Powering Sustainable Agricultural Growth: The Impact of Renewable Energy Consumption on Kenya's Agriculture Sector

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DOI: https://dx.doi.org/10.51244/IJRSI.2025.1210000297

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

ABSTRACT

This study examines the impact of renewable energy consumption on Kenya's agricultural sector from 1987 to 2023 using an ARDL model. Results reveal that renewable energy exerts initially negative but significant positive effects on agricultural output with lags of three to six years, reflecting the time required for irrigation, mechanization and storage systems to enhance productivity. Non-renewable energy shows negative short-term but positive lagged impacts, highlighting cost and efficiency trade-offs. Labour contributes positively in the short run but displays delayed negative effects, while gross capital formation displays mixed outcomes, indicating timing and efficiency challenges. The ECM model indicates a rapid adjustment toward long-run equilibrium by correcting 71.7% of disequilibrium annually. The F-Bounds testing confirms a stable long-run association and the diagnostic checks, normality, heteroskedasticity, serial correlation and CUSUM tests support the model's robustness and reliability. The results of this study emphasize that the adoption of renewable energy delivers substantial delayed gains in agricultural growth and productivity, thereby emphasizing the need for sustained investment, proper implementation and maintenance of renewable energy infrastructure to drive and accelerate sustainable sectoral growth in Kenya while ensuring environmental preservation at the same time. This study therefore recommends aligning of Kenya's agricultural energy transition with the Sustainable Development and Ecological modernization frameworks by integrating decentralized renewable energy systems into Vision 2030 and rural electrification interventions so as to boost productivity, resilience and environmental sustainability.

Keywords: Renewable energy consumption, agriculture sector, sustainable agricultural development

INTRODUCTION

Globally, the agricultural sector is essential in making sure that there is adequate food for the population and raw materials for the industries. The sector also provides job opportunities and contributes about 4.3% to the global GDP (Food and Agriculture Organization of the United Nations, 2020). The document asserts that in the case of the developed world, agriculture is highly mechanized and technology-driven, thereby boosting its growth.

According to (FAO,2020) this important sector is a backbone of Kenya's economy as it contributes substantially to employment, food security and the GDP. Despite its significance, the agriculture sector faces significant energy-related challenges such as unreliable electricity supply, the high non-renewable energy costs and limited access to modern energy technologies in rural areas. The traditional dependence on non-renewable energies serves to increase production costs, reduces efficiency and exposes farmers to environmental and price instabilities. Renewable energy sources such as solar, wind, geothermal and biomass offer a viable roadmap to enhancing energy security and sustainability. While the uptake of renewable energy is increasing in Kenya, the direct contribution of renewable energy consumption to agricultural output remains underexplored. The sector's energy needs, such as post-harvest processing and cold storage, as well as agro-processing, suggest that renewable energy could play a significant role in boosting growth and productivity. On the other hand, infrastructural readiness, technology adoption, capital deployment and human resource absorption may moderate or delay the benefits of clean green energy adoption. Empirical evidence from other jurisdictions such as the sub-Saharan Africa and Asia, shows positive relationships between renewable energy access and agricultural growth and productivity. This needed to be done in the Kenyan context.

According to Kenya National Bureau of Statistics (2023**)**, the agriculture sector in Kenya continues to contend with the ever-rising power costs, intermittent power supply, power blackouts, load shedding and low integration of renewable energy systems. Though there's increased uptake of renewable energy, its direct impact on agricultural output remains underexplored. The understanding of this relationship is important in guiding investment decisions, policy formulation and in spearheading technological adoption and achieving sustainable and climate-resilient agricultural growth. Therefore, this study sought to establish the short-run and long-run effects of the use of renewable energy on agricultural output while at the same time exploring how labour and gross capital formation moderate this important relationship.

The results of this study will go a long way in helping policymakers, investors and other agricultural stakeholders with an evidence-based and data-driven picture into the role of renewable energy consumption in enhancing sustainable agricultural development while ensuring environmental preservation and conservation. By establishing both contemporaneous and delayed effects of renewable energy consumption, the study highlights the timing and magnitude of renewable energy interventions that are necessary in optimizing growth and productivity. This is meant to improve efficiency and strengthen resilience against environmental and economic shocks. This study also sought to fill a key gap in the literature where a few studies have rigorously investigated the dynamic and sector-specific impacts of renewable energy consumption on Kenya's agricultural output using advanced econometric methodologies such as the ARDL and ECM, while accounting for the moderating roles of the non-renewable energy forms, labour and capital inputs.

LITERATURE REVIEW

Some empirical studies, such as Obange (2019), while exploring data for the period 1970-2010 using the VECM in Kenya, found that renewable energy consumption has a substantial and positive impact on the performance of the agricultural sector, with this effect being one-directional. The study found a one-way relationship where energy consumption drives agricultural growth. However, it did not consider other factors that may influence the level of agricultural growth apart from energy consumption. This study exploited other variables in the model, as energy consumption cannot be the only factor influencing the growth of the sectors. This study also adopted capital, labour and non-renewable energy constructs as the study's control variables. Other factors affecting sectoral growth, beyond the listed factors, were accounted for by the error term in this study.

