(-4))	-1.178193	0.426928	-2.759697	0.0121
D(GCF)	0.131822	0.023569	5.593085	0.0000
D(GCF(-1))	0.024648	0.023397	1.053433	0.3047
D(GCF(-2))	0.047901	0.021714	2.206042	0.0392
D(GCF(-3))	0.092972	0.022659	4.103102	0.0006
CointEq(-1)*	-0.763072	0.081764	-9.332655	0.0000

R-squared	0.848691	Mean dependent var	0.030105
Adjusted R-squared	0.760428	S.D. dependent var	0.026461
S.E. of regression	0.012951	Akaike info criterion	-5.571499
Sum squared resid	0.004026	Schwarz criterion	-4.931668
Log likelihood	123.6442	Hannan-Quinn criter.	-5.341933
F-statistic	9.615451	Durbin-Watson stat	1.624827
Prob(F-statistic)	0.000001		
* p-value incompatible with t-Bounds distribution.			

The ECM model in Table 4.5 estimates the short-run dynamics and adjustment process of manufacturing output in response to renewable and non-renewable energy generation, labour and gross capital formation, based on the ARDL (1, 1, 3, 5, 4) specification using 39 annual observations over the 1985-2023 time period. The constant term is 10.00686. This is highly significant and captures the baseline level of manufacturing sector output growth in the absence of short-term shocks from the explanatory variables.

Renewable energy generation in the current period does not have a significant immediate effect on manufacturing output, with a coefficient of 0.009095. This indicates that short-term fluctuations in renewable energy generation do not directly influence manufacturing sector production. Non-renewable energy generation, however, displays delayed but meaningful effects. While the contemporaneous and immediate change is negative and insignificant at -0.011076, the first and second lags are positive and significant. A 1% increase in non-renewable energy generation one year earlier raises current manufacturing output by 0.040%, while a 1% increase two years ago raises output by 0.038%. This finding implies that non-renewable-based energy contributes to production with a delay, likely reflecting the time required for investments and infrastructure to influence industrial processes.

Labour input largely shows insignificant short-run effects, except for the fourth lag. The immediate change of 0.360737 is insignificant and the first three lags are also insignificant. However, the fourth lag is negative and significant at -1.178193. This implies that a 1% increase in labour four years earlier is associated with a 1.178% decline in current manufacturing output. This delayed negative impact may reflect inefficiencies in labour absorption or mismatches between labour growth and the technological requirements of the manufacturing sector.

Gross capital formation is a strong and consistent driver of manufacturing sector output in the short run. The immediate change is positive and significant at 0.131822, thus implying that a 1% increase in gross capital formation in the current year raises manufacturing sector output by 0.132%. Moreover, the second and third lags of gross capital formation remain positive and significant at 0.047901 and 0.092972, respectively, thus demonstrating that capital investments continue to support manufacturing performance over subsequent years. This phenomenon reflects the gradual productivity gains from infrastructure, machinery and technology upgrades.

The ECM term has a coefficient of -0.763072 and is highly significant. This confirms the presence of cointegration and a rapid adjustment toward the long-run equilibrium. This indicates that approximately 76.3% of any disequilibrium from the previous year is corrected within the current year, highlighting the manufacturing sector's ability to quickly return to its long-term growth path following short-term shocks.

Model diagnostics confirm the robustness of the ECM model. The R-squared of 0.848691 implies that about 85% of the short-run variation in manufacturing sector output is explained by the model, while the adjusted R-squared of 0.760428 accounts for the number of regressors. The F-statistic value of 9.615451 confirms the joint

significance of the explanatory variables. The Durbin-Watson statistic of 1.624827 implies no major autocorrelation issues.

The ECM findings demonstrate that renewable energy generation does not exert an immediate short-run influence, whereas non-renewable energy generation contributes positively with a delay. Gross capital formation emerges as the strongest positive driver both contemporaneously and over subsequent years, while labour shows a delayed negative effect, pointing to potential inefficiencies in workforce absorption. The manufacturing sector exhibits a very high speed of adjustment, correcting the majority of disequilibrium within a year and thereby maintaining resilience and alignment with long-run growth.

