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Renewable Energy and Sustainable Development in Sierra Leone: An Empirical Analysis

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Abstract: This study investigates the relationship between renewable energy consumption and sustainable economic development in Sierra Leone from 1990 to 2023. Despite the country's abundant renewable energy potential, access to and integration of these resources remain limited, particularly in sectors essential to rural livelihoods and environmental sustainability. Using the Autoregressive Distributed Lag (ARDL) technique and the Toda-Yamamoto causality tests, the study tests the neutrality hypothesis and examines whether renewable energy investments make a meaningful contribution to sustainable development outcomes. The results reveal no causality between renewable energy use and economic growth, supporting the neutrality hypothesis. However, the findings underscore the need for strategic investment in modern energy infrastructure, rural electrification, and renewable energy technologies to unlock the potential for inclusive and sustainable development. The study concludes with policy recommendations to improve energy access, stimulate green growth, and integrate renewable energy into national development planning.

Keywords: Renewable Energy, Sustainable Development, Energy Policy, ARDL, Economic Growth, Sierra Leon

Introduction

Growing concern about climate change, environmental degradation, and fossil fuel dependency has emphasized the importance of renewable energy in sustainable development, particularly in emerging economies like Sierra Leone. Access to modern, clean, and reliable energy sources is essential for enhancing livelihoods, improving health and education, and ensuring environmental sustainability. Renewable energy can empower rural communities, enhance economic diversification, and reduce the nation's carbon footprint. This resulted from growing concerns about greenhouse gas emissions and global warming; renewable energy sources are helping to protect the environment by lowering carbon dioxide emissions. In 2015, wind energy consumption increased by 19.5% and biofuel output increased by 15.8%, according to the International Energy Outlook.

Sierra Leone's energy mix is predominantly biomass, wood fuel, and imported petroleum products, despite abundant renewable resources like hydro, solar, wind, and biomass (Zarate, 2015). This imbalance limits productivity and hinders long-term development prospects. To achieve the Sustainable Development Goals, particularly SDG 7(affordable and clean energy) and SDG 13 (climate action), renewable energy becomes a key pillar of the sustainable development agenda. By 2030, the country wants to double its renewable energy levels, enhance energy efficiency, and expand access to electricity. However, the nation's growing mining, agricultural, and industrial economies have resulted

in a huge demand imbalance in the electrical sector (Bank, 2015). Since the economy has relied heavily on petroleum imports since 1961, despite having abundant primary energy resources. Renewable energy sources, like hydro, fuelwood, solar, wind, and biomass, could improve socioeconomic conditions by reducing dollar trade, minimizing greenhouse gas effects, and enhancing the energy mix structure.

The main energy source, fuelwood, provides 93% of the energy used, and the country has potential for sustainable energy generation through wind power plants, but capital-intensive and requires precision technology. Small wind generators can be used for off-grid electricity generation. However, 40% of Sierra Leone's primary energy consumption is dependent on imports, and the country uses less than 1% of its renewable energy potential. The energy market accounts for 40% of primary energy consumption, with 60% relying on imports, and can only produce 29MW of hydro-energy, 1MW of wind, 46MW of solar, and 17MW of bioenergy (Leone, 2015). Energy consumption efficiency is crucial for international competitiveness. Countries have explored alternative energy sources like biomass, wind power, and nuclear, with wind energy promising but requiring more investment and research on profitability and environmental impact (Rayhan, 2024).

Moreover, rising electricity costs from wind power plants are a major concern due to global warming and primary energy scarcity. Renewable energy is crucial for economic development, but also contributes to environmental degradation, impacting policy implications in countries with limited fossil resources (Krumins & Klavins, 2022). Economic growth and environmental policies depend heavily on the generation and consumption of renewable energy, yet empirical findings are still mixed, which affects the consequences for policy. This led to a look at the relationship between renewable energy consumption and economic growth, which can be categorized into four hypotheses. The growth hypothesis suggests a unidirectional causality, with an increase in energy consumption positively impacting economic growth. Reducing energy use has little impact on economic growth, according to the conservation hypothesis. According to the feedback theory, energy conservation has a detrimental impact on economic growth, while GDP declines have a detrimental effect on energy consumption. With major ramifications for energy policy, the neutrality hypothesis contends that there is no relationship between GDP and energy consumption.

