Renewable Energy Generation and Agricultural Sector Growth in Kenya: Implications for a Sustainable Energy Transition

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ABSTRACT

This study examines the influence of renewable energy generation on agricultural output in Kenya for the period 1980-2023 using annual data from the World Development Indicators and the U.S. Energy Information Administration. While exploiting the ARDL–ECM framework, the analysis estimates long-run elasticities, short run dynamics as well as the speed of adjustment while controlling for labour, non-renewable energy generation and gross capital formation. The long-run results indicate that renewable energy generation has a strong positive and statistically significant effect on agricultural sector output, thus highlighting the growth-enhancing role of renewable energy in energy-intensive agricultural systems. Non-renewable energy generation also contributes positively, though the impacts are not as intense. This indicates an ongoing structural shift in Kenya's energy–agricultural growth linkage. Short-run findings reveal that renewable energy generation fluctuations support agricultural performance, while non-renewable energy displays mixed but generally favourable effects. Gross capital formation consistently boosts output, whereas labour shows negative short-run elasticities, thereby pointing to persistent inefficiencies and technology–labour mismatches in the sector. The coefficient of the ECM shows rapid convergence, with more than 65% of disequilibrium corrected annually, thus demonstrating strong adjustment toward long-run equilibrium and resilience of agricultural output to energy-related shocks. These findings provide new empirical evidence on the renewable energy–productivity linkage in a developing economy, showing that scaling renewable energy generation can enhance agricultural growth, stabilize output responses to energy shocks and strengthen long-run agricultural performance, while offering relevant insights for the design of energy transition interventions that promote sustainable and climate-resilient agricultural development.

Keywords: Renewable energy generation, Non-renewable energy, Agriculture, ARDL, ECM, Kenya, Agricultural sector growth

INTRODUCTION

Kenya's energy landscape has undergone substantial transformation over the past two decades, with renewable energy emerging as a key pillar of its development agenda. As of 2023, renewable energy sources played a decisive role in meeting the country's overall electricity demand. Hydro-electric power generates about 826 MW, which is roughly 30–40% of the total energy generation, while geothermal energy contributes approximately 950 MW of power, thus providing approximately 40% of the total grid electricity and thus positions Kenya as Africa's leader in geothermal power development. Wind power, which is largely generated from the Lake Turkana Wind Power Station in Athwana, generates about 310 MW of power, while solar power contributes about 50 MW of power, primarily through off-grid installations mostly in rural areas. Put together, these renewable energy sources supply nearly 2,261 MW of power annually, thus enabling Kenya to produce about 12 terawatt-hours of

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electricity every year. However, national electricity demand stands at about 14 terawatt-hours. This results in an energy deficit driven by transmission losses, grid inefficiencies, an ever expanding consumption base, low ramp-up and grid penetration rates. (Our World in Data, 2024). These energy shortages lead to persistent power blackouts and load-shedding episodes. This discourages and disrupts production, service delivery as well as agricultural operations.

Renewable energy is a critical driver of agricultural productivity in Kenya as it reduces production costs, stabilizes energy supply and also supports sustainable growth and productivity. While renewable energy generation from geothermal, hydro, solar as well as wind has increased over time, its integration into agriculture demonstrates a clear and measurable impact on the sector's output, mediated by differences in infrastructure, technology adoption as well as capital deployment. Understanding this dynamic is important for designing the necessary policies targeted towards growth maximization within the agricultural sector in Kenya.

Despite Kenya's ever-increasing renewable energy base, sector-specific studies remain limited, especially agriculture-related, with most research focusing on aggregate GDP effects. Using the ECM framework, this study captures both short-run and long-run effects of renewable energy generation on agriculture, thus providing insights into dynamic adjustment processes. The findings serve to highlight the importance of targeted renewable energy investments, grid modernization as well as energy strategies tailored to agricultural development, thereby offering clear policy guidance to maximize productivity and sustain agricultural growth in Kenya.

LITERATURE REVIEW

As per the US Department of Energy (2021), renewable energy generation is the process that involves the production of electrical power from renewable energy sources.

Using the GMM approach in order to assess the influence of renewable and non-renewable energy generation on economic growth, Atems and Hotaling (2018) established that both the renewable and non-renewable sources of energy positively impacted economic productivity, while renewable energy losses during transmission and distribution negatively affected economic and sectoral growth. The analysis employed a cross-panel dataset across 174 countries covering the 1980–2012 time period. The study, however, failed to explore sector-specific effects and regarded renewable energy in aggregate, thus limiting insights into the individual energy types. This shortcoming has been addressed in this study by disaggregating and isolating renewable energy constructs into specific sources and examining their effects on sectoral growth in Kenya.

Oyeleke and Akinlo (2020) aimed to examine the association between renewable energy generation and economic growth in Nigeria. the study exploited an ECM methodology with data for the period 1980 to 2017. Findings of the study established a cointegration existing between renewable energy generation and economic development, thereby highlighting that gas energy, physical capital as well as current interest rates play very important roles in promoting long-term economic and sectoral growth. The study further identified hydro-power generation as an important enabler of economic expansion. The study, however, treated economic growth is an aggregate variable and thus failed to analyze sector-specific impacts. To mitigate this, this study investigates disaggregated renewable energy sources beyond hydroelectric power and examines their effects on sectoral growth in Kenya, thus justifying why it had to be done.

Yoo and Kim (2006) sought to assess the existing linkage between electricity generation and Indonesia's economic expansion. The study established a one-way causality running from economic growth to electricity generation, without any two-way effect. This analysis covered the period spanning from 1971 to 2002.The study, however, cannot be replicated in Kenya due to differences in natural resources and energy endowments. Furthermore, the study aggregated electricity generation without disaggregating it into its various forms by source, thus limiting insights into the individual contributions of each type of energy. This study mitigates these shortcomings by assessing the specific impacts of major renewable energy sources on sectoral growth in Kenya.