Sartbayeva *et al.* (2023) examined the link between renewable energy consumption, economic growth and the agro-industrial sector in Kazakhstan, utilizing data from 1991 to 2021. Their findings revealed a one-way relationship where agricultural production influences renewable energy consumption. The study employed hierarchical regression analysis for its assessment. However, despite being conducted in a more developed economy, the research did not quantify the strength of the relationship. The study, just like many studies in this area, suffers from the problem of aggregation of the impacts, hence making policymaking a nullity. This study addressed this shortcoming by disaggregating energy consumption into the various amounts of renewable energy consumed. This study is disaggregated to mitigate this.

Liang *et al.* (2020), in Kazakhstan, while analyzing the consumption patterns of livestock products in Kazakhstan over the periods 1992–2000 and 2000–2013 using both qualitative and quantitative methods, made use of descriptive statistics, trend analysis and assessment of socio-economic and ecological factors to analyze the characteristics and determinants of milk, meat and egg consumption across different regions. The study established the presence of a feedback cause-effect relationship between the consumption of renewable energy and the performance of the agricultural sector. This is because the animal feeds needed energy to prepare and in turn, the increased renewable energy consumption meant more output from the important sector. The study, however, is silent on the magnitudes of the associations. The ARDL and ECM methodologies employed by this study are critical in determining not only the magnitudes and direction but also the speeds of adjustment too.

Smagulova *et al.* (2023), also in Kazakhstan aimed to investigate the relationship existing between the two variables by coming up with an econometric model intended to determine the connection existing between electricity generation and usage and digital farms on increased output from the agricultural industry. The study made use annual data from 2017 to 2021 and employed multiple regression analysis to examine the influence of factors such as electricity production and the total number of digital agricultural farms on gross agricultural output in Kazakhstan. The methodology is robust but may be limited by the relatively short five-year period. Smagulova *et al.* (2023) concluded that these variables possessed a significant influence on agricultural production. The study, however, is from a more developed economy. This was needed to conduct this study in Kenya as Kazakhstan may not reflect the Kenyan situation politically, economically, climate-wise and also in terms of energy resources endowments. The time period under consideration was also too short for a sound econometric study. This study addressed this shortcoming for exploiting a sufficient dataset of the period 19802023.

Zou (2022) aimed to investigate the connection between agricultural productivity and energy consumption in China, utilizing the Toda Yamagoto tests along with data from 1953 to 2020. The findings revealed a reciprocal relationship between energy use and agricultural output. However, the study considered energy consumption as a single aggregate variable, highlighting the need for further analysis by separating renewable and non-renewable energy sources to understand their individual effects. Additionally, given that China is at a different level of economic development than Kenya, conducting a similar study in Kenya was necessary to account for regional differences.

Ahmad *et al.* (2019), in its quest to establish the linkage between renewable energy uptake, economic growth and environmental dynamics in China, while exploiting the 1981-2996 dataset, determined that there was no Granger-causality existing between the usage of energy and the performance of the agricultural sector and suggested that the stringent energy-saving mechanisms employed in the agricultural industry will not ultimately adversely affect agricultural activities. However, a Granger-causality bidirectional relationship was found to exist between the variables across eastern and western China in the period 1990-2008, but no causal relationship in central China. The differences were attributed to economic and social differences amongst the regions (Hu *et al.,* 2011. The study, however, harbours the inadequacies of aggregation, which is one of the critical shortcomings of existing literature that this study sought to mitigate.

Similarly, Tiwari *et al.* (2021), in a bid to establish the linkage between electricity consumption and overall growth of the economic sectors, drawing on data covering the period 1960-2015, established a unidirectional long-run heterogeneous panel causality flowing from electricity usage to agricultural productivity in India. The inquiry also established a causality flowing from industrial growth to electricity usage. The study, besides being silent on the intensities of the association, cannot be replicated in Kenya due to the social and economic differences between Kenya and India, hence the need for this study.

According to Martinho (2016), a study done in 12 EU member states' farms using data for the period 1989-2009 and for the years 2004–2012 to establish the efficiency and growth implications of renewable energy use in the agricultural sector across Europe, found that energy consumption negatively affected agricultural growth. It was therefore concluded that though the relationship was significant, it was negative. The data under consideration was analyzed using the different econometric techniques; the GMM and frameworks drawing from the Kaldor developments. The study, however, did not solely focus on renewable energy but instead dealt with energy consumption as a variable. aggregation of the impacts is one of the gaps of past knowledge that this study sought to address.