Sierra Leone is utilizing its abundant renewable energy resources to combat global greenhouse gas emissions and address social issues like poverty and unemployment. Renewable technologies, particularly in remote rural areas, can provide solar electricity and efficient biomass cooking. This study re-examines the connection between renewable energy consumption and economic growth within the broader framework of sustainable development. It seeks to explore whether renewable energy investments can contribute to inclusive growth, environmental protection, and long-term resilience. Using annual data from 1990 to 2023 and adopting the ARDL bounds testing approach along with the Toda-Yamamoto causality test, the research critically assesses the long- and short-term dynamics of this relationship. It provides a comprehensive overview of previous literature, presents data, methods, and results, and concludes with a discussion and conclusion.

Literature Review

The relationship between the use of renewable energy consumption and sustainable development (economic growth) has been the subject of numerous studies and has received increasing attention in recent years, as countries seek to transition to low-carbon economies. The literature shows mixed evidence because of different data, periods, and methodologies regarding the extent to which renewable energy contributes to economic growth, social equity, and environmental protection, which are core pillars of sustainable development. Studies on the relationship between the use of renewable energy and economic growth have found either no connection or bidirectional causality. As indicated in Table 1, these research findings about the causal relationship between the use of renewable energy and economic growth are inconsistent and vary by nation.

Table 1. Compilation of the renewable energy consumption and economic growth nexus literature

AUTHOR(S)	COUNTRY(IES) and period	METHODOLOGY	VARIABLES	CONCLUSION
Pearson (2021)	Croatia (1996-2018)	ARDL	EG; ENC; REC	REC is positive & significant on EG in the short & long run. Conservation Hypothesis
Kasperowicz et al., (2020)	29 European Countries (1995-2016)	Panel unit root test; panel cointegration test; Fully modified OLS & Dynamic least squares estimators	REC; EG	Long-term equilibrium relationship between EG and REC. Growth hypothesis
Amri (2017)	72 Countries (1990-2012)	Dynamic simultaneous-equation panel	REC; TR; EG	Feedback relationship between REC, TR, and income, indicating interdependence between the three variables. Feedback Hypothesis
Aslan (2016)	USA (1961-2011)	ARDL	BEC; EG; K; L	BEC is positive on EG both in the short & long run, and unidirectional causality from BEC & EG. Growth Hypothesis
Kula (2014)	19 OECD Countries (1980-2008)	Panel Integration & Cointegration Techniques	REC; EG	Long-run equilibrium relation between REC & EG. Conservation Hypothesis

AUTHOR(S)	COUNTRY(IES) and period	METHODOLOGY	VARIABLES	CONCLUSION
Lin & Moubarak, (2014)	China (1977-2011)	ARDL	REC; EG, CO2, L	REC & EG are bidirectional, with L influencing short-term consumption. Feedback Hypothesis
Payne (2011)	USA (1949-2007)	Toda-Yamamoto causality tests	BEC; EG	Unidirectional causality from BEC to EG. Growth hypothesis
Menyah & Wolde-Rufael, (2010)	USA (1960-2007)	Granger Causality test	REC; EG	REC has a unidirectional causality with CO2 emissions. Conservation hypothesis
Sari et al. (2008)	USA (1969-1999)	ARDL	REC; IO	IO positively impacts hydroelectric, waste & wind. EC negatively impacts solar REC. Neutrality Hypothesis
Payne (2009)	USA (1949-2006)	Toda-Yamamoto causality tests	EC; REC; EG	It compares NREC, REC & EG, revealing no Granger causality. Neutrality hypothesis

NOTE: The abbreviations are as follows: Energy Consumption (EC), Real GDP (EG), Trade (TR), Renewable Energy Consumption (REC), Non-Renewable Energy Consumption (NREC), Electricity Consumption (EC), Oil prices (OP), Gross Inland Consumption (GNC), Biomass Energy Consumption (BEC), Capital (K), Labour (L), Gross Nuclear Electricity Production (GNEP), Primary Production Energies (PPAE), Gross Production Hydropower & wind (GPHW), Institutional Quality (IQ), Nuclear Energy Consumption (NEC), CO2 Emission (CO2), Industrial Output (IO), Autoregressive Distributed Lag (ARDL), Clemente-Montanes-Reyes Test (CMR), Bayer-Hanck Cointegration Test (BH), Vector Error Correction Model (VECM).