4.5.3 F-Bounds Test

Table 4.6. F-Bounds Test

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	14.51641	10%	2.45	3.52
K	4	5%	2.86	4.01
		2.5%	3.25	4.49
		1%	3.74	5.06

To examine the existence of a long-run relationship, the ARDL bounds testing procedure was applied as shown in Table 4.6. The computed F-statistic of 14.51641 exceeds the 1 percent upper critical value of 5.06, thus leading to the rejection of the null hypothesis of no cointegration. This confirms that manufacturing output and the independent variables share a stable long-run equilibrium relationship.

Post Diagnostic Tests

Normality Test

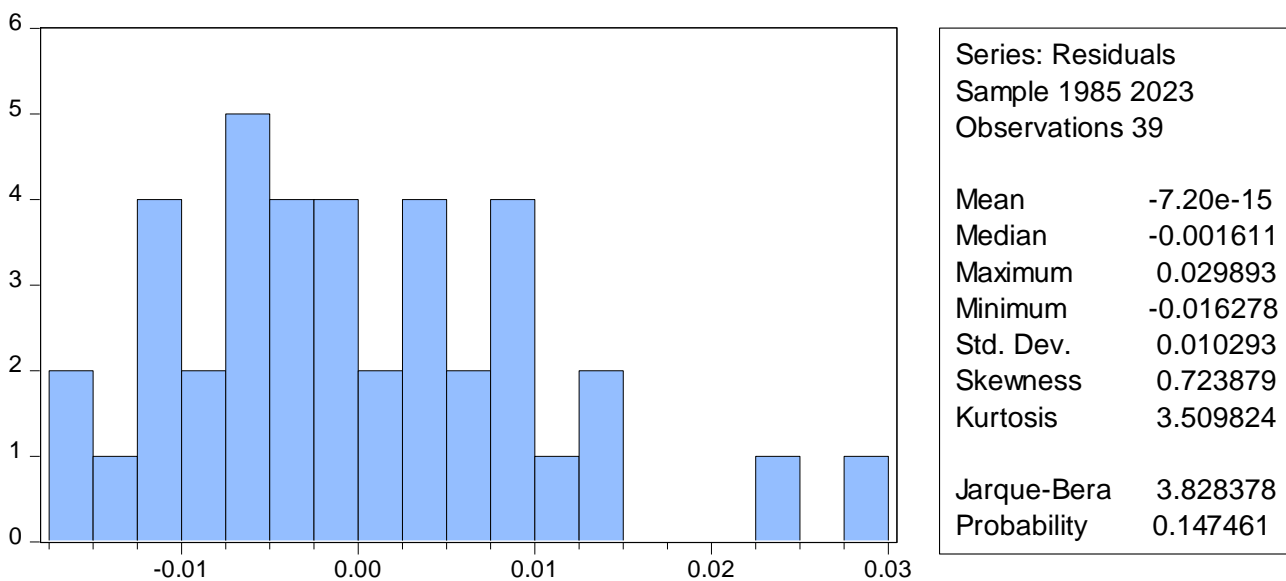


Figure 4.1 Normality Test

With a probability of 0.147461 as in Figure 4.1, the analysis confirmed that the model residuals were symmetrically distributed.

4.5.4.2 Test for Serial Correlation

Table 4.7 Serial Correlation LM Test

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	1.002587	Prob. F(2,18)	0.3865
Obs*R-squared	3.909079	Prob. Chi-Square(2)	0.1416

The serial correlation test in Table 4.7 returned an F-statistic of 1.002587 with a probability of 0.3865 and an observed R-squared of 3.909079 with a corresponding probability of 0.1416. Both results exceed the 5 percent significance threshold, thus leading to the non-rejection of the null hypothesis of no serial correlation, indicating that the residuals are independently distributed, thus satisfying a fundamental assumption of time series modeling.