Jeon (2022) aimed at assessing the nexus between energy generation and economic expansion across 47 US states during the 1999-2017 period using a two-step GMM methodology and established that renewable energy generation promoted economic growth. On the other hand, the generations of non-renewable energy had negative effects on economic growth. Given the United States' stronger economic and infrastructural position compared to Kenya, the findings may not be replicable. This study mitigated this geographical gap by assessing the effects of energy generation on sectoral growth within the Kenyan context.

Adedoyin *et al.* (2020) examined the existing linkage between energy generation and environmental-economic outcomes in the EU member states for the period 1992-2014 using the GMM. Results showed that a 1% rise in renewable energy generation increased carbon emissions by 0.04% in the USA and 0.02% in Central and Eastern European economies, while reducing emissions by 0.02% in New Member States. The results for New Member States and the Commonwealth Environmental Kuznets Curve aligned with the inverted U-shape of the Environmental Kuznets Curve, while results from Central and Eastern European nations did not. The study also established the presence of variations in environmental degradation across member states. The study, however, is from more advanced economies and might therefore not be replicable to the Kenyan scenario, thus calling for this study.

Ohler and Fetters (2014) sought to examine the causal linkage between renewable energy generation and GDP growth using econometric models, while analyzing time-series data from 20 OECD economies for the period 1980- 2010. The study established that renewable energy generation significantly enhanced GDP, thus indicating that increased investment in renewable energy can promote economic growth and development. However, the study faced potential data accuracy issues and challenges in isolating the specific effects of renewable energy from other contributing factors. Its findings emphasize the critical role of renewable energy generation in promoting sustainable economic growth and illustrate the broader economic implications of renewable energy generation. Nonetheless, given the relatively advantaged energy positions of the richer OECD economies, these results may not directly apply to the Kenyan case, thus motivating the need for this study in the Kenyan context and other countries with similar energy endowments.

Bayraktutan *et al.* (2011) assessed the association between renewable energy generation and economic growth in 30 OECD member states using panel regression techniques, while covering the period from 1990 to 2008. Their results revealed that renewable energy generation had a strong positive effect on the economic performance of the member states, thus emphasizing the very crucial role of renewable energy investments in promoting growth and development. However, the study faced some limitations, including biases inherent in panel data and difficulties in fully accounting for country-specific economic factors. While the findings emphasize the importance of renewable energy in driving sustainable economic growth, it was conducted in countries with substantial renewable energy resource endowments compared to Kenya, thus limiting the direct applicability of its results. This gap motivates the need for this study within the Kenyan context.

Ullah *et al.* (2024) assessed the association between hydroelectric power generation, economic growth and financial performance across 10 hydro-power generating countries over the 1990-2020 period. Findings indicate that hydropower generation promotes both economic and financial development, with a two-way kind of relationship observed among all the three variables. The study therefore supports the feedback hypothesis. The study exploited the panel-corrected standard errors, the Augmented Mean Group method, the WesterlundEdgerton LM bootstrap as well as the Dumitrescu-Hurlin panel causality methods. However, the dependence on broad cross-country data limits the ability to capture country-specific variations in hydropower's impact on growth. This study addresses this shortcoming by using Kenya-specific data and incorporating other renewable energy sources beyond hydroelectric power, thus enhancing relevance for countries with similar energy contexts.

Hdom (2019) sought to unravel the relationship existing between carbon emissions, energy production from nonrenewable and renewable energy sources and economic growth across South American countries across the 1980-2010-time period. Using the ARDL on panel data, the study assessed how different energy generation mixes influence both economic performance and environmental outcomes. Findings indicated that renewable energy generation reduced carbon emissions in the long run while positively impacting economic activity amongst the South American countries. However, the South American countries studied are more endowed with renewable energy resources and possess different economic and social structures compared to Kenya, thus limiting the replicability of the findings. This justifies the need for this study to assess the Kenyan context.

Onyeisi *et al.* (2016) assessed the influence of the energy generation capacity on economic growth in Nigeria across the 1980-2015 time period. The study modelled Real GDP as a function of energy generation capacity, gross capital formation as well as and unemployment. Exploiting the co-integration tests, the VECM as well as the Granger causality tests, the study established the existence of a stable long-term association amongst the variables, as confirmed by two co-integrating equations, thereby suggesting relevance for long-term policy planning. Nonetheless, the VECM results showed that power generation capacity had an insignificant effect on Real GDP, thus indicating that there was no direct short-term causality during the study period. The study recommended enhancing transparency in power sector policies, ensuring full budget implementation, as well as strengthening legislative oversight to mitigate corruption. While the Nigerian context provides useful insights, its status as a leading oil producer implies energy generation and consumption patterns that differ from Kenya, thus necessitating a Kenya-specific investigation.

The existing body of knowledge shows that renewable energy generation generally supports economic growth. However, most of the studies reviewed relied on aggregated energy measures, thus limiting their applicability to countries like Kenya. Many analyses sought to assess the overall economic growth without considering sector specific effects as well as cross-country panels often overlook country-specific dynamics. This study addresses these gaps by disaggregating renewable energy forms, using Kenya-specific data and also examines their effects on sectoral growth, thus providing evidence that is directly relevant for guiding sustainable energy and economic policy in not only in Kenya, but also in economies at the same stage of development and renewable energy resource endowment as Kenya.