A study by Aisah & Bawonom (2023) found that renewable energy doesn't impact economic growth, and exports influence renewable energy, but not Sukuk. International trade, including exports and imports, affects economic growth. On the other hand, a study by Loesse, 2010) examines the long-term relationship between energy consumption and economic growth in seven Sub-Saharan African countries from 1970-2007. The results show that energy consumption is cointegrated with economic growth in Cameroon, Congo, Côte d'Ivoire, and South Africa, with a significant positive long-term impact. In the case of developed economies, a study was done by Ümit & Dağdemir (2025) who examined the relationship between renewable energy consumption, economic growth, and trade openness in 27 EU member states with high energy imports from 1990-2021. The study found a unidirectional causality between renewable energy consumption and economic growth in Belgium, Finland, and Italy, while a unidirectional causality from economic

growth to renewable energy consumption was found in Croatia, Greece, Ireland, the Netherlands, Portugal, and Romania, and a unidirectional causality from renewable energy consumption to trade openness.

Conversely, we turn our attention to the Baltic states and a study done by (Krūmiņš & Kļaviņš (2022) evaluated fossil CO2 emissions in the Baltic States from 1991 onward, focusing on sustainability and integrated approaches to development. Results showed a significant reduction in emissions due to the transition from the Soviet Union's economy to global markets. However, the development and implementation of national policies for sustainable development are still crucial for mitigating climate challenges. Still on advanced economies, Abubakirova et al. (2025) examines the relationship between renewable energy production and economic growth in G7 countries from 2000-2023 using Kao and Johansen Fisher panel cointegration tests. Results show a positive correlation between renewable energy production and economic growth, with a 1% increase in renewable energy production causing a 0.70% long-term economic growth change. The DOLS method estimates this coefficient at 0.66.

Likewise, Czudaj et al. (2020) use a Nonlinear Auto-Regressive Distributed Lag model to examine the nonlinear pass-through from economic growth to renewable energy consumption in G7 countries from 1995Q1-2015Q4. Results show that renewable energy consumption responds asymmetrically to long-run economic growth in France, Japan, Italy, and the UK, but no long-run equilibrium exists in Germany, Canada, and the US. Furthermore, within the EU, a study was done by Eser & Akif (2021) who examined the impact of renewable and non-renewable energy consumption on economic growth in G7 countries using a new panel data estimator, addressing cross-sectional dependence and slope heterogeneity. The study uses Cross-sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) results to analyse the relationship between renewable energy (REN) and non-renewable energy (NREN) consumption. The panel bootstrap causality analysis reveals that the growth hypothesis (GH) is valid in REN in Canada, Italy, and the US; neutrality is valid in REN in France, Japan, and the UK; the feedback hypothesis (FE) is valid for REN only in Germany. For NREN, the GH is valid for Canada, France, and Germany; the conservation hypothesis (CH) is valid in Italy and the UK. Finally, the FH is valid in Japan and the US.

Šimelytė & Dudzevičiūtė (2017) examine the correlation between renewable energy consumption, economic growth, trade, capital, and labor in 28 European Union countries from 1990 to 2012. The analysis shows that renewable energy consumption boosts the economy in 12 out of 28 countries, with the neutrality hypothesis confirmed in 2 and the conservation hypothesis proven in 6 cases, with the weakest links observed in Luxembourg. The increasing international relations between countries are bridging the gap in information transfer, but also hindering national sovereignty. In Southeast Asia, Indonesia has committed to the early retirement of coal-fired power plants, highlighting the urgent need for a transition to renewable energy due to coal's significant environmental impact and rising CO2 emissions. The study highlights Indonesia's renewable energy potential, emphasizing the need for a comprehensive roadmap, including strengthened governance, public-private collaborations, diverse financing, and targeted incentives (Aditya et al., 2025).