RESEARCH METHODOLOGY

In order to determine the influence of renewable energy consumption on the agricultural sector in Kenya, the Solow Swan growth model was adopted. The basic Cobb-Douglas production function was linearized by the introduction of lags. The outputs were therefore interpreted as percentages. The lagged effects were also incorporated as results of economic decisions do not occur instantaneously but take time.

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

Where $Ln(AGR_t)$ is the logged agricultural output at time t, LnA is the total factor productivity, $\alpha_1 Ln(REC_t)$ is

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

logged renewable energy consumption, $\alpha_2 Ln(NREC_t)$ is logged non-renewable energy consumption, $\alpha_3 Ln(K_t)$ is logged gross capital formation, $\alpha_4 Ln(L_t)$ is logged labour, while the values with *(t-1)* are the lagged values of the variables in the model, while ε_t is the error term.

RESULTS AND DISCUSSION

Descriptive statistics

Table 4:1 -Descriptive Statistics

	AGR (”000000”)	REC	NREC (“000000”)	L (“{000000”)	GCF(“OF_GDP”)
Mean	1102373.	19791.70	0.137666	13.54270	20.09076
Median	1077750.	16115.00	0.117500	12.73076	19.73131
Maximum	1783299.	46600.00	0.242000	23.18485	25.44904
Minimum	593460.3	6000.000	0.072000	5.341202	15.00382
Std. Dev.	348262.3	10732.72	0.057575	5.556273	2.956138
Skewness	0.368935	0.900081	0.577631(	0.205444	0.087421
Kurtosis	1.892409	2.769333	1.841721	1.682008	2.157324
Jarque-Bera	3.247219	6.038611	4.906443	3.494208	1.357899
Probability	0.197186	0.048835	0.086016	0.174278	0.507149
Sum	48504415	870835.0	6.057312	595.8787	883.9934
Sum Sq. Dev.	5.22E+12	4.95E+09	0.142540	1327.503	375.7664
Observations	44	44	44	44	44

(Source: Author,2025)

Table 4.1 provides a statistical highlight of Kenya’s agricultural sector and related variables; renewable and non-renewable energy consumption, gross capital formation and labour. The findings show that agricultural output averaged 1.10 trillion shillings, emphasizing the critical economic role it plays despite seasonal and climatic fluctuations. Renewable energy consumption shows a rising pattern, averaging 19791.70 kilowatt-hours. This reflects Kenya’s increasing efforts in adopting renewable energy uptake, while non-renewable consumption remained dominant, averaging 137666.2 kilowatt-hours due to persistent industrial and transport dependence on non-renewable energies. Labour recorded a steady increase, with a mean of 13.5 million. This indicates consistent population and workforce growth supporting agricultural sector growth and productivity. Gross capital formation averaged 20.09% of GDP, thus emphasizing Kenya’s sustained investment efforts in infrastructure and industrial development.

Stationarity Test Results

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	

AGR	-2.001507 (0.5840)	-4.964347 (0.0014)	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 presents the ADF stationarity test results. The results confirm that agricultural output, renewable energy consumption, non-renewable energy consumption and gross capital formation are non-stationary at level but become stationary after first differencing, hence integrated of order one. Labour, however, is stationary at level, making it I(0). The mix of I(0) and I(1) variables fulfills the conditions for applying the ARDL bounds testing approach.

Lag Length Determination

The selection of the optimum lag length was determined using the AIC criterion in the ARDL framework. This ensured the model captured relevant dynamics with optimal simplicity for both long-run and short-run estimations.

ARDL Analysis: Influence of Renewable Energy consumption on the growth of the Agriculture sector in Kenya, ARDL Test

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

Dependent Variable: AGR				
Method: ARDL				
Date: 07/08/25 Time: 18:24				
Sample (adjusted): 1987 2023				
Included observations: 37 after adjustments				
Maximum dependent lags: 1 (Automatic selection)				
Model selection method: Akaike info criterion (AIC)				
Dynamic regressors (7 lags, automatic): REC NREC L GCF				
Fixed regressors: C				
Number of models evalulated: 4096				
Selected Model: ARDL(1, 7, 3, 7, 7)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
AGR(-1)	0.282817	0.112999	2.502826	0.0408
REC	-0.067696	0.048539	-1.394688	0.2058
REC(-1)	-0.052828	0.036293	-1.455606	0.1888
REC(-2)	-0.012091	0.042688	-0.283229	0.7852
REC(-3)	0.112919	0.041338	2.731598	0.0293
REC(-4)	0.025640	0.038634	0.663665	0.5281
REC(-5)	-0.110642	0.032288	-3.426682	0.0110
REC(-6)	-0.088877	0.031220	-2.846809	0.0248
REC(-7)	-0.207625	0.041923	-4.952563	0.0017