RESEARCH METHODOLOGY

This research modifies the traditional Solow–Swan framework by incorporating renewable energy generation as well as the control variables in non-renewable energy generation, capital and labour inputs in the agricultural production function, using data from the WDI and EIA. To empirically estimate this relationship, the Cobb–Douglas function is log-linearized. Logging enables the transformation of the non-linear production form into a linear regression model. This serves to facilitate an estimation of parameters as well as allowing all coefficients to be interpreted as elasticities. This makes it suitable to evaluate how percentage changes in renewable energy generation affects agricultural sector output. This is consistent with the assertions of Mankiw *et al.* (1992), who demonstrate the empirical robustness of the log-linearized Solow-type framework when the additional growth enhancing inputs are introduced in the model.

Incorporating the energy variables in this model is theoretically sound. This is due to the fact that energy is a complementary input that enhances the growth and productivity of both capital and labour inputs. Renewable energy, in particular, supports irrigation, mechanization as well as post-harvest technologies, which are the key enablers of modern agricultural sector growth and productivity. The non-renewable energy dynamics are relevant in powering existing machinery and transport technologies. The use of lagged renewable energy generation terms mirrors the moderate absorption of energy inputs within the agricultural sector. Adjustment processes in the agricultural sector occur over many periods due to infrastructure constraints, learning curves as well as seasonality in the production process. Allowing for lags in the model is therefore consistent with economic theory as well as empirical evidence on energy–economic growth dynamics.

In order to capture both the short run and long-run adjustment processes, this piece of knowledge employs the ARDL model. ECM will also be adopted for dynamic equilibrium adjustment. The ARDL is appropriate for mixed-order integration orders. The ECM reveals the speed at which short-run deviations from the long-run agricultural sector growth path are corrected. This serves to provide a dynamic interpretation of how renewable energy generation shape agricultural sector output over time.

Therefore, the basic Production function of

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

Where Y is the output, in this regard, the agricultural sector output, A is the total factor productivity, K is capital, L is labour, α is output elasticity of capital while (1−α) is the output elasticity of labour

Equation 3.1 was modified into

$Ln(AGR_t) = LnA + \alpha_1 Ln(REG_t) + \alpha_2 Ln(NREG_t) + \alpha_3 Ln(K_t) + \alpha_4 Ln(L_t) + \beta_1 Ln(REG_{t-1}) + \beta_2 Ln(NREG_{t-1}) + \beta_3 Ln(K_{t-1}) + \beta_4 Ln(L_{t-1}) + \varepsilon_t$..(3.2)

Where $Ln(AGR_t)$ is the logged agricultural sector output at time t, LnA is the part of agricultural sector output not captured by either capital or labour, $\alpha_1 Ln(REG_t) + \alpha_2$ is the logged renewable energy generation at time t, $\alpha_2 Ln(NREG_t)$ is the logged non-renewable energy generation at time t, $\alpha_3 Ln(K_t) + \alpha_4$ is the logged capital, $+\alpha_4 Ln(L_t)$ is the logged labour while the variables with (t-1) indicate lags.

RESULTS AND DISCUSSION

Descriptive statistics

Table 4:1 -Descriptive Statistics

	AGR(”000000”)	REG(“000000”)	NREG(“000000”)	L(“{000000”)	GCF(“OF_ GDP”)
Mean	1102373.	4.914184	1.115578	13.54270	20.09076
Median	1077750.	3.887850	1.022550	12.73076	19.73131
Maximum	1783299.	11.48400	2.785300	23.18485	25.44904
Minimum	593460.3	1.182000	0.102000	5.341202	15.00382
Std. Dev.	348262.3	3.006695	0.813648	5.556273	2.956138
Skewness	0.368935	0.968854	0.360692	0.205444	0.087421
Kurtosis	1.892409	2.740128	1.874294	1.682008	2.157324
Jarque-Bera	3.247219	7.007456	3.277285	3.494208	1.357899
Probability	0.197186	0.030085	0.194244	0.174278	0.507149
Sum	48504415	216.2241	49.08542	595.8787	883.9934
Sum Sq. Dev.	5.22E+12	388.7293	28.46698	1327.503	375.7664
Observations	44	44	44	44	44

(Source: Author,2025)

Table 4.1 presents the statistical summary of key variables, including agricultural sector output, renewable energy generation, non-renewable energy generation, gross capital formation and labour, contextualized within Kenya's economy. Agricultural output averaged 1.10 trillion KES with a standard deviation of 348 billion, thus reflecting its critical role despite seasonal and climatic vulnerabilities. Its moderate skewness and kurtosis, besides an acceptable Jarque-Bera probability, indicate a relatively even distribution with occasional high-output years. Renewable energy generation, averaging 4,914,184 kWh and exhibiting substantial variability, highlights Kenya's strategic push toward sustainable energy adoption through hydropower, wind as well as geothermal energy sources. Non-renewable generation averaged 1,115,578 kWh with lower but notable variation, thereby emphasizing its historical role as a fallback source when renewable energy capacity is limited. Labour grew steadily from 5,341,202 to 23,184,849 over the period, supporting agricultural productivity, while gross capital formation averaged 20.09% of GDP, hence demonstrating stable investment conducive to long-term growth.

The descriptive statistics reflect Kenya's gradual structural transformation and economic diversification. Positive skewness in renewable energy generation and moderate kurtosis in agriculture justify log transformations for econometric modeling. These patterns capture Kenya's evolving development trends and patterns, shaped by consistent agricultural sector output, expanding renewable energy capacity, steady population growth as well as sustained investment, thus highlighting the linkage between renewable energy development, labour, gross capital formation and agricultural sector output in driving long-term agricultural sector growth.