Test for Heteroskedasticity

Table 4.8 Heteroskedasticity Test: Breusch-Pagan-Godfrey

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	0.305992	Prob. F(18,20)	0.9927
Obs*R-squared	8.421189	Prob. Chi-Square(18)	0.9717
Scaled explained SS	2.779185	Prob. Chi-Square(18)	1.0000

The heteroskedasticity test results in Table 4.8 produced an F-statistic of 0.305992 with an associated probability of 0.9927. These findings strongly support the null hypothesis of homoskedasticity, indicating that the residual variance is constant over time. This consistency in variance enhances the reliability of the coefficient estimates and the validity of hypothesis testing.

CUSUM stability Test

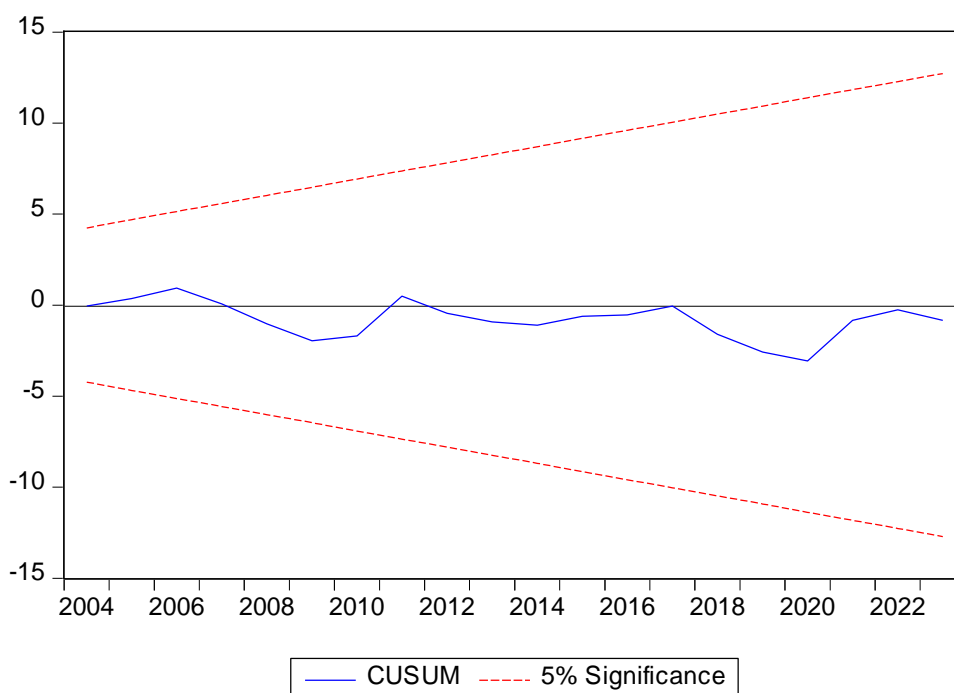


Figure 4.2 CUSUM Stability Test

The CUSUM test for structural stability, as shown in Figure 4.2, shows that the recursive residuals and their cumulative sums remained within the 5% significance boundaries throughout the study period, thereby confirming that the model is structurally stable, with no major policy or structural breaks affecting the relationship between renewable energy generation and manufacturing sector output.

CONCLUSIONS AND POLICY IMPLICATIONS

This study demonstrates that renewable energy generation is a key driver of long-run manufacturing growth in Kenya, with the effects of labour and gross capital formation to a great extent, complementing energy investments. Short-run effects are limited, thus highlighting the need for sustained and coordinated renewable energy-industrial policies.

For local policy, these findings reinforce Kenya's Energy Act (2019) and Vision 2030, suggesting that scaling up renewable energy infrastructure and incentivizing private sector adoption can accelerate manufacturing and industrial productivity while reducing dependence on non-renewable energy sources. Globally, the results align with SDG 7 and SDG 9, supporting strategies and interventions for affordable, clean energy and sustainable industrialization. The evidence also provides a framework for aligning national energy targets with international commitments such as the Paris Agreement, thereby promoting green manufacturing and environmental resilience and sustainability.

Policymakers can use these insights to prioritize renewable energy in manufacturing as well as industrial planning, optimize capital and labour deployment and to also design interventions that foster energy-efficient, competitive and sustainable manufacturing. The study thus offers actionable guidance for both Kenya and other developing economies pursuing green industrial growth.

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