NREC	-0.271538	0.116333	-2.334132	0.0523
NREC(-1)	0.338585	0.127249	2.660807	0.0324
NREC(-2)	0.019098	0.108987	0.175234	0.8659
NREC(-3)	0.417027	0.129969	3.208657	0.0149
L	1.716309	1.081074	1.587595	0.1564
L(-1)	-0.301677	1.701800	-0.177270	0.8643
L(-2)	-2.268661	1.728076	-1.312825	0.2306
L(-3)	2.139133	1.886039	1.134193	0.2941
L(-4)	-3.181687	2.097392	-1.516973	0.1731
L(-5)	2.793991	2.452747	1.139127	0.2921
L(-6)	-4.855929	2.783281	-1.744678	0.1246
L(-7)	4.337322	1.543880	2.809364	0.0262
GCF	-0.032973	0.057902	-0.569456	0.5868
GCF(-1)	0.086335	0.046738	1.847214	0.1072
GCF(-2)	-0.232436	0.064752	-3.589666	0.0089
GCF(-3)	0.198371	0.063642	3.117010	0.0169
GCF(-4)	-0.106129	0.048863	-2.171972	0.0664
GCF(-5)	0.199645	0.064921	3.075217	0.0179
GCF(-6)	-0.078539	0.057053	-1.376591	0.2111
GCF(-7)	0.067598	0.063365	1.066808	0.3215
C	11.50460	2.226687	5.166690	0.0013
R-squared	0.999328	Mean dependent var		27.76565
Adjusted R-squared	0.996547	S.D. dependent var		0.269067
S.E. of regression	0.015812	Akaike info criterion		-5.499480
Sum squared resid	0.001750	Schwarz criterion		-4.193330
Log likelihood	131.7404	Hannan-Quinn criter.		-5.039001
F-statistic	359.2182	Durbin-Watson stat		3.128133
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 agriculture sector was estimated using 37 adjusted observations over the period from 1987 to 2023. The optimal lag structure was selected based on the AIC criterion and specified as ARDL (1, 7, 3, 7, 7), reflecting one lag of the dependent variable and multiple lags for the independent variables. The dependent variable in this model is agricultural sector output, while the independent variables include renewable energy consumption, non-renewable energy consumption, labour and gross capital formation. All data were log-transformed, making the interpretation elasticity-based.

The coefficient of the lagged dependent variable, AGR(-1), is 0.282817, with a standard error of 0.112999, a tstatistic of 2.502826 and a probability value of 0.0408. This coefficient is statistically significant at the 5% level. It indicates that a 1% increase in agricultural output in the previous period leads to a 0.282817% increase in the current period's output. This positive carryover effect is consistent with the notion of inertia in agricultural production where past harvests, investment cycles and seasonal factors influence current outcomes. It demonstrates the partial but meaningful path dependence in the performance of the agriculture sector.

The contemporaneous value of renewable energy consumption has a coefficient of -0.067696, a standard error of 0.048539, a t-statistic of -1.394688 and a probability value of 0.2058. This result is statistically insignificant, suggesting that a 1% increase in renewable energy consumption in the current year has no meaningful effect on agriculture output. This may reflect the sector's limited short-term sensitivity to energy changes, particularly if energy-intensive applications such as irrigation, drying and refrigeration are not widespread or are delayed in their impact.

The lagged value of renewable energy consumption at lag one, REC(-1), has a coefficient of -0.052828, a standard error of 0.036293, a t-statistic of -1.455606 and a probability value of 0.1888. This too is statistically insignificant, indicating no notable effect one year after consumption changes. The second lag, REC(-2), has a coefficient of -0.012091, a standard error of 0.042688, a t-statistic of -0.283229 and a probability of 0.7852, remaining statistically insignificant. However, at lag three, REC(-3) shows a significant coefficient of 0.112919, with a standard error of 0.041338, a t-statistic of 2.731598 and a probability of 0.0293. This implies that a 1% increase in renewable energy consumption three years earlier is associated with a 0.112919 % increase in current agricultural output. This lagged impact is likely driven by the gradual integration of renewable energy technologies in farm-level activities, such as solar-powered irrigation or biogas-based processing, which require time to implement and become productive.

Interestingly, REC(-5) has a coefficient of -0.110642, standard error of 0.032288, a t-statistic of -3.426682 and a probability value of 0.0110, which is statistically significant at the 5% level. This result suggests that a 1% increase in renewable energy consumption five years earlier reduces agricultural output today by 0.110642%. Similarly, REC(-6) has a coefficient of -0.088877, a standard error of 0.031220, a t-statistic of -2.846809 and a probability value of 0.0248, also indicating a significant negative effect. The seventh lag, REC(-7), is even more impactful, with a coefficient of -0.207625, a standard error of 0.041923, a t-statistic of -4.952563 and a probability of 0.0017. This implies that a 1% increase in renewable energy consumption seven years ago reduces current agricultural output by 0.207625%. These delayed negative effects may be attributed to the initial inefficiencies, poor targeting or technical failures in past renewable energy investments, especially in off-grid rural areas where equipment maintenance and energy reliability are known challenges.