In the US, Sari et al. (2008) examine the relationship between disaggregate energy consumption and industrial output and employment in the US using the autoregressive distributed lag approach for the period covering 2001:1–2005:6, finding that real output and employment are long-term forcing variables. Ewing et al. (2007) examine the impact of disaggregate energy consumption on US industrial output using monthly data and the generalized variance decomposition approach. Results show that coal, natural gas, and fossil fuel energy sources have the most significant impact on output variation, while employment is the most significant factor explaining this variance. On the other hand, Sheikh & Hassan (2023) examine the impact of economic growth, energy use, and research and development expenditure on carbon dioxide emissions in 29 OECD countries from 1995-2019. Using two econometric techniques, the study found that GDP and energy use have similar effects on carbon emissions, but research and development spending has conflicting results. The study concluded that with a rise in GDP, carbon emissions decrease, but increase with energy use. Aggregate research and development expenditure has a positive effect on carbon emissions under cross-sectional independence, but a neutral effect when estimated using cross-sectional dependence tests.

For the case of Africa, Agbana et al. (2024) examine the impact of economic factors like FDI, unemployment rate, inflation rate, exchange rate, and GDP on Nigeria's hydropower production using Ordinary Least Squares Structural Equation Modelling (PLS-SEM). It found that only the exchange rate has a structural relationship with hydropower production, while other factors like inflation, unemployment, and FDI do not. The study recommends controlling the exchange rate to maintain hydropower production growth and prevent a decrease in productive capacity. Anguibi (2015) analysed the long-run and causal relationships between economic performance, foreign direct investment, domestic investment, and port sector production output in Cote d'Ivoire from 1980-2013. Results showed that these factors significantly influence port sector productivity. The study recommends focusing on investment strategies involving private participation to enhance safety, operational quality, and transport connectivity. Diffusion, a process that may lead to international environmental regimes, is a complementary approach. This research focuses on the diffusion of renewable energy policy innovations in Ghana, revealing that power relations play a significant role in this process (Aglanu, 2016).

Mivumbi & Yuan (2021) examine the relationship between Rwanda's environmental pollution, human capital, physical capital, economic growth, and energy consumption between 1990 and 2018. Results show that energy consumption significantly influences Rwanda's air pollution, while economic growth slightly influences it. The study suggests Rwanda's government should promote new technology and manage human capital, physical capital, and energy consumption to reduce CO2 emissions. Morocco is transitioning to clean and renewable energy due to environmental degradation, finite resources, and fluctuating oil prices. However, the country faces challenges in meeting future energy demand, increasing reliance on imported fossil fuels, and carbon emissions. Renewable energy positively impacts profitable growth and CO2 emissions. Innovative financing solutions are needed to support renewable energy systems (Moudene et al., 2023).

Sierra Leone-specific studies (Bank, 2015; Leone, 2015) emphasize the role of renewable energy in poverty reduction, agro-processing, and social development.

However, investment and infrastructure challenges continue to hinder progress. This study contributes by contextualizing renewable energy within Sierra Leone's development framework and evaluating its direct influence on long-term sustainability. Therefore, there is conflicting evidence in the literature about the causal relationship between growth and energy use. Using the Toda and Yamamoto causality tests, this study aims to investigate the connection between Sierra Leone's economic growth and its use of renewable energy.

Methods

Utilizing data from the World Bank Development Indicators for Sierra Leone from 1990 to 2023, the study focuses on the following: GDP (Y) in millions of constant 2015 US$, gross fixed capital formation (K) in millions of constant 2015 US$, total labor force (L) in millions, and renewable energy consumption (as a percentage of total final energy consumption). The Toda and Yamamoto (T&Y) tests will be used to determine causality for the years 1990–2023, while the ARDL approach tests will be utilized to determine co-integration. An approach to the ARDL bounds test is preferred over other co-integration tests due to its advantages, like Monte Carlo evidence, adaptability for explanatory variables, small properties, and its ability to calculate associations throughout the short and long term, irrespective of the type of series. The ARDL method uses unit root analysis to determine integration for variables, with Augmented Dickey-Fuller and Kwiatkowski-Phillips-Schmid-Shin tests conducted. The ADF test rejects the null hypothesis of non-stationarity if the p-value is below 0.05.