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)
REG	-0.932019 (0.9427)	-5.267663(0.0005)	I (1)
NREG	-1.190329 (0.8983)	-5.343954 (0.0005)	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)

The ADF results in Table 4:3 show that the variables in the model exhibit a mixture of integration orders, which strongly supports the use of the ARDL framework. The agriculture sector output records an ADF statistic of –2.001507 at level with a probability of 0.5840, thus indicating clear non-stationarity. Once first-differenced, however, the statistic improves substantially to –4.964347 with a probability of 0.0014, confirming that it becomes stationary after differencing and is therefore integrated of order one. This behaviour is expected because agricultural output in Kenya typically responds to long-term structural forces such as climatic cycles, market shocks, as well as input availability, all of which produce trending behaviour characteristic of I(1) variables.

Renewable energy generation also displays non-stationarity in levels, with a statistic of –0.932019 and a high probability of 0.9427, but becomes strongly stationary after first differencing. This is reflected by the statistic of –5.267663 and the probability value of 0.0005. This pattern is economically reasonable because renewable generation expands gradually in response to infrastructure investments and the commissioning of new geothermal, wind and hydropower plants, which serve to naturally introduce long-run growth patterns in the economy. A similar outcome is observed for non-renewable energy generation, which is non-stationary at level at –1.190329 with a probability value of 0.8983 and becomes stationary at first difference at –5.343954 with a probability value of 0.0005. This aligns with Kenya's historical reliance on non-renewable sources during periods of demand pressure or hydropower shortfalls, which produces sustained movements over time rather than short-term fluctuations.

Labour behaves differently. Its ADF statistic at level is –3.558792 with a probability of 0.0494, thereby indicating stationarity in levels at the 5% significance level. The loss of significance after differencing further confirms that labour is an I(0) variable. This outcome is logical because labour supply changes gradually and predictably in line with population growth, which tends to follow a stable and non-explosive trajectory. Gross capital formation is non-stationary at level, as seen in the statistic of –2.754643 with a probability of 0.2212, but becomes stationary after differencing at –5.703648 with a probability value of 0.0002. This result fits the economic behaviour of investment ratios, which usually follow medium-term trends shaped by macroeconomic conditions, fiscal policies and infrastructure cycles.

Therefore, the mixture of I(0) and I(1) variables, with labour stationary in levels while agricultural sector output, renewable generation, non-renewable generation and gross capital formation are stationary only after first differencing, provides a strong methodological justification for using the ARDL model as it is a model well suited to such datasets because it accommodates variables with different integration orders, provided none is integrated of order two. It also captures both short-run adjustments and long-run equilibrium relationships, making it particularly appropriate for annual Kenyan energy and sectoral output data, which tend to exhibit gradual structural changes alongside short-term fluctuations.

Lag Length Determination

The study relied on the AIC criterion in order to determine the appropriate lag structure within the ARDL framework. The EViews software automatically evaluated various lag combinations and selected those that offered the best balance between explanatory power and model simplicity. The chosen lags reflect the underlying behaviour of each variable in the model and were applied consistently in both the long-run and short-run estimations. These optimal lag selections ensured that the dynamics of the system were adequately captured without overfitting and the final lag orders are reported together with the ARDL results.

ARDL ANALYSIS

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

Dependent Variable: AGR				
Method: ARDL				
Date: 07/08/25 Time: 17:58				
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): REG NREG L GCF				
Fixed regressors: C				
Number of models evalulated: 4096				
Selected Model: ARDL(1, 7, 7, 7, 7)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
AGR(-1)	0.343947	0.114362	3.007527	0.0573
REG	0.198119	0.025390	7.803097	0.0044
REG(-1)	-0.076423	0.021035	-3.633083	0.0359

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REG(-2)	-0.020347	0.023572	-0.863200	0.4515
REG(-3)	-0.007081	0.023943	-0.295722	0.7867
REG(-4)	-0.026711	0.024065	-1.109937	0.3480
REG(-5)	-0.142926	0.027227	-5.249339	0.0135
REG(-6)	0.161650	0.031789	5.085045	0.0147
REG(-7)	-0.290857	0.033417	-8.703762	0.0032
NREG	0.044488	0.010802	4.118639	0.0259
NREG(-1)	0.032511	0.009113	3.567623	0.0376
NREG(-2)	0.040220	0.009632	4.175527	0.0250
NREG(-3)	-0.050686	0.008887	-5.703317	0.0107
NREG(-4)	0.037291	0.008382	4.448894	0.0211
NREG(-5)	0.004754	0.007135	0.666336	0.5529
NREG(-6)	0.013782	0.007730	1.782998	0.1726
NREG(-7)	-0.046927	0.008432	-5.565637	0.0114
L	-2.362663	0.730670	-3.233557	0.0481
L(-1)	1.900661	0.997028	1.906326	0.1527
L(-2)	-1.154416	0.818329	-1.410699	0.2531
L(-3)	-4.098242	1.016212	-4.032860	0.0274
L(-4)	4.802853	0.931832	5.154205	0.0142
L(-5)	1.892753	1.262291	1.499458	0.2307
L(-6)	-7.940099	1.245049	-6.377338	0.0078
L(-7)	7.165741	0.908051	7.891346	0.0042
GCF	0.187256	0.029169	6.419727	0.0077
GCF(-1)	0.051098	0.037293	1.370178	0.2642
GCF(-2)	0.042450	0.032045	1.324684	0.2771
GCF(-3)	0.170211	0.025669	6.630910	0.0070
GCF(-4)	-0.125005	0.031162	-4.011449	0.0278
GCF(-5)	0.270743	0.032825	8.248020	0.0037
GCF(-6)	-0.090287	0.028978	-3.115682	0.0526
GCF(-7)	-0.131792	0.032179	-4.095555	0.0263
C	16.35853	2.575887	6.350639	0.0079
R-squared	0.999931	Mean dependent var		27.76565
Adjusted R-squared	0.999171	S.D. dependent var		0.269067
S.E. of regression	0.007745	Akaike info criterion		-7.557941
Sum squared resid	0.000180	Schwarz criterion		-6.077638

Log likelihood	173.8219	Hannan-Quinn criter.		-7.036065
F-statistic	1316.459	Durbin-Watson stat		2.968504
Prob(F-statistic)	0.000030			
*Note: p-values and any subsequent tests do not account for model selection.				