Regarding non-renewable energy consumption, the contemporaneous value of NREC has a coefficient of 0.271538, a standard error of 0.116333, a t-statistic of -2.334132 and a probability value of 0.0523. This coefficient is marginally significant at the 10% level and suggests that a 1% increase in non-renewable energy consumption in the current period leads to a 0.271538% reduction in agriculture output. This negative outcome may stem from the rising costs of fossil fuels or the unsuitability of non-renewable energy infrastructure for the unique demands of the agricultural sector. On the other hand, the first lag of non-renewable energy consumption, NREC(-1), has a coefficient of 0.338585, a standard error of 0.127249, a t-statistic of 2.660807 and a probability value of 0.0324. This coefficient is statistically significant at the 5% level, indicating that a 1% increase in NREC one year ago raises agricultural output today by 0.338585%. This may reflect time-lagged benefits of energy used for land preparation, storage or input production. NREC(-3) is also significant, with a coefficient of 0.417027, a standard error of 0.129969, a t-statistic of 3.208657 and a probability of 0.0149. This implies that a 1% increase in non-renewable energy consumption three years earlier results in a 0.417027% rise in output, possibly driven by delayed input-output responses in agricultural mechanization. Other lags of non-renewable energy consumption are statistically insignificant.

Labour enters the model through multiple lags, with only the seventh lag, L(-7), showing statistical significance. Its coefficient is 4.337322, with a standard error of 1.543880, a t-statistic of 2.809364 and a probability value of 0.0262. This result suggests that a 1% increase in labour input seven years ago increases current agricultural output by 4.337322%. This substantial and highly delayed effect may capture the impact of long-term agricultural education, skill development or rural employment programs that take years to manifest through productivity.

Gross capital formation also exhibits mixed results across lags. The second lag, GCF(-2), has a coefficient of 0.232436, a standard error of 0.064752, a t-statistic of -3.589666 and a probability of 0.0089, which is statistically significant. This implies that a 1% increase in capital investment two years ago is associated with a 0.232436% reduction in output, possibly reflecting sunk costs or misallocated funds. On the other hand, the third lag, GCF(-3), shows a positive and significant coefficient of 0.198371, a standard error of 0.063642, a t-statistic of 3.117010 and probability of 0.0169. This means that a 1% increase in capital investment three years earlier leads to a 0.198371% increase in agricultural output, indicating delayed but productive investments. Similarly, GCF(-5) has a positive and significant coefficient of 0.199645, with a standard error of 0.064921, a t-statistic of 3.075217 and a probability value of 0.0179. These findings suggest that capital investment can have either negative or positive outcomes depending on timing, project type and implementation efficiency.

The constant term in the model is 11.50460, with a standard error of 2.226687, a t-statistic of 5.166690 and a probability of 0.0013, which is highly significant. This value captures the baseline level of output not explained by the regressors, including institutional, policy or environmental factors.

The ARDL results show that renewable energy consumption exerts both positive and negative effects on agricultural output, depending on the lag period, with insignificant short-term impacts but significant effects appearing between the third and seventh year. This reflects the long gestation period of renewable energy investments in agriculture, such as irrigation and storage systems, which take time before boosting productivity. Non-renewable energy provides positive medium-term support but has a negative immediate impact, suggesting that while fossil fuels can temporarily enhance farm operations, their costs and inefficiencies undermine shortrun output. Labour influences are highly delayed, consistent with the seasonal and structural dynamics of agricultural employment, while capital investment displays alternating productivity effects, indicating inefficiencies or misallocation in some periods. The findings emphasize that the agriculture–energy relationship in Kenya is strongly dependent on timing, implementation and sector-specific dynamics.

The model has a very high explanatory power, with an R-squared value of 0.999328 and an adjusted R-squared of 0.996547. This indicates that over 99.9% of the variation in agricultural output is explained by the included variables and their lags. The F-statistic is 359.2182 with a probability value of 0.000000, confirming that the regressors are jointly significant. The D-W statistic is 3.128133, which is higher than the ideal value of 2, suggesting potential negative serial correlation and warranting further diagnostic testing.

Influence of renewable energy consumption on the growth of the agricultural sector in Kenya, ARDL Error Correction Regression

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

ARDL Error Correction Regression				
Dependent Variable: D(AGR)				
Selected Model: ARDL(1, 7, 3, 7, 7)				
Case 3: Unrestricted Constant and No Trend				
Date: 07/08/25 Time: 18:24				
Sample: 1980 2023				
Included observations: 37				
ECM Regression				
Case 3: Unrestricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	11.50460	1.233369	9.327783	0.0000
D(REC)	-0.067696	0.026746	-2.531086	0.0392
D(REC(-1))	0.280675	0.037713	7.442427	0.0001
D(REC(-2))	0.268585	0.038212	7.028788	0.0002
D(REC(-3))	0.381504	0.039371	9.690048	0.0000
D(REC(-4))	0.407144	0.040916	9.950698	0.0000
D(REC(-5))	0.296502	0.038731	7.655370	0.0001
D(REC(-6))	0.207625	0.025145	8.256955	0.0001
D(NREC)	-0.271538	0.054894	-4.946549	0.0017