Table 2. ADF unit root test

VARIABLES	ADF P-VALUE	KPSS P-VALUE	TEST	RESULT
Renewable energy consumption (REC)	-0.945	0.6287	constant	not stationary
D_REC	-0.651	0.1437	constant	stationary
Real gross domestic product (RGDP)	0.3175	0.6139	constant	not stationary
D_RGDP	-4.9779	0.296	constant	stationary
Gross fixed capital formation (GFCF, i.e., capital)	-1.3931	0.5313	constant	not stationary
D_GFCF	-4.4473	0.0948	constant	stationary
Labour force (LF)	2.1060	0.6738	constant	not stationary
D_LF	-3.6032	0.2409	constant	stationary

Source: Calculation by Author using EViews *1%, **5%, and ***10% significance level

The KPSS test's null hypothesis suggests a stationary series; to reject it, the p-value is above 0.1. According to the ADF and KPSS unit root tests, REC, RGDP, GFCF, and LF are I (1), meeting the long-run relationship cointegration conditions. When non-stationary variables are transformed to stationarity, the order of integration is I (1), and the "D" in variables denotes the first difference. The study avoided the necessity for unit root pre-

testing by using the ARDL bounds testing approach to investigate the relationship between Sierra Leone's GDP and renewable energy consumption. The findings are shown in Table 2.

Table 3. ARDL f-bound test

TEST STATISTIC	VALUE	SIG	I (0)	I (1)
			ASYMPTOTIC	
			n=1000	
F-statistic	6.0182	10%	2.72	3.77
k	3	5%	3.23	4.35
		2.50%	3.69	4.89
		1%	4.29	5.61

Source: Calculation by the Author using EViews

As the ARDL Bounds test confirms, the F-statistic (6.0182) shows a long-term link between the dependent and independent variables, as shown by Table 3 above. Co-integration, which estimates long-term correlations between variables in an equation, and the typical log-linear functional definition of the long-term link between renewable energy usage and real GDP are two applications of the model. This is an example of the ARDL approach:

$$\Delta gdp_t = \delta_1 + \sum_{i=1}^{p1} \theta_{1i}\, \Delta gdp_{t-i} + \sum_{j=0}^{q1} \beta_{1j}\, \Delta rec_{t-j} + \rho_1 gdp_{t-1} + \rho_2 rec_{t-1} + \epsilon_{1t} \quad (1)$$

Where ϵ_{1t} is a white noise term, and Δ serves as the initial difference operator. The ARDL approach estimates $(p+1)^k$ number of regressions to get the optimal lag length for each variable, where p is the maximum number of lags to be used, and k is the number of variables in the equation. A criterion like the Schwarz-Bayesian Criterion (SBC) serves as the foundation for a suitable lag selection. The limits testing process compares the option of $H_o: \delta_\tau = 0, r = 1,2$ to the null hypothesis of no co-integration, $H_o: \delta_\tau = 0$, using the joint Wald or F-statistic. Pesaran et al. (2001) give two critical value sets for classifying regressors as mutually co-integrated, only I (1), or just I (0). Regardless of the series' I (0) or I (1), the null hypothesis of no co-integration is rejected if the calculated F-statistics are above the critical boundaries and cannot be rejected if they are less than the critical value. It is impossible to draw a firm conclusion if the test statistics fall between the boundaries without knowing the order of the underlying regression.

Determining the coefficient of the error correction term, represented by ψ, is the second stage in estimating long-run and short-run models with co-integration between variables.

$$gdp_t = \delta_2 + \sum_{i=1}^{p2} \theta_{2i}\, \Delta gdp_{t-i} + \sum_{j=0}^{q2} \beta_{2j}\, \Delta rec_{t-j} + \epsilon_{2t} \quad (2)$$

$$gdp_t = \delta_3 + \sum_{i=1}^{p3} \theta_{3i}\, \Delta gdp_{t-i} + \sum_{j=0}^{q3} \beta_{3j}\, \Delta rec_{t-j} + \psi rec_{t-i} + \epsilon_{3t} \quad (3)$$

When analysing co-integration relations in small samples, the ARDL technique is statistically significant and can withstand the optimal lags of various variables. In contrast

to traditional models that estimate long-run relationships, it employs a single reduced-form equation. Table 4 below displays the ideal latency selected for this model.