(Source: Author, 2025)

The ARDL model in Table 4:5 for agricultural sector output shows a rich set of relationships between the sector and both renewable and non-renewable energy generation, alongside labour and gross capital formation. The coefficient on the lag of agricultural sector output is positive at 0.343947 with a probability value of 0.0573. This suggests moderate but persistent path dependence, thereby implying that past agricultural sector performance carries into the current period, which is economically reasonable because agricultural activity depends heavily on previous cycles of land preparation, investment, and weather conditions that create inertia in output.

Renewable energy generation shows a mixture of immediate and lagged effects. The contemporaneous coefficient is strongly positive, with a coefficient of 0.198119 with a highly significant probability value of 0.0044. This indicates that an increase in renewable energy generation is associated with a significant and meaningful increase in the level of agricultural output. This linkage is sensible in the Kenyan context because agriculture relies on energy for productive activities such as irrigation, processing, storage as well as transport. Hence, greater renewable generation and consequently, supply, improves reliability and reduces overall production costs. Several lags of renewable energy generation, however, carry varying signs. The seventh lag is large and negative with a coefficient of –0.290857 and a probability of 0.0032, while the fifth and sixth lags show sizeable negative and positive effects respectively. These alternating effects reflect the delayed adjustment processes in the agricultural sector, where shocks to energy availability feed through the productive operations such as planting, harvesting and distribution cycles over multiple seasons. The combination of significant positive short-run effects and mixed longer-run adjustments aligns with the seasonal and climate-dependent structure of Kenyan agriculture.

Non-renewable energy generation also shows a significant influence on agricultural activity. The contemporaneous coefficient is positive at 0.044488 with a probability value of 0.0259 and several of its lags are statistically significant. The presence of positive coefficients across the first, second, and fourth lags, combined with negative effects at the third and seventh lags, implies that thermal energy continues to play a stabilising role when renewable sources fluctuate, especially during drought periods that reduce hydro-electric power generation. This pattern fits Kenya’s historical energy mix, where thermal generation has provided backup supply to prevent production disruptions in energy-dependent sectors, including agriculture.

Labour displays a highly dynamic pattern with alternating signs across the lags. The current labour coefficient is negative with a coefficient of 2.362663 and a probability value of 0.0481, while the fourth and seventh lags are large and positive with coefficients of 4.802853 and 7.165741, respectively, both being statistically significant. These trends reflect demographic and structural realities in Kenya’s agricultural sector. The immediate negative effect suggests that rapid growth in the labour force may initially stifle growth due to underemployment, land fragmentation or limited capital. On the other hand, the strong positive effects at longer lags indicate that population growth and labour force expansion eventually contribute to higher agricultural sector output once the workforce is absorbed into productive activities or after households adjust their production decisions. The strong negative effect at the sixth lag further highlights the sector’s sensitivity to labour reallocations. This could be due to migration to non-farm activities or shifts in rural employment opportunities.

Gross capital formation displays strong and economically meaningful effects on agricultural sector output. The contemporaneous coefficient is positive and significant with a value of 0.187256. This reflects the importance of investment in infrastructure, machinery, irrigation systems, as well as storage facilities to boost agricultural growth and productivity. Several lags also show large, significant contributions, such as the third lag with a coefficient of 0.170211 and the fifth lag with a coefficient of 0.270743. Negative effects at the fourth, sixth and seventh lags point to cyclical adjustments, where periods of heavy investment may initially divert resources or reflect structural reforms that temporarily slow output before benefits start to materialize.

The diagnostic tests support the robustness of the model. The R-squared is extremely high at 0.999931. Although such a value must be interpreted cautiously, it is consistent with models using highly persistent log-transformed macroeconomic variables with multiple lags. The Durbin–Watson statistic of 2.968504 indicates no evidence of serial correlation. The F-statistic is large and highly significant, thereby confirming strong joint explanatory power. The extremely low standard error of regression of 0.007745 points toward the model's precision, while the negative Akaike value points to an efficiently fitted specification.

The ARDL output paints a coherent economic story that suggests that agricultural output in Kenya is strongly influenced by energy availability, investment cycles as well as labour dynamics. Renewable energy generation emerges as a central enabler of agricultural sector growth. This is consistent with Kenya's structural shift toward clean green energy and the agriculture sector's increasing dependence on technologies that are heavily energy reliant. Non-renewable energy still plays a buffering role, labour responds slowly but meaningfully through lags, while gross capital formation remains a consistent foundation for agricultural sector growth. The combination of immediate and lagged effects is fully aligned with the seasonal, resource-dependent as well as investment sensitive nature of Kenyan agriculture.