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

D(NREC(-1))	-0.436126	0.079017	-5.519387	0.0009
D(NREC(-2))	-0.417027	0.088469	-4.713803	0.0022
D(L)	1.716308	0.648811	2.645314	0.0332
D(L(-1))	1.035831	0.806532	1.284302	0.2399
D(L(-2))	-1.232830	0.749316	-1.645274	0.1439
D(L(-3))	0.906302	0.803013	1.128627	0.2962
D(L(-4))	-2.275385	0.812007	-2.802173	0.0264
D(L(-5))	0.518607	1.187860	0.436589	0.6756
D(L(-6))	-4.337323	1.093900	-3.965009	0.0054
D(GCF)	-0.032973	0.029410	-1.121154	0.2992
D(GCF(-1))	-0.048510	0.032548	-1.490427	0.1797
D(GCF(-2))	-0.280947	0.036205	-7.759982	0.0001
D(GCF(-3))	-0.082575	0.030396	-2.716640	0.0299
D(GCF(-4))	-0.188704	0.027976	-6.745274	0.0003
D(GCF(-5))	0.010941	0.029298	0.373445	0.7199
D(GCF(-6))	-0.067598	0.027921	-2.421069	0.0460
CointEq(-1)*	-0.717183	0.077013	-9.312503	0.0000
R-squared	0.965224	Mean dependent var		0.024356
Adjusted R-squared	0.886186	S.D. dependent var		0.037389
S.E. of regression	0.012614	Akaike info criterion		-5.715696
Sum squared resid	0.001750	Schwarz criterion		-4.583700
Log likelihood	131.7404	Hannan-Quinn criter.		-5.316615
F-statistic	12.21223	Durbin-Watson stat		3.128133
Prob(F-statistic)	0.000061			
* p-value incompatible with t-Bounds distribution.				

(Source: Author, 2025)

The ECM model in Table 4:4 presents the short-run effects of renewable and non-renewable energy consumption, labour and gross capital formation on agricultural sector output in Kenya, together with the adjustment speed toward long-run equilibrium. The model is estimated using 37 observations based on the ARDL(1,7,3,7,7) specification.

The constant term has a coefficient of 11.50460 with a standard error of 1.233369, a t-statistic of 9.327783 and a probability value of 0.0000. This is highly significant and captures the autonomous short-run growth in agriculture when all differenced regressors are neutral.

Renewable energy consumption shows an immediate negative impact. The coefficient of the contemporaneous differenced value is -0.067696 with a t-statistic of -2.531086 and a probability value of 0.0392. This result indicates that a 1% increase in renewable energy consumption in the current year reduces agricultural output by 0.0677%, which may reflect short-term inefficiencies, installation disruptions or adjustment costs in adopting renewable systems. However, the lagged values reveal significant and positive effects. The first lag has a coefficient of 0.280675 with a probability value of 0.0001, showing that renewable energy consumption in the previous year raises current agricultural output by 0.281%. The second lag is 0.268585 with a probability value of 0.0002, while the third lag is 0.381504 with a probability value of 0.0000. The fourth lag rises further to 0.407144 with a probability value of 0.0000, representing the strongest positive effect. The fifth lag is 0.296502 with a probability value of 0.0001 and the sixth lag is 0.207625 with a probability value of 0.0001. These findings demonstrate that renewable energy consumption has clear delayed benefits, with substantial productivity gains becoming visible between one and six years later. This suggests that renewable energy projects in irrigation, mechanization and storage require time for full integration and adaptation before their contributions to output materialize.

Non-renewable energy consumption consistently shows negative and significant effects. The contemporaneous coefficient is -0.271538 with a t-statistic of -4.946549 and a probability value of 0.0017, indicating that a 1% increase in non-renewable energy consumption reduces agricultural output by 0.272% in the same year. The first lag is -0.436126 with a probability value of 0.0009 and the second lag is -0.417027 with a probability value of 0.0022. These consistent negative impacts confirm that reliance on fossil fuels undermines agricultural productivity, likely due to high operating costs, volatile pricing and inefficiencies linked to pollution and environmental degradation.

Labour input reveals both positive and negative influences. The contemporaneous coefficient is 1.716308 with a probability value of 0.0332, meaning that a 1%increase in labour raises agricultural output by 1.72% in the same period. However, the fourth lag is negative at -2.275385 with a probability value of 0.0264 and the sixth lag is -4.337323 with a probability value of 0.0054. These delayed contractionary effects suggest that while labour can immediately contribute to productivity, structural inefficiencies, underemployment or low absorption of unskilled workers eventually weigh down agricultural performance over time.