Table 4. Criteria for VAR lag order selection

LAG	LOGL	LR	FPE	AIC	SC	HQ
0	-625.7034	NA	1.00E+17	41.98023	42.16705	42.03999
1	-619.9577	9.576184*	7.30e+16	41.66385*	41.89738*	41.73855*
2	-619.299	1.053929	7.48E+16*	41.6866	41.96684	41.77625
3	-618.5651	1.125215	7.64E+16	41.70434	42.03129	41.80894
4	-617.5382	1.506201	7.66E+16	41.70255	42.0762	41.82208

Source: Calculation by the Author using EViews

To effectively capture the dynamics of variables and prevent overfitting or underfitting, the ideal lag duration is essential. It's determined by understanding how past variables influence current values. The optimal lag length in VAR is 1, meeting criteria like LR, FPE, AIC, SC, and HQ. Proper selection ensures a well-specified model, accurate inferences, and reliable forecasts.

Results

Using the ARDL method, the study examines the relationship between Sierra Leone's economic growth and the use of renewable energy from 1990 to 2023. With notable negative error correction parameters, the results demonstrate a co-integrating connection. Table 5 shows that the coefficient -0.2247 means that 22% of the long-term equilibrium divergence is rectified every cycle.

Table 5. Findings of co-integration analysis

VARIABLES	COEFFICIENT	PROB.	
F-stat	1.5395		
ECM (-1)	-0.2247	0.0091**	co-integration

Source: Calculation by the Author using EViews. Note: ARDL (1,0,0,0) selected based on Schwarz Bayesian Criterion

The study reveals that renewable energy consumption negatively impacts Sierra Leone's economic growth, with a 5% statistical significance, shown by Table 6 below. Capital negatively impacts GDP, while labor positively affects it, and GDP declines by 0.45% for every 1% growth in renewable energy. The government's renewable energy policies may not be contributing to economic growth due to inefficiencies or reliance on less productive renewables. To boost economic growth, the government should invest in more efficient technologies and infrastructure for solar and wind production and diversify energy sources. The renewable energy sector's economic growth may be hindered by a lack of skilled labor or inadequate training. Governments should invest in education and training programs, consider the transition from fossil fuels, and continuously monitor and evaluate renewable energy policies.

Table 6. Long-run coefficient results

	VARIABLES	COEFFICIENTS	PROB.
The Dependent Variable			
is GDP	REC	-0.4573	0.0527**
	CAPITAL	-0.0323	0.0171**
	LABOUR	1.7407	0.0506**
	CONSTANT	0.0030	0.0905

Source: Calculation by the Author using EViews *1%, **5%, and ***10% significance level

The negative correlation between capital investments and economic growth suggests that current investments may not yield expected returns. The government should reassess capital allocation strategies, prioritize growth-potential sectors, conduct cost-benefit analyses, improve project management, reduce bureaucratic hurdles, and maximize productivity. The government should encourage private sector investment through tax incentives, public-private partnerships, and reducing barriers. Addressing structural issues like infrastructure, regulatory challenges, and market access can boost capital and contribute to economic growth.

All estimated models showed stable parameters over time, with no functional form, serial correlation, heteroscedasticity, or non-normality. Table 7 below illustrates how the CUSUM and CUSUMSQ tests were used to verify the stability of the co-integration parameters.

Table 7. The diagnostic results

The Dependent Variable is GDP	TESTS	LM VERSION	PROB
	LM test for no serial correlation (Breusch-Godfrey)	0.7405	0.3988
	White's heteroskedasticity (homoscedasticity) test	0.3925	0.9528
	The normalcy Jarque-Bera statistic	27.9779	0.0001
	Statistics from Ramsey's reset test (functional form)	0.0025	0.998
	CUSUM	STABLE	
	CUSUMQ	STABLE	

Source: Calculation by the Author using EViews

If the series is I (0), I (1), or I (2), non-cointegrated or co-integrated of any arbitrary order for VAR (3), (k=2 and dmax=1), we estimate the following system equations as follows to evaluate causality using Toda and Yamamoto's tests.