ARDL Error Correction Regression

Table 4:6-Influence of renewable energy generation on growth of the agriculture sector in Kenya, ARDL Error Correction Regression

ARDL Error Correction Regression		
Dependent Variable: D(AGR)		
Selected Model: ARDL(1, 7, 7, 7, 7)		
Case 3: Unrestricted Constant and No Trend		
Date: 07/08/25 Time: 17:58		
Sample: 1980 2023		
Included observations: 37		

ECM Regression				
Case 3: Unrestricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	16.35853	0.831685	19.66914	0.0003
D(REG)	0.198119	0.011975	16.54383	0.0005
D(REG(-1))	0.326272	0.017165	19.00767	0.0003
D(REG(-2))	0.305924	0.014629	20.91157	0.0002
D(REG(-3))	0.298844	0.016158	18.49564	0.0003

D(REG(-4))	0.272133	0.014311	19.01550	0.0003
D(REG(-5))	0.129207	0.013144	9.829918	0.0022
D(REG(-6))	0.290857	0.014205	20.47592	0.0003
D(NREG)	0.044488	0.004848	9.175911	0.0027
D(NREG(-1))	0.001566	0.004690	0.333924	0.7604
D(NREG(-2))	0.041786	0.004758	8.781805	0.0031
D(NREG(-3))	-0.008900	0.004600	-1.934618	0.1485
D(NREG(-4))	0.028391	0.003665	7.747456	0.0045
D(NREG(-5))	0.033145	0.003818	8.681163	0.0032
D(NREG(-6))	0.046927	0.003822	12.27813	0.0012
D(L)	-2.362663	0.301403	-7.838894	0.0043
D(L(-1))	-0.668590	0.285832	-2.339105	0.1013
D(L(-2))	-1.823006	0.333678	-5.463366	0.0121
D(L(-3))	-5.921249	0.441523	-13.41097	0.0009
D(L(-4))	-1.118396	0.386415	-2.894286	0.0628
D(L(-5))	0.774358	0.440553	1.757694	0.1770
D(L(-6))	-7.165741	0.506382	-14.15085	0.0008
D(GCF)	0.187256	0.011730	15.96399	0.0005
D(GCF(-1))	-0.136320	0.015121	-9.015227	0.0029
D(GCF(-2))	-0.093870	0.011603	-8.090159	0.0039
D(GCF(-3))	0.076341	0.012060	6.330030	0.0080
D(GCF(-4))	-0.048664	0.012727	-3.823751	0.0315
D(GCF(-5))	0.222079	0.016026	13.85724	0.0008
D(GCF(-6))	0.131792	0.013400	9.834895	0.0022
CointEq(-1)*	-0.656053	0.033318	-19.69073	0.0003
R-squared	0.996424	Mean dependent var		0.024356
Adjusted R-squared	0.981609	S.D. dependent var		0.037389
S.E. of regression	0.005070	Akaike info criterion		-7.774158
Sum squared resid	0.000180	Schwarz criterion		-6.468008
Log likelihood	173.8219	Hannan-Quinn criter.		-7.313679
F-statistic	67.25715	Durbin-Watson stat		2.968504
Prob(F-statistic)	0.000003			
* p-value incompatible with t-Bounds distribution.				

(Source: Author, 2025)

The ECM model as in Table 4:6 shows how renewable energy generation, non-renewable energy generation, labour as well as gross capital formation influence short-run changes in agricultural sector output, while the ECM term captures the speed at which the system returns to long-run equilibrium. The constant term of 16.35853 which is highly significant with a probability value of 0.0003. This reflects the average short-run contribution to the change in agricultural sector output after accounting for all differenced regressors. This indicates the presence of substantial internal momentum in agricultural activity during transitional adjustments.

Short-run changes in renewable energy generation emerge as a dominant enabler of agricultural sector growth. The contemporaneous coefficient for D(REG) is 0.198119 with a t-statistic value of 16.54383 and a probability of 0.0005. This shows that a 1% short-run increase in renewable energy generation increases agricultural sector output by 0.198119%. Every lag of renewable energy generation, up to the sixth, remains highly significant. For example, D(REG(-1) has a coefficient of 0.326272, while that of D(REG(-2) is 0.305924. Both of them have extremely strong t-values above 19.00000 and probability values below 0.001. These sustained positive elasticities indicate that renewable energy shocks not only create immediate benefits for the agricultural sector but also generate persistent gains across several time periods. This pattern means that agriculture is highly energy-dependent for irrigation, processing, preservation as well as mechanization. Hence, renewable energy reliability stabilizes production cycles, reduces operational costs and also enhances value addition along the supply chain.

Non-renewable energy generation also contributes to the agriculture sector in the short run, though with a more mixed pattern. The contemporaneous coefficient of D(NREG) is 0.044488 with a probability value of 0.0027. This implies that a 1% increase in non-renewable energy generation increases agricultural sector output by 0.044488% in the short run. Lags such as D(NREG(-2) with a coefficient of 0.041786 and D(NREG(-4) with a coefficient of 0.028391 are positive and significant. These findings confirm that non-renewable energy sources remain relevant to Kenya's agricultural activities, particularly where rural electrification gaps limit renewable energy access. However, the presence of a negative and insignificant coefficient at D(NREG(-3**)** highlights that variations in non-renewable energy supply may also impose volatility, consistent with fuel-price shocks and generator-based production costs.

Labour displays a largely negative short-run effect on agricultural sector output. This reflects structural rigidities and labour inefficiencies common in Kenya's predominantly manual agricultural workforce. The contemporaneous labour coefficient, D(L), is -2.362663, with a probability value of 0.0043. This implies that a 1% short-run increase in agricultural labour reduces output by 2.362663%. Lags such as D(L(-2) with a coefficient of -1.823006 and D(L(-3) with a coefficient of 5.921249 follow the same negative and significant trend. This negative elasticity aligns with the reality of labour congestion, diminishing returns on smallholder farms as well as the substitution of labour with energy-based technologies. Positive but insignificant effects at lags D(L(-5) with a coefficient of 0.774358 show periods where labour may complement energy-driven mechanization, though the gains are not robust.

Gross capital formation displays strong short-run effects on agricultural sector growth. The contemporaneous term D(GCF) has a coefficient of 0.187256 with a probability value of 0.0005, showing that gross capital accumulation stimulates agricultural activity in the immediate term. However, both positive and negative lags emerge. For example, D(GCF(-1) and D(GCF(-2) have negative coefficients of -0.136320 and -0.093870, respectively, while D(GCF(-5) and D(GCF(-6) are positive at 0.222079 and 0.131792. This alternating pattern suggests that capital investments exert short-term adjustment costs before generating growth and productivity gains in preceding periods. This is consistent with installation delays, learning curves as well as seasonal alignment of agricultural cycles.

The ECM term, CointEq(-1), is -0.656053 with a t-statistic of -19.69073 and a probability value of 0.0003. This indicates strong and stable long-run convergence. The negative sign and magnitude mean about 65.6053% of any deviation from the long-run agricultural sector growth path is corrected within one period. This rapid speed of adjustment depicts a well-behaved ECM where agricultural sector output consistently returns to equilibrium aftershocks to renewable energy generation, labour or capital. This signifies that Kenya's agricultural sector is structurally anchored to long-run fundamentals such as sustained energy availability, capital stock as well as production technologies. This allows short-run disturbances to be quickly absorbed.

The ECM results confirm that renewable energy generation is the strongest and most persistent short-run enabler of agricultural sector growth, non-renewable energy retains supportive but volatile influence, gross capital formation enhances agricultural growth with mild adjustment friction and labour constraints continue to constrain output over the short run. The rapid speed of adjustment highlights the strong long-run relationship between agricultural productivity and Kenya's evolving energy landscape. This reinforces the central role of energy security and investment in driving agricultural sector growth.

F-Bounds Test

Table 4:7-Influence of renewable energy generation on growth of the agriculture sector in Kenya, F-Bounds Test

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	33.23357	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-Bounds test as depicted by Table 4:7 rejects the null hypothesis of no long-run relationship. This is due to the F-statistic of 33.23357 that exceeds the upper I(1) critical values at all significance levels, thus confirming the presence of a stable long-run linkage between agricultural sector output and renewable energy generation.

Post Diagnostic Tests

Test for Normality

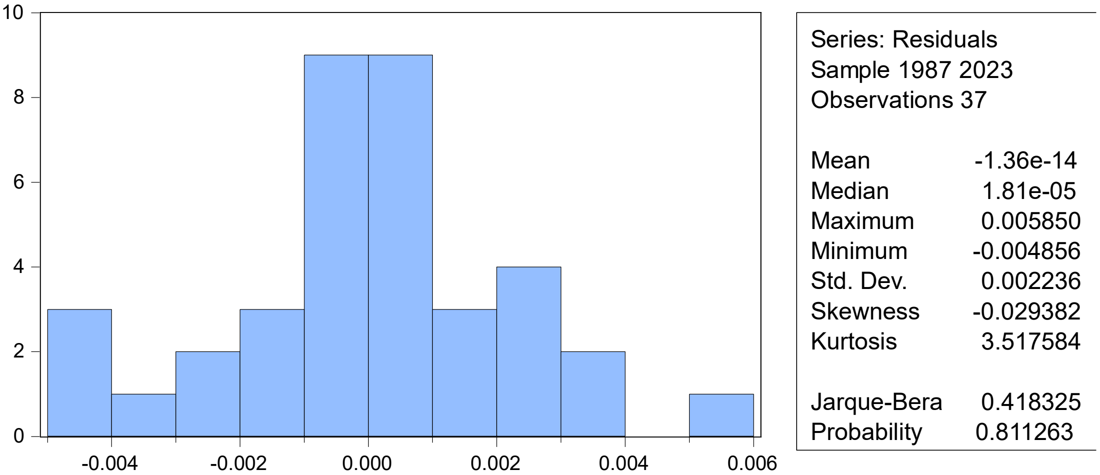

Figure 4:1-Influence of renewable energy generation on growth of the agriculture sector in Kenya: Test for Normality

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(Source: Author, 2025)

Since the p-value of 0.811263, as shown in Figure 4.1, is greater than the conventional significance level of 0.05, the null hypothesis of normality cannot be rejected, thus indicating that the residuals are normally distributed.

4.7.2 Test for Serial Correlation

Table 4:8-Influence of renewable energy generation on growth of the agriculture sector in Kenya, BreuschGodfrey Correlation Test

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	4.020368	Prob. F(2,1)	0.3326
Obs*R-squared	32.90741	Prob. Chi-Square(2)	0.0000

(Source: Author, 2025)

The Breusch-Godfrey LM test results as in Table 4:8 proved the absence of serial correlation. The F-statistic value of 4.020368 with a p-value of 0.3326 fails to reject the null of no serial correlation, suggesting there was no evidence of autocorrelation based on the F-test.

Test for Heteroskedasticity

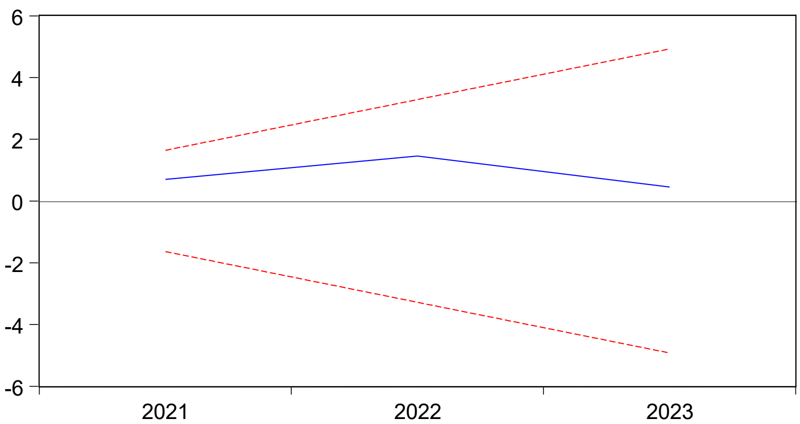
Table 4:9-Influence of renewable energy generation on growth of agriculture sector in Kenya Heteroskedasticity Test: Breusch-Pagan Godfrey

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	1.524171	Prob. F(33,3)	0.4151
Obs*R-squared	34.91736	Prob. Chi-Square(33)	0.3770
Scaled explained SS	0.288958	Prob. Chi-Square(33)	1.0000

(Source: Author, 2025)

The Breusch-Pagan-Godfrey test for heteroskedasticity in table 4:9 indicated no evidence of heteroskedasticity. All test statistics such as the F-statistic value of 1.524171 with a p-value of 0.4151, the observed R-squared value of 34.91736 with a p-value of 0.3770 and the scaled explained SS value of 0.288958 with a p-value of 1.0000, all fail to reject the null hypothesis of constant variance. This confirms that the ARDL model residuals are homoskedastic, thus supporting the reliability of the estimated coefficients.

Cumulative Sum of Recursive Residuals (CUSUM) Stability Test



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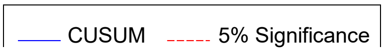

Figure 4:2-Influence of renewable energy generation on growth of the agriculture sector in Kenya, CUSUM Stability Test

(Source: Author, 2025)

Evidence from the CUSUM test in Figure 4:2 shows that the residuals remain within the 5% bounds. This indicates that the parameters were stable and had no structural breaks. This confirms the model's robustness over the entire study period.

CONCLUSION

This study aimed to establish how renewable energy generation influences agricultural sector growth in Kenya. It incorporated labour, non-renewable energy generation and gross capital formation as the control variables. The ARDL and ECM findings provide an empirically reliable proposition. Over the long run, renewable energy generation emerges as a consistent enabler of agricultural sector output, thus indicating growth in clean energy generation strengthens agricultural production capacity, enhances value addition and also serves to stabilize agricultural cycles.

The short-run dynamics emphasize a long-run relationship between renewable energy generation and agricultural sector growth in Kenya. Renewable energy variations have positive impacts on agricultural sector output across several periods. This shows that the gains of improved generation of renewable energies are not only immediate but also unfold gradually as farmers adjust production systems, storage processes as well as irrigation patterns.

The ECM term confirms a strong and stable long-run association between renewable energy generation and agricultural sector performance as approximately 65.6053% of deviations from equilibrium are corrected within one period. This indicates a rather rapid adjustment of agricultural output back to its long-run path after any shock or deviation from the equilibrium. These findings highlight a sector whose long-run trajectory is deeply reliant on energy availability and capital accumulation, with renewable energy playing a leading role in improving growth and productivity as well as playing a pivotal role in reducing vulnerability to energy-related disruptions.

These results emphasize the importance of scaling up renewable energy generation in order to achieve sustainable and climate-resilient agricultural transformation. The findings also emphasize that Kenya's energy transition is not just an environmental necessity but it's also a direct enabler of agricultural sector growth, technological upgrading as well as a long-run agricultural sector stabilizer.

POLICY IMPLICATIONS

Findings of this study point to several priority areas for policy intervention. The strong long-run and short-run effects of renewable energy generation on agricultural output make a strong case for accelerating investments in renewable energy infrastructure, especially in the rural and off-grid farming regions. Expanding solar-powered irrigation, mini-grids, agro-processing facilities as well as cold storage systems would strengthen agricultural growth and productivity by reducing input costs and enhancing production efficiency.

The rapid speed of adjustment back to the equilibrium revealed by the ECM results confirms that agricultural sector growth responds quickly to structural improvements, implying that policy interventions that serve to enhance energy reliability, reduce power losses and also expand access to modern energy solutions can lead to both immediate and sustained gains for the agricultural sector. A coordinated strategy between the Ministry of Energy and the Ministry of Agriculture is therefore very critical in aligning renewable energy investments with agricultural value chain priorities.

Renewable-energy generation and adoption in agricultural activities should be strengthened through alignment with global initiatives that serve to promote clean-energy transitions within the important sector. Frameworks such as FAO's Energy-Smart Agrifood Systems agenda, the joint IRENA–FAO programme on Renewable Energy for Agri-Food Systems, as well as IFAD's Renewable Energy for Smallholder Agriculture approach, emphasize the need for clean green energy solutions to enhance growth, reduce harmful emissions and also build resilience within the agricultural sector. Other initiatives, such as the Powering Agriculture Energy Grand Challenge, the International Water Management Institute's SoLAR initiative in East Africa as well as the NGOdriven interventions like the Solar Electric Light Fund and Practical Action's Renewable Energy for Agricultural Livelihoods projects serve to demonstrate global shift and efforts towards integrating this important energy form into agricultural activities such as irrigation, processing, storage as well as post-harvest handling activities. These initiative, put together, enables farmers and investors within the agricultural sector to access clean technologies and solutions, lowering the costs of production, strengthening climate-smart practices as well as improving foodsystem sustainability across the world.

LIMITATIONS OF THE STUDY

While this piece of knowledge provides robust insights into the relationship between renewable energy generation and agricultural sector growth, certain limitations should be noted. The research relies on nationallevel time series data, a data type that may not capture localized variations in renewable energy access or productivity across different regions. This limitation presents avenues for further research, but do not compromise the reliability of the core findings.

AREAS FOR FURTHER RESEARCH

Going with the findings of this study, future research could explore the impact of renewable energy generation on agricultural growth using farm-level data to capture local variations in renewable energy access and agricultural sector performance. Future Studies could also focus on technological adoption, irrigation practices as well as climate-specific variations, so as to avail a more complete understanding of agricultural dynamics. Future research could also extend the analysis to include off-grid, transmission as well as renewable energy reliability indicators**.** The knowledge of this would surely deepen insights into how renewable energy generation influences agricultural sector growth in developing economies like Kenya.

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