Gross capital formation exerts predominantly negative short-run effects. The contemporaneous coefficient is 0.032973 with a probability value of 0.2992, which is statistically insignificant. The second lag is strongly negative at -0.280947 with a probability value of 0.0001, while the third lag is -0.082575 with a probability value of 0.0299. The fourth lag is -0.188704 with a probability value of 0.0003 and the sixth lag is -0.067598 with a probability value of 0.0460. These results indicate that gross capital formation often suppresses agricultural output in the short run, possibly due to delayed project implementation, misallocation of resources or long gestation periods before capital investments can be productively utilized.

The ECM term has a coefficient of -0.717183 with a standard error of 0.077013, a t-statistic of -9.312503 and a probability value of 0.0000. This coefficient is highly significant and negative as expected, confirming cointegration. It implies that about 71.7% of disequilibrium from the previous year is corrected in the current period, showing a relatively fast adjustment speed where most shocks are absorbed within one to two years.

The diagnostic statistics indicate strong model performance. The R-squared is 0.965224, showing that 96.5% of the variation in agricultural output is explained by the short-run regressors. The adjusted R-squared is 0.886186. The F-statistic is 12.21223 with a probability value of 0.000061, confirming that the variables are jointly significant. The D-W statistic is 3.128133, suggesting possible negative autocorrelation in the residuals, which may call for robustness checks.

The ECM results demonstrate that renewable energy consumption has an initially negative but strongly positive delayed effect on agricultural output, reflecting the time required for renewable systems to be integrated and absorbed into farm operations. Non-renewable energy consumption consistently reduces output, highlighting its cost inefficiencies and environmental burden. Labour exerts both immediate positive and delayed negative effects, underlining productivity challenges in rural employment structures. Gross capital formation tends to contract output in the short run, likely due to inefficiencies in project timing and sectoral alignment. The relatively fast adjustment speed of over 71% correction annually confirms that agriculture in Kenya is highly responsive to restoring equilibrium, even amid short-run volatility.

Influence of renewable energy consumption on the growth of the agricultural sector in Kenya, F-Bounds Test

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

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	11.03744	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)

The F-statistic of 11.03744 as shown in Table 4:46, is well above the 1% upper bound critical value of 5.06. Thus, the test confirms the presence of a long-run relationship among the variables, supporting the validity of the ARDL model.

Post Diagnostic Tests

Test for Normality

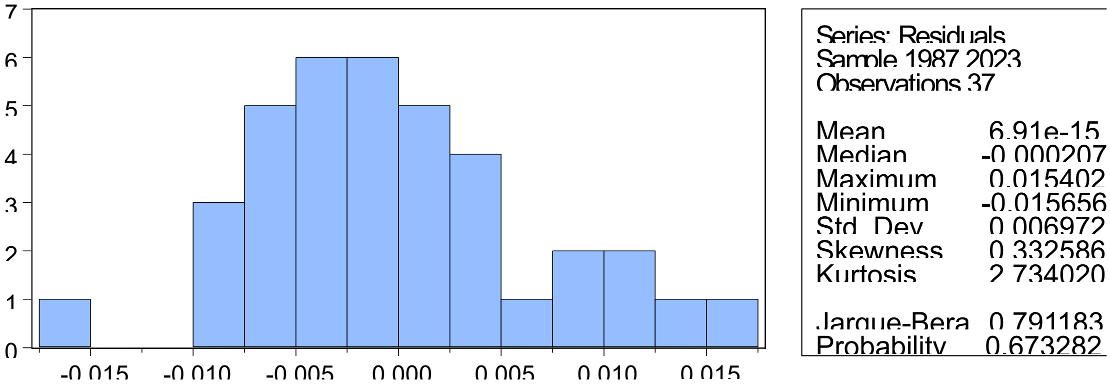

Figure 4:1-Influence of renewable energy consumption on the growth of the agricultural sector in Kenya, J-B Normality Test

(Source: Author, 2025)

Residuals in Figure 4:1 assumed normality based on smooth curve and a probability value of 0.673282 which is above the conventional 0.05.

4.7.2 Test for Serial Correlation

Table 4:6-Influence of renewable energy consumption on the growth of the agricultural sector in Kenya, Breusch-Godfrey Correlation LM Test

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	3.226306	Prob. F(2,5)	0.1259
Obs*R-squared	20.84648	Prob. Chi-Square(2)	0.0000

(Source: Author, 2025)

The Breusch-Godfrey LM test in Table 4:6 yields an F-statistic of 3.226306 and a p-value of 0.1259, which is not significant, confirming no serial correlation. However, the observed R-squared test gives a p-value of 0.0000, which could raise some concern, though the high D-W of 3.13 supports the LM conclusion.

Test for Heteroskedasticity

Table 4:7-Influence of renewable energy consumption on the growth of the agricultural sector in Kenya, Heteroskedasticity Test: Breusch-Pagan-Godfrey

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	1.606881	Prob. F(29,7)	0.2668
Obs*R-squared	32.16787	Prob. Chi-Square(29)	0.3126

Scaled explained SS	0.998249	Prob. Chi-Square(29)	1.0000

(Source: Author, 2025)

The Breusch-Pagan-Godfrey test in Table 4:7 reports an F-statistic of 1.606881 and a p-value of 0.2668 and an observed R-squared with a value of 0.3126, both of which are insignificant. Therefore, the residuals are homoskedastic.

Cumulative Sum of Recursive Residuals (CUSUM) Stability Test

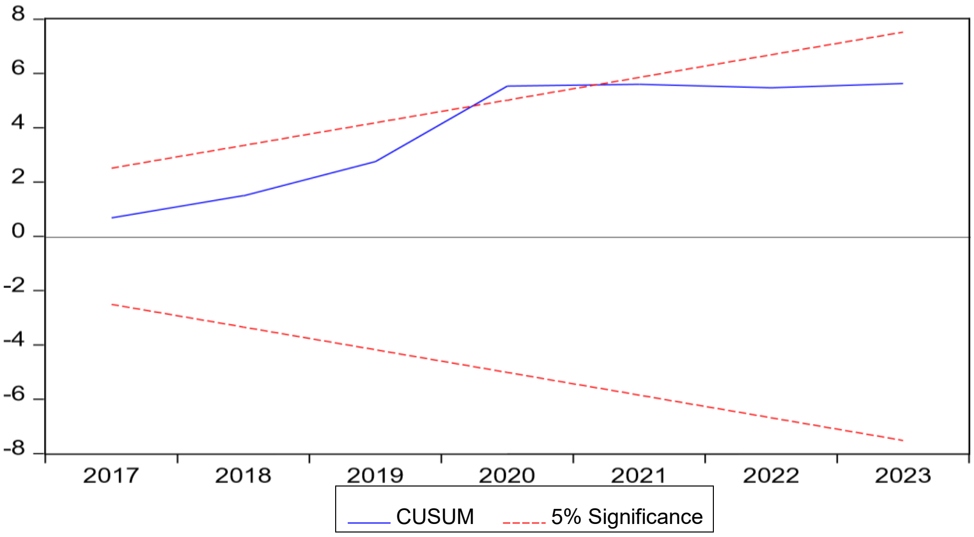

Figure 4:2-Influence of renewable energy consumption on the growth of the agricultural sector in Kenya, Heteroskedasticity, CUSUM Stability Test

(Source: Author, 2025)

The CUSUM test in Figure 4:2 confirms that the model is stable over the sample period, as the cumulative sum of residuals remains within the 5% confidence interval bands.

CONCLUSION AND POLICY IMPLICATIONS

Agriculture presents a distinct pattern. Renewable energy consumption reduces output contemporaneously, possibly due to installation disruptions and early inefficiencies, but shows strong and consistent positive effects across all subsequent lags. This delayed yet powerful influence indicates that renewable energy supports irrigation, mechanization and storage after sufficient adaptation and absorption. Non-renewable energy consumption, on the other hand, is consistently negative, reflecting the high costs and inefficiencies of fossil fuel use in farming systems. Labour exerts both immediate positive and delayed negative effects, with the latter suggesting that structural inefficiencies in rural employment eventually outweigh short-term gains. Gross capital formation predominantly suppresses output in the short run, further confirming the sector's misalignment between investment timing and productive needs. Importantly, agriculture displays a high speed of adjustment, with about 72% of disequilibrium corrected annually, signaling resilience and flexibility in restoring equilibrium despite short-run volatility.

This study therefore emphasizes the need to align Kenya's agricultural energy transition with the Sustainable Development and Ecological Modernization frameworks, emphasizing renewable energy as both a driver of productivity and environmental stewardship. Policymakers should integrate the study's findings into national strategies such as Vision 2030 and the Rural Electrification Programme by prioritizing decentralized renewable systems, ensuring maintenance support and incentivizing green investments to enhance agricultural resilience and energy efficiency. Comparative insights from other African and global experiences further affirm that structured, inclusive renewable energy policies yield sustained agricultural and rural growth.

Therefore, the consumption of renewable energy is an important accelerator of agricultural sector growth and necessary interventions should be taken to increase their uptake. Such measures could include introduction of carbon tax to discourage fossil energy consumption and removing taxes on the consumption of renewable energy forms.

LIMITATIONS OF THE STUDY

This body of knowledge was limited by data constraints. This is due to the fact that sector-specific renewable energy consumption figures were derived from national aggregates. This could potentially reduce the accuracy in capturing true sectoral effects that could inform sector-specific interventions.

AREAS FOR FURTHER RESEARCH

Though this study is an invaluable tool for designing energy policies in Kenya, this is a macro-level study. Hence, more efforts should be made to replicate this study at the county and regional levels.

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