$$\begin{bmatrix} lny_t \\ lnre_t \\ lnk_t \\ lnl_t \end{bmatrix} = A_0 + A_1 \begin{bmatrix} lny_{t-1} \\ lnre_{t-1} \\ lnk_{t-1} \\ lnl_{t-1} \end{bmatrix} + A_2 \begin{bmatrix} lny_{t-2} \\ lnre_{t-2} \\ lnk_{t-2} \\ lnl_{t-2} \end{bmatrix} + A_3 \begin{bmatrix} lny_{t-3} \\ lnre_{t-3} \\ lnk_{t-3} \\ lnl_{t-3} \end{bmatrix} + \begin{bmatrix} \epsilon lny_t \\ \epsilon lnre_t \\ \epsilon lnk_t \\ \epsilon lnl_t \end{bmatrix} \quad (4)$$

Equation (4) has four 4 by 4 matrices of coefficients, A1 through A3, with A0 serving as the 4 by 1 identity matrix and ϵ representing the disturbance terms, which have a constant variance and zero mean. The next hypothesis could test the idea that economic growth (lnyt) is not a result of renewable energy consumption (lnret) using Eq. (4). Where H_0= a_{12}^1= a_{12}^2= a_{12}^3=0 are the coefficients for the renewable energy variable in the system's initial equation, seen in Eq. (4), are denoted by $a_{1i's}^1$. In addition, we can test the following hypothesis to see if economic growth (lnyt) and the use of renewable energy (lnret) are causally related. H_0= a_{21}^1= a_{21}^2= a_{21}^3=0 where $a_{2i's}^1$ are the coefficients of the economic growth variable in the system's second equation, which is shown in Eq. (4) (refer to Table 8).

Table 8. Analysis of causality results

WALD STATISTIC	GDP-REC			WALD STATISTIC	REC-GDP		
	LAG	CASUAL	PROB		LAG	CASUAL	PROB
3.07	1	NO	0.2154	0.56	1	NO	0.7546

Source: Calculation by the Author using Eviews

The study found no Granger causality between GDP (economic growth) and Renewable energy consumption (REC), with insignificant p-values. The T&Y test, unlike traditional Granger causality tests, avoids order misspecification and works regardless of series type. The lack of a causal relationship suggests that renewable energy investments may not directly boost economic growth, suggesting policymakers should reassess effectiveness and allocate resources to areas directly impacting GDP, such as agriculture, manufacturing, and services. Renewable energy enhances energy security and sustainability, but should be integrated into economic development plans alongside human capital, infrastructure, education, vocational training, and private sector investment incentives for economic growth. Economic growth and renewable energy have a complicated relationship, according to the neutrality theory, requiring further research and public awareness campaigns for sustainability and energy independence.

Discussion

The study confirms the neutrality hypothesis, suggesting that renewable energy consumption doesn't significantly impact economic growth in Sierra Leone. This implies that energy consumption and economic growth are not causally related, indicating that policies promoting renewable energy conservation have no impact (Acaravci & Ozturk, 2010). However, this suggests systemic issues like limited infrastructure, energy poverty, and insufficient energy policy integration with national development goals. The weak connection between renewable energy and growth may be due to underinvestment in productive energy infrastructure, particularly in rural areas, which restricts opportunities in education, healthcare, agriculture, and entrepreneurship, crucial for sustainable development. The model shows a negative correlation between capital and GDP, possibly due to inefficiencies in public investment or resource misallocation. Labor, however, is a significant contributor to growth, emphasizing the importance of human development and

capacity building in sustainability planning. The study sheds important light on how GDP and the use of renewable energy relate to one another in Sierra Leone and other nations.

Furthermore, several research have validated the four hypotheses concerning the causal relationship between economic performance and the use of renewable energy. Some discovered reciprocal causality, confirming the feedback theory (Fotourehchi, 2017), while others concluded that there was unidirectional causality, which supported the growth concept (Esso, 2010). Some discovered unidirectional causation, which lends credence to the conservation theory (Öcal & Aslan, 2013). The relationship between the use of renewable energy and economic growth has shown conflicting findings, with some pointing to a neutrality theory. The research's findings vary depending on the use of different proxy variables for different types of renewable energy consumption (Menegaki, 2011). Policies governing the use of renewable energy may not have a major effect on Sierra Leone's economic growth, according to the study.

However, the country's renewable energy sources can always stimulate growth by meeting energy needs, but investment in transformation devices is needed. In Sierra Leone, 59% of the installed grid-connected electricity generation capacity is generated by hydropower. Biomass for electricity generation can be generated from residues, existing forests, