

Do Institutions Condition the Output Gains from Renewable Electricity? Time-Series Evidence from Kenya, 1971–2023

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Abstract:

Background: Kenya generates most of its electricity from hydro, geothermal and wind sources, yet evidence on whether this renewable mix raises long-run output, and whether institutions shape that effect, is limited and inconsistent. Earlier Kenyan studies also measure renewable energy as a share of final energy, which is dominated by firewood and charcoal rather than clean power.

Materials and Methods: The study uses annual data for 1971 to 2023: output, capital and employment from Penn World Table 11.0; a composite institutional quality index built from three Varieties of Democracy (V-Dem) indices; and the renewable share of electricity generation from World Bank data extended with Ember data. A production function in which institutions condition the productivity effect of renewable electricity is estimated with the ARDL bounds testing approach, using finite-sample critical values, conditional marginal effects and twelve robustness checks.

Results: Output, capital, labour, the renewable share and institutional quality are cointegrated ($F = 4.87$, finite-sample $p = 0.024$). At average institutional quality, a 10 percentage point rise in the renewable share is associated with 2.3% higher long-run output ($p = 0.061$). Institutional quality has no significant direct effect, and the interaction between the renewable share and institutional quality is negative (-0.303 , $p = 0.001$) in the main model and significant in all twelve robustness checks. The output gain from a greener mix is largest when institutions were weak and hydropower dominated, and is not significant at the highest levels of institutional quality.

Conclusion: Stronger institutions have not amplified the output gains from renewable electricity in Kenya. The cost structure of renewable expansion matters as much as its scale, so power procurement should be judged by the price and reliability of the electricity it delivers.

Key Word: Renewable electricity; Institutional quality; Economic growth; ARDL bounds test; Moderation; Kenya.

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I. Introduction

Kenya Vision 2030 treats reliable and affordable energy as a foundation for industrialisation and growth, and the country has built one of the cleanest electricity systems in Sub-Saharan Africa¹. Renewable sources supplied between 47% and 96% of Kenya's electricity in every year from 1971 to 2023, first from hydropower and, since the 1980s, increasingly from geothermal and later wind plants. Real GDP nevertheless grew by only 4.7% in 2024 and 4.6% in 2025², well short of the 10% a year that Vision 2030 sets as its target. Whether a renewable electricity system translates into higher output, and under what conditions, is therefore a practical question for Kenyan energy and growth policy.

The energy-growth literature offers four competing hypotheses. Under the growth hypothesis, energy is a factor of production and its use raises output; under the conservation hypothesis, causality runs from growth to energy; the feedback hypothesis allows both; and the neutrality hypothesis finds no relationship^{3,4}. Stern⁵ argues that energy is an essential input whose contribution conventional growth accounting understates. Evidence for renewable energy specifically is mixed. Apergis and Payne⁶ report bidirectional causality between renewable energy consumption and growth in Eurasia, and Inglesi-Lotz⁷ finds a positive effect of renewable energy consumption on growth across OECD countries. For Kenya, Nyasha and Odhiambo⁸ find that renewable energy consumption has no significant effect on growth in either the short or the long run over 1990 to 2019.

Institutions may explain part of this inconsistency. North⁹ defines institutions as the rules that shape transaction costs and incentives, and power infrastructure is unusually exposed to them: projects are capital-intensive, contracts run for decades, and returns depend on regulation, procurement and the creditworthiness of state utilities. Eberhard and Gratwick¹⁰ identify a stable regulatory framework, competitive procurement and

sound utility finances as determinants of successful independent power projects in Sub-Saharan Africa. Panel evidence for Africa reports positive long-run effects of both renewable energy and institutional quality on green growth¹¹. These arguments suggest that institutions might condition the output return to renewable electricity.

Three gaps remain. First, no study has tested whether institutional quality moderates the relationship between renewable electricity and output in Kenya within a time-series framework. Second, studies of Kenya commonly measure renewable energy as its share of total final energy consumption. In Kenya that share lies between 71% and 83% throughout 1990 to 2018 because combustible biomass, mainly firewood and charcoal, supplied between 45% and 82% of total energy use over 1971 to 2014¹², so it measures reliance on traditional biomass rather than the use of modern renewable electricity, and it tends to fall rather than rise as an economy develops. Third, the governance indicators most studies use begin in 1996¹³, and moderation is usually judged from the sign of an interaction coefficient rather than from conditional marginal effects¹⁴.

This study addresses these gaps. It examines whether institutional quality moderates the long-run relationship between renewable electricity and real output in Kenya over 1971 to 2023, using the autoregressive distributed lag (ARDL) bounds testing approach of Pesaran et al.¹⁵. Renewable electricity is measured by its share of total generation, constructed from World Bank data for 1971 to 2015 and extended with Ember data, and its level in gigawatt-hours is used as an alternative. Output, physical capital and employment are taken from Penn World Table 11.0¹⁶, and institutional quality is measured with a composite of three V-Dem indices that cover the whole period¹⁷. The study asks whether the renewable share of electricity and institutional quality each affect long-run output, and whether the effect of the renewable share rises with institutional quality.

The results show a stable long-run relationship between output and its determinants. At average institutional quality, a greener electricity mix is associated with higher output, but institutions do not amplify this effect. The interaction is negative and robust: the output gain from renewable electricity was largest when institutions were weak and hydropower dominated, and it is not significant at the highest levels of institutional quality. The study contributes a long single-country test of the renewables-institutions interaction for Kenya, a measure of renewable energy that reflects electricity rather than biomass, and conditional marginal effects that show where in Kenya's institutional history renewable electricity has been associated with output gains. The question matters beyond technique: Kenya has relied increasingly on independent power producers to add renewable capacity¹⁸, so whether stronger institutions raise the output return to that capacity bears directly on whether governance reform or contract design is the more useful policy lever. Section II reviews the literature and states the hypotheses, Section III presents the theoretical framework, Section IV describes the data and method, Section V reports the results, Section VI discusses them, and Section VII concludes.

II. Literature review and hypotheses

2.1 Energy and economic growth

The empirical energy-growth literature began with Kraft and Kraft¹⁹, who found causality running from income to energy consumption in the United States. Several decades of subsequent work have produced conflicting results that depend on country, period, method and the measure of energy. Ozturk³ and Payne⁴ review this literature and conclude that no consensus exists on the direction of causality, with roughly comparable support for the growth, conservation, feedback and neutrality hypotheses. Stern⁵ attributes part of the disagreement to the treatment of energy as a minor intermediate input. He argues that energy is essential to production, that its contribution depends on its quality as well as its quantity, and that shifts towards higher-quality energy carriers such as electricity have been an important source of productivity growth.

2.2 Renewable energy and growth

Studies of renewable energy specifically are more recent. Apergis and Payne⁶ find bidirectional causality between renewable energy consumption and growth for a panel of Eurasian countries. Inglesi-Lotz⁷ reports that renewable energy consumption has a positive and significant effect on growth across OECD countries. Evidence for Africa is less favourable. Teklie and Yağmur¹¹, using a panel of 49 African countries over 2000 to 2021, find a positive long-run but insignificant short-run effect of renewable energy on green growth, which they attribute to upfront investment costs. For Kenya, Nyasha and Odhiambo⁸ find no significant effect of renewable energy consumption on growth over 1990 to 2019.

The measure of renewable energy matters for these results. In low-income countries the share of renewables in total final energy consumption is dominated by traditional biomass, so a high share often reflects limited access to modern energy rather than investment in clean power. Renewable electricity, by contrast, reflects the generation mix of the modern power system that supplies industry and services. The distinction is large in Kenya, where renewable sources supply most of the electricity while households rely mainly on firewood and charcoal.

2.3 Institutions and the power sector

New institutional economics holds that institutions shape economic performance through their effect on transaction costs and incentives⁹. The power sector is especially sensitive to institutions because generation assets are long-lived and immobile, so investors depend on credible regulation, enforceable contracts and the financial health of state-owned off-takers. Eberhard and Gratwick¹⁰ find that independent power projects in Sub-Saharan Africa succeed where policy and regulatory frameworks are clear, procurement is competitive and utilities can pay. In a study of five countries including Kenya, Eberhard et al.¹⁸ document Kenya's dependence on hydropower and its vulnerability to climate variability, the reforms after 2004 that created a geothermal development company and opened generation to independent producers, and the variation in tariffs across power purchase agreements. Evidence on how institutions interact with energy is limited and mixed. Teklie and Yağmur¹¹ find positive effects of institutional quality on green growth in Africa, while Kolawole et al.²⁰ find that institutional quality has a negligible effect on sustainable energy supply in West Africa, with causality running from energy supply to institutions rather than the reverse. Neither study tests whether institutions change the output return to renewable energy within a single country.

2.4 Evidence from Kenya and hypotheses

Kenyan evidence on energy and growth is limited to studies that treat renewable energy and institutions separately. Nyasha and Odhiambo⁸ find no significant growth effect of renewable energy consumption, measured as a share of final energy. No study has examined whether institutional quality moderates the relationship between renewable electricity and output in Kenya, and those that use governance data are limited to the period after 1996. Following the growth hypothesis and the essential-input view of energy⁵, the institutional literature^{9,10} and the argument that institutions condition returns to infrastructure, the study tests three hypotheses.

H1: The renewable share of electricity has a positive long-run effect on real output in Kenya.

H2: Institutional quality has a positive long-run effect on real output in Kenya.

H3: The long-run effect of the renewable share of electricity on real output increases with institutional quality.

H3 is tested against the alternative that institutions do not change the return to renewable electricity, or that the return is lower when institutions are stronger, so that the interaction is negative.

III. Theoretical framework

The framework adds electricity to an aggregate production function in the spirit of Stern⁵, distinguishing between the quantity of electricity and the share produced from renewable sources. Output in year t is:

$$Y_t = A_t K_t^\alpha L_t^\gamma \quad (1)$$

where Y is real output, K the physical capital stock, L employment and A total factor productivity (TFP). Renewable electricity affects output through TFP: a larger renewable share lowers the variable cost of power and the exposure of the economy to imported fuel prices. Institutional quality, G , also shifts TFP, and the effect of the renewable share depends on institutions:

$$A_t = A_0 \exp(\lambda G_t + \theta_t S_t + \varepsilon_t), \quad \theta_t = \theta_0 + \theta_1 G_t \quad (2)$$

where S is the renewable share of electricity generation. Substituting (2) into (1), taking logarithms and centring S and G on their sample means (s and g) gives the estimating equation:

$$y_t = \beta_0 + \beta_1 k_t + \beta_2 l_t + \beta_3 s_t + \beta_4 g_t + \beta_5 (s_t \times g_t) + \varepsilon_t \quad (3)$$

where lower-case y , k and l are natural logarithms. Because of centring, β_3 is the effect of the renewable share at average institutional quality, β_4 is the effect of institutional quality at the average renewable share, and $\beta_5 = \theta_1$. The quantity of interest for H3 is the conditional effect of the renewable share at each observed level of institutional quality:

$$ME(g) = \beta_3 + \beta_5 g, \quad \text{Var}[ME(g)] = \text{Var}(\hat{\beta}_3) + g^2 \text{Var}(\hat{\beta}_5) + 2g \text{Cov}(\hat{\beta}_3, \hat{\beta}_5) \quad (4)$$

The institutional view predicts $\beta_5 > 0$. If renewable expansion under stronger institutions relies on more expensive contracts, or if the cheapest renewable resources were developed first, β_5 may be zero or negative. Equation (3) is a long-run relationship; the ARDL model in Section IV links it to annual growth through an error correction term.

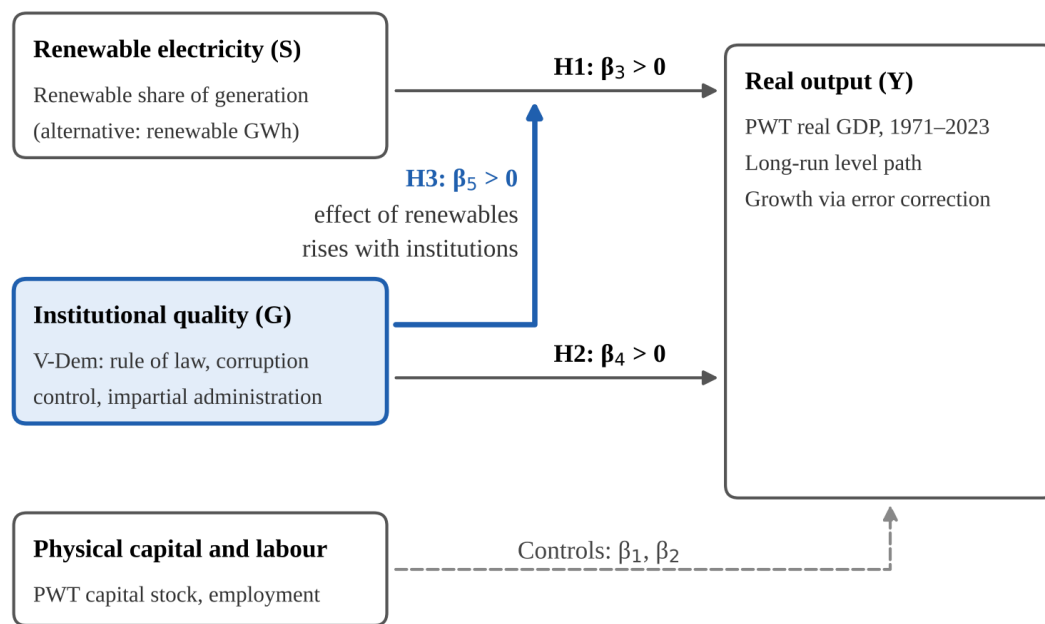


Figure no 1: Conceptual framework

Source: Authors' construction based on Section III.

IV. Data and econometric method

4.1 Data and variables

The study uses annual data for Kenya from 1971, the first year of World Bank electricity data, to 2023, the last year in Penn World Table 11.0, giving 53 observations. Table 1 defines the variables.

Table no 1: Variables, measures and sources

Variable	Symbol	Measure	Source	Transformation
Real output	Y	Real GDP at constant national prices (rgdpna)	PWT 11.0	Natural log, y
Physical capital	K	Capital stock at constant national prices (rnna)	PWT 11.0	Natural log, k
Labour	L	Persons engaged (emp)	PWT 11.0	Natural log, l
Renewable share	S	Renewable electricity as a share of total generation	World Bank WDI (1971 to 2015); Ember via Our World in Data (2016 to 2023)	Proportion, centred, s
Renewable electricity	RE	Electricity generated from renewable sources, GWh	As above	Natural log, centred, re (alternative)
Institutional quality	G	First principal component of V-Dem rule of law (v2x_rule), political corruption (v2x_corr, reversed) and rigorous and impartial public administration (v2clrspct)	V-Dem v16	Standardised, centred, g
Human capital	H	Human capital index (hc)	PWT 11.0	Natural log, centred, h (robustness)

Three measurement choices correct weaknesses in the earlier literature. First, renewable energy is measured as the renewable share of electricity generation rather than of final energy consumption. The World Bank renewable share of final energy for Kenya lies between 71% and 83% throughout 1990 to 2018 because it is dominated by household biomass¹², so it does not capture the modern power system. Second, the World Bank series on electricity generation by source (fossil, hydroelectric and other renewable shares, and non-hydro renewable output) ends in 2015. Renewable and total generation for 2016 to 2023 are taken from Ember via Our World in Data and scaled by the ratio of the two sources over their 2000 to 2015 overlap (0.967 for renewable and 0.965 for total generation), over which the two renewable series are correlated at 0.99. Third, institutional quality is measured with V-Dem indices that cover the whole period, since the Worldwide Governance Indicators begin only in 1996¹³. The three indices are standardised, the corruption index is reversed, and the first principal component is rescaled to unit standard deviation.

4.2 Econometric method

Unit roots are tested with the augmented Dickey-Fuller²¹, Phillips-Perron²² and KPSS²³ tests, and with the Zivot and Andrews²⁴ test, which allows one structural break. The long-run relationship in equation (3) is estimated with the ARDL approach of Pesaran and Shin²⁵ and Pesaran et al.¹⁵, which is valid with a mix of I(0) and I(1) regressors. The conditional error correction model is:

$$\Delta y_t = c_0 + \phi y_{t-1} + \sum_{j=1}^5 \pi_j x_{j,t-1} + \sum_{i=1}^{p-1} \gamma_i \Delta y_{t-i} + \sum_{j=1}^5 \sum_{i=0}^{q_j-1} \delta_{ji} \Delta x_{j,t-i} + u_t \quad (5)$$

where x_1 to x_5 are k , l , s , g and $s \times g$, and the long-run coefficients are $\beta_j = -\pi_j / \phi$. Lag orders are selected by the Akaike information criterion over all combinations of one or two lags on a common sample. Cointegration is tested with the bounds F-test of $\phi = \pi_1 = \dots = \pi_5 = 0$ and the t-test of $\phi = 0$. Because asymptotic critical values are too permissive in samples of this size²⁶, finite-sample critical values and p-values are simulated for the actual sample size and lag structure²⁷. The conditional effect in equation (4) is computed by the delta method and evaluated across the observed range of institutional quality¹⁴.

Three specifications are estimated: Model A uses the level of renewable electricity (re), Model B the renewable share (s), and Model C adds human capital to Model A. Each is checked for serial correlation (Breusch-Godfrey), heteroskedasticity (Breusch-Pagan-Godfrey), non-normality (Jarque-Bera), functional form (Ramsey RESET) and parameter stability (CUSUM and CUSUM of squares)²⁸. Robustness checks use fully modified OLS²⁹, dynamic OLS³⁰ and canonical cointegrating regression³¹, a linear trend, heteroskedasticity-robust standard errors, alternative institutional measures, controls for total electricity generation and human capital, and a dummy for the 1999 to 2000 drought. Causality is examined with the Toda and Yamamoto³² procedure. Estimation uses Python 3.13 with statsmodels 0.15 and arch 8.0.

V. Results

5.1 Descriptive statistics

Table 2 summarises the data. Renewable electricity rose from 440 GWh in 1971 to 11,108 GWh in 2023. The renewable share of generation fluctuated widely, from 96.5% in 1989 to 47.0% in 2000, when drought reduced hydropower output and thermal generation filled the gap. Averaged by decade, the share was 67.9% in the 1970s, 90.3% in the 1980s, 84.1% in the 1990s, 70.4% in the 2000s and 83.6% since 2011. Institutional quality fell to its lowest level in 1984, rose sharply around the 2002 change of government and again after the 2010 Constitution, and peaked in 2021. The renewable share is almost uncorrelated with institutional quality (−0.07) and only weakly correlated with output (0.22), whereas output, capital and employment are highly correlated with each other (0.94 to 1.00).

Table no 2: Descriptive statistics, Kenya, 1971 to 2023 (n = 53)

Variable	Mean	Std. dev.	Minimum	Maximum	Year of minimum	Year of maximum
Real GDP (US\$ million, constant national prices)	127,897	75,863	38,501	315,169	1971	2023
Capital stock (US\$ million, constant national prices)	271,279	171,048	81,011	721,478	1971	2023
Persons engaged (million)	12.32	5.11	4.84	19.95	1971	2023
Renewable electricity (GWh)	4,122	3,032	440	11,108	1971	2023
Total electricity generation (GWh)	5,083	3,482	728	12,508	1971	2022
Renewable share of electricity (%)	79.5	12.8	47.0	96.5	2000	1989
Institutional quality index, G	0.00	1.00	−1.10	1.85	1984	2021

Sources: Penn World Table 11.0; World Bank WDI; Ember via Our World in Data; V-Dem v16.

The three V-Dem indices are highly correlated over 1971 to 2023 (0.89 to 0.95), and the first principal component explains 94.8% of their variance with nearly equal loadings (0.59 on rule of law, 0.57 on corruption control and 0.58 on public administration). Figure 2 plots the renewable share and institutional quality.

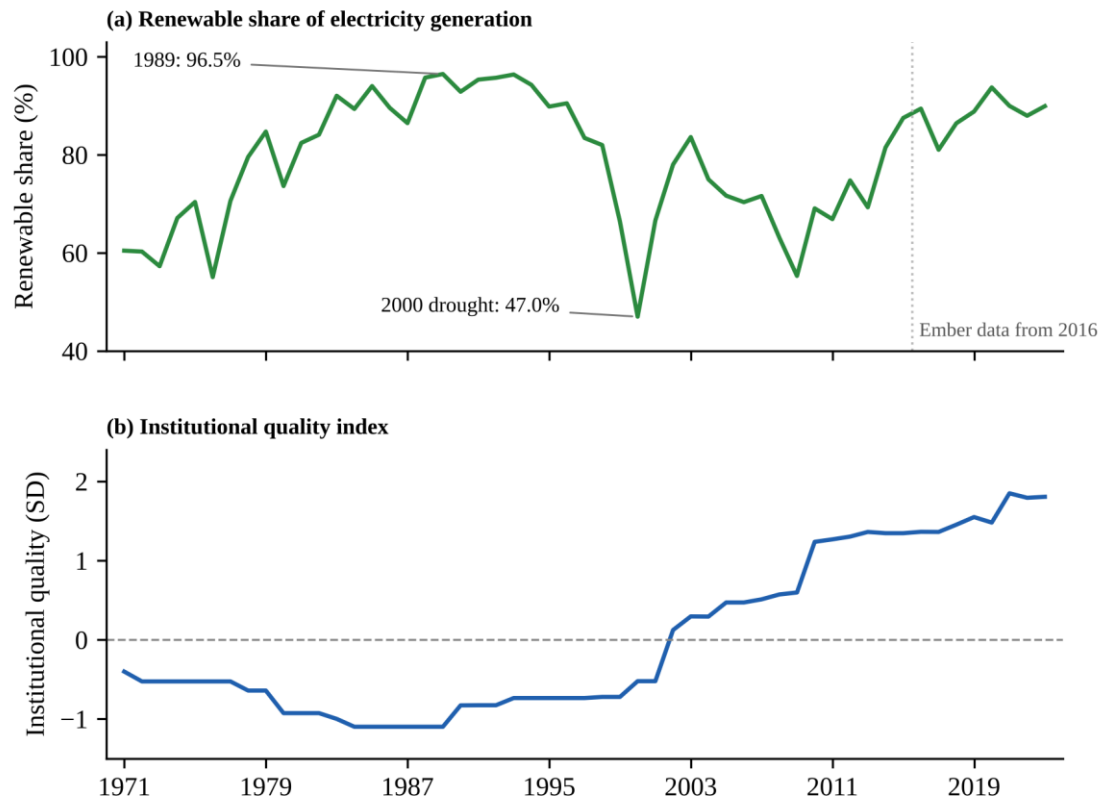


Figure no 2: Renewable share of electricity and institutional quality in Kenya, 1971 to 2023

Source: World Bank WDI (1971 to 2015) and Ember via Our World in Data (2016 to 2023, scaled to the WDI level); V-Dem v16.

5.2 Unit roots

Table 3 reports the unit root tests. Output, the renewable variables, institutional quality and the share interaction are I(1): the ADF and PP tests do not reject a unit root in levels but reject it in first differences. Capital and employment are smooth series for which the first-difference tests reject only at the 10% level (PP $p = 0.097$ and 0.052), but their second differences are clearly stationary, as are those of every other series (all ADF p -values below 0.001), so no variable is I(2). The Zivot-Andrews statistics are all above the 5% critical value of -5.08 except for human capital (-5.21 , break in 1998), which enters only one robustness check, so the unit root findings are not driven by unmodelled breaks.

Table no 3: Unit root and structural break tests

Variable	ADF level	ADF first difference	PP level	PP first difference	KPSS level	KPSS first difference	Zivot-Andrews (break year)
y	-1.52 (0.821)	-5.35 (0.000)	-1.67 (0.765)	-5.36 (0.000)	0.152 (0.046)	0.149 (0.394)	-3.13 (1992)
k	-1.33 (0.879)	-2.39 (0.145)	-0.88 (0.958)	-2.58 (0.097)	0.224 (0.009)	0.326 (0.115)	-3.68 (2002)
l	-0.66 (0.975)	-2.61 (0.091)	0.15 (0.995)	-2.84 (0.052)	0.251 (0.005)	0.607 (0.022)	-4.05 (1995)
h	-2.80 (0.198)	-6.26 (0.000)	-1.68 (0.760)	-3.92 (0.002)	0.214 (0.011)	0.112 (0.528)	-5.21 (1998)
re	-2.66 (0.252)	-7.41 (0.000)	-2.56 (0.297)	-7.46 (0.000)	0.169 (0.031)	0.252 (0.187)	-3.77 (1997)
s	-2.46 (0.347)	-7.61 (0.000)	-2.44 (0.360)	-7.90 (0.000)	0.141 (0.059)	0.118 (0.503)	-4.03 (1997)
g	-2.03 (0.584)	-6.99 (0.000)	-2.06 (0.570)	-7.30 (0.000)	0.264 (0.004)	0.589 (0.024)	-3.37 (1980)
re $\times$ g	0.39 (0.997)	-1.66 (0.454)	0.60 (0.997)	-8.10 (0.000)	0.288 (0.002)	0.967 (0.003)	-3.55 (2001)
s $\times$ g	-1.97 (0.616)	-7.88 (0.000)	-1.77 (0.717)	-7.92 (0.000)	0.166 (0.033)	0.238 (0.204)	-3.09 (1981)

Notes: Test statistics with p-values in parentheses. Levels include an intercept and trend; first differences include an intercept. ADF lags selected by AIC (maximum 4). KPSS has stationarity as its null hypothesis. The Zivot-Andrews 5% critical value is -5.08.

5.3 Cointegration and model choice

Table 4 reports the bounds tests for the three specifications. Model A, which uses the level of renewable electricity, does not establish cointegration ($F = 2.80$, finite-sample $p = 0.247$ against $I(1)$ regressors) and its residuals are serially correlated (Breusch-Godfrey $p = 0.008$). Model C, which adds human capital, passes the bounds test but also has serially correlated residuals ($p = 0.001$) and fails the CUSUM of squares test. Model B, which uses the renewable share, establishes cointegration: the F-statistic of 4.87 exceeds the finite-sample 5% upper bound of 4.19 ($p = 0.024$), and the t-statistic of -4.87 exceeds the simulated 5% upper t-bound of -4.24 ($p = 0.014$). Model B is the only specification that both establishes cointegration and passes the serial correlation tests, so it is the preferred model. The level of renewable electricity is examined as a robustness check.

Table no 4: ARDL bounds tests for cointegration

	Model A: renewable level	Model B: renewable share	Model C: level with human capital
Selected ARDL order	(2, 1, 1, 2, 2, 2)	(1, 1, 1, 2, 2, 1)	(2, 1, 2, 1, 2, 1, 2)
Observations	51	52	51
F-statistic	2.80	4.87	4.62
Finite-sample p-value, $I(0)$ / $I(1)$	0.059 / 0.247	0.003 / 0.024	0.002 / 0.024
t-statistic on $y(t-1)$	-3.72	-4.87	-5.24
Breusch-Godfrey LM, 1 lag (p)	0.008	0.288	0.001
Conclusion	No cointegration; serial correlation	Cointegrated	Serial correlation

Notes: Case III (unrestricted intercept, no trend). ARDL order lists the lag of output followed by the regressors in the order k, l, (h), renewable variable, g, interaction. For Model B the finite-sample 5% F-bounds are 2.91 ($I(0)$) and 4.19 ($I(1)$), and the simulated 5% t-bounds are -2.77 and -4.24.

5.4 Long-run estimates

Table 5 reports the long-run coefficients of Model B. Capital and labour have positive and significant elasticities of 0.88 and 0.21. The renewable share has a positive coefficient of 0.235 ($p = 0.061$): at Kenya's average institutional quality, a 10 percentage point increase in the share of electricity from renewable sources is associated with about 2.3% higher long-run output. The coefficient is significant at the 10% level with conventional standard errors and at the 5% level with heteroskedasticity-robust standard errors ($t = 2.34$). Institutional quality has no significant direct effect (-0.041, $p = 0.148$), so H2 is not supported.

Table no 5: Long-run coefficients, Model B (dependent variable: log real GDP)

Variable	Coefficient	Standard error	t-statistic	p-value
Physical capital, k	0.879	0.089	9.92	< 0.001
Labour, l	0.208	0.073	2.86	0.007
Renewable share, s (β_3)	0.235	0.121	1.93	0.061
Institutional quality, g (β_4)	-0.041	0.028	-1.48	0.148
$s \times g$ (β_5)	-0.303	0.087	-3.50	0.001
Constant	0.129	0.957	0.13	0.894

Notes: Standard errors by the delta method; 38 degrees of freedom. Heteroskedasticity-robust (HC1) t-statistics: k 10.48, l 3.15, s 2.34, g -1.51, $s \times g$ -3.86.

The interaction between the renewable share and institutional quality is negative and highly significant (-0.303, $p = 0.001$). This is the opposite of H3: the output effect of a greener electricity mix is smaller, not larger, when institutions are stronger.

5.5 Short-run dynamics and diagnostics

The error correction coefficient in Model B is -0.459 ($p < 0.001$): about 46% of a deviation from the long-run path is corrected within a year. In the short run, output growth rises with the growth of the capital stock (2.02, $p < 0.001$) and with lagged growth in institutional quality (0.043, $p = 0.051$), and falls with the lagged change in the renewable share (-0.105, $p = 0.018$), consistent with the costs of adjusting the generation mix. Table 6 reports the diagnostic tests. There is no evidence of serial correlation, heteroskedasticity, non-normality or functional form misspecification. The CUSUM statistic stays inside its 5% bands. The maximum CUSUM of squares deviation (0.289) is marginally above its simulated 5% critical value (0.284), with the largest deviation in

2003, which points to some instability in the variance of the residuals around the early 2000s reforms; the results are unchanged when a dummy for the 1999 to 2000 drought is added (Table 7).

Table no 6: Diagnostic tests, Model B

Test	Statistic	p-value
Breusch-Godfrey LM, 1 lag	1.128	0.288
Breusch-Godfrey LM, 2 lags	1.384	0.500
Breusch-Pagan-Godfrey LM	9.735	0.715
Jarque-Bera	0.444	0.801
Ramsey RESET, F	1.486	0.231
CUSUM	Within 5% bands	
CUSUM of squares, maximum deviation (5% critical value)	0.289 (0.284)	
R ² / adjusted R ² (error correction form)	0.586 / 0.444	

5.6 Conditional marginal effects

Figure 3 plots the long-run effect of the renewable share across the observed range of institutional quality. At the weakest institutions, recorded in 1984, the effect is 0.567 (95% confidence interval 0.350 to 0.785), so a 10 percentage point increase in the renewable share is associated with about 5.7% higher long-run output. The effect declines as institutional quality rises, falls to zero at about 0.8 standard deviations above the mean, and is -0.326 (-0.826 to 0.174) at the strongest institutions, recorded in 2021. It is significantly positive in 31 of the 53 years and significantly negative in none. Renewable electricity has therefore been associated with higher output mainly in the years of weak institutions, which were also the years of hydropower dominance before 2002.

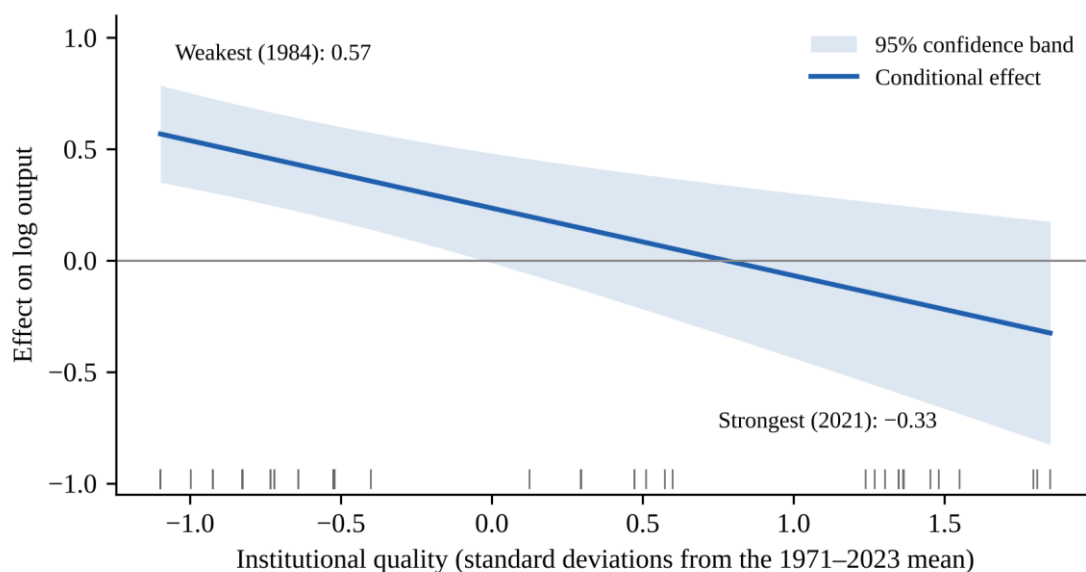


Figure no 3: Conditional effect of the renewable share of electricity on long-run output

Source: Model B long-run estimates (Table 5); delta-method 95% confidence band; tick marks show observed values of institutional quality.

5.7 Robustness and causality

Table 7 reports the main coefficients under alternative estimators and specifications. The negative interaction is significant at the 5% level in every case, with t-statistics between -2.04 and -8.84 . The renewable share is positive in every specification, though significant at the 5% level only in four. Institutional quality is never significantly positive, and is significantly negative in three specifications. Controlling for total electricity generation reduces the renewable share coefficient to 0.097 and makes it insignificant while leaving the interaction negative and significant, which indicates that part of the share effect reflects the overall expansion of the power system.

Table no 7: Robustness of the Model B long-run coefficients: coefficient (t-statistic)

Specification	Renewable share, s	s × g	Institutional quality, g
Model B, ARDL (Table 5)	0.235 (1.93)	-0.303 (-3.50)	-0.041 (-1.48)
HC1 robust standard errors	0.235 (2.34)	-0.303 (-3.86)	-0.041 (-1.51)
Linear trend added (Case V)	0.125 (1.24)	-0.325 (-4.87)	-0.070 (-2.89)
Fully modified OLS	0.084 (1.20)	-0.211 (-3.22)	0.006 (0.37)

Specification	Renewable share, s	$s \times g$	Institutional quality, g
Canonical cointegrating regression	0.093 (1.09)	-0.209 (-2.99)	0.007 (0.41)
Dynamic OLS (one lead, one lag)	0.325 (4.68)	-0.278 (-8.84)	-0.037 (-2.38)
G = simple average of three indices	0.235 (1.93)	-0.303 (-3.50)	-0.041 (-1.48)
G = rule of law only	0.264 (2.18)	-0.270 (-2.76)	-0.048 (-1.15)
G = corruption control only	0.186 (1.32)	-0.255 (-2.34)	-0.080 (-2.23)
G = impartial public administration only	0.205 (1.48)	-0.341 (-3.47)	-0.024 (-1.17)
Total electricity generation added	0.097 (0.60)	-0.212 (-2.04)	-0.017 (-0.55)
Human capital added	0.225 (2.19)	-0.258 (-3.44)	-0.040 (-1.67)
Drought dummy, 1999 to 2000	0.221 (1.67)	-0.297 (-3.29)	-0.046 (-1.42)

Notes: All ARDL variants confirm cointegration (asymptotic p-values against I(1) regressors between 0.001 and 0.026). The simple-average index gives results virtually identical to the principal component because the three loadings are nearly equal. In Model A, which uses the level of renewable electricity but does not establish cointegration, the long-run coefficient on renewable electricity is 0.259 ($t = 2.23$) and the interaction is 0.031 ($t = 0.27$).

The Toda and Yamamoto³² tests, based on a vector autoregression in output, the renewable share and institutional quality with one lag selected by the Akaike criterion and one additional lag, find no Granger causality from the renewable share to output ($p = 0.250$) or from institutional quality to output ($p = 0.658$). There is weak evidence of causality from output to the renewable share ($p = 0.070$), consistent with the conservation hypothesis, and none between institutions and the renewable share in either direction ($p > 0.9$).

VI. Discussion

The results support H1 only at average and weak institutions, and do not support H2 or H3. A greener electricity mix is associated with higher long-run output at Kenya's average institutional quality, institutional quality has no direct long-run effect, and stronger institutions reduce rather than raise the output effect of the renewable share.

The positive association between the renewable share and output differs from the null result of Nyasha and Odhiambo⁸, who measure renewable energy as a share of final energy consumption. The difference in measures is the likely explanation. A share dominated by household biomass would not be expected to raise output and may fall as incomes rise, whereas the share of renewables in electricity reflects the cost and reliability of power supplied to firms. The result is consistent with the essential-input view of energy⁵ and with the positive panel estimates of Inglesi-Lotz⁷, and the causality tests, which point weakly from output to the renewable share, show that the association should not be read as evidence that renewables drive growth in the short run.

The negative interaction is the central finding, and it is robust to every alternative tested. Three explanations are consistent with it. The first is the cost and timing of renewable capacity. In the 1980s and 1990s, when institutional quality was lowest, hydropower supplied between 55% and 87% of Kenya's electricity, from plants with low running costs. After the reforms of the early 2000s, institutions improved while new renewable capacity, particularly geothermal and wind, was increasingly developed, in part by independent power producers, under long-term power purchase agreements with tariffs that varied widely across contracts¹⁸. Stronger institutions may have made these contracts possible without making the resulting power cheaper. The second explanation is diminishing returns: the lowest-cost renewable sites were developed first, so later increases in the share, which coincide with stronger institutions, added less to output. The third is climate exposure. Hydropower dependence made the share volatile, as the 2000 drought showed, but the interaction remains negative when the drought years are controlled for.

The results bear on the institutional argument set out in Section 2.3. Institutions may matter most for whether power projects are built and financed¹⁰ rather than for the output return to the electricity they produce, which is consistent with Kolawole et al.²⁰, who find little effect of institutions on sustainable energy supply. The interaction cannot distinguish between these channels because, in a single time series, rising institutional quality also tracks time, and the composition of renewable generation changed over the same period. The finding should therefore be read as evidence that the output gain from renewable electricity has not risen with institutional quality in Kenya, not as evidence that better institutions are harmful.

The earlier version of this study inferred a growth-enhancing interaction from a joint test of three coefficients while the interaction itself was insignificant. Estimating the model on verified data and reporting conditional marginal effects shows instead that the interaction is negative and that the renewable effect is concentrated in the period of weaker institutions.

VII. Conclusion

7.1 Conclusions

This study examined whether institutional quality moderates the long-run relationship between renewable electricity and real output in Kenya over 1971 to 2023. Output, capital, labour, the renewable share of

electricity and institutional quality are cointegrated. At average institutional quality, a 10 percentage point rise in the renewable share is associated with about 2.3% higher long-run output. Institutional quality has no significant direct effect, and the interaction between the renewable share and institutional quality is negative and robust across all twelve alternative specifications. The output gain from a greener mix is largest at the weakest levels of institutional quality, in the hydropower era, and is not significant at the strongest.

7.2 Policy implications

1. Renewable electricity policy should track cost as well as share. The output gain associated with the renewable share has declined as the system expanded through new capacity under long-term contracts, so further increases in the share should be judged by their effect on the cost and reliability of power to firms, not by the share alone.
2. Procurement institutions should be judged by the price of the power they deliver. Since institutional improvement has not raised the output return to renewable electricity, reforms in power procurement should focus on competitive tendering and transparent tariff setting, which Eberhard and Gratwick¹⁰ and Eberhard et al.¹⁸ identify as conditions for successful independent power projects.
3. Diversification away from hydropower remains justified on resilience grounds. The 2000 drought, when the renewable share fell to 47%, shows the risk of reliance on a single renewable source; geothermal and wind reduce that exposure.
4. Studies and policy documents should measure renewable energy in electricity, not in final energy. A share of final energy dominated by firewood and charcoal does not measure clean power and can mislead policy.

7.3 Limitations and future research

The study relies on 53 annual observations, so tests of interaction effects have limited power. The renewable share series combines World Bank data to 2015 with Ember data from 2016, scaled to a common level, and may contain small breaks at the splice. Model B was selected among three pre-specified models because it was the only one to pass both the cointegration and serial correlation tests, which carries some risk of specification search, although the negative interaction holds in all variants. The CUSUM of squares test indicates marginal instability around 2003. Rising institutional quality is correlated with time and with changes in the composition of renewable generation, so the interaction cannot separate institutional effects from the effects of cost, technology and site quality. Future work could use plant-level or tariff data to test whether contract prices explain the declining return, county-level data since devolution in 2013, or panel data for East Africa that allow the interaction to differ across countries.

Declarations

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Author contributions. Conceptualisation: J. K. Kirui, I. K. Kemboi and N. Koske. Data curation, formal analysis and writing of the original draft: J. K. Kirui. Methodology, supervision, and writing (review and editing): I. K. Kemboi and N. Koske.

Data availability. All data are publicly available: Penn World Table 11.0 (<https://doi.org/10.34894/FABVLR>), V-Dem v16 (<https://doi.org/10.23696/vdemds26>), World Bank World Development Indicators, and Ember electricity data distributed by Our World in Data (<https://github.com/owid/energy-data>). The analysis dataset and code are available from the corresponding author on request and will be deposited in a public repository on acceptance.

Ethics statement. Not applicable. The study uses only publicly available country-level secondary data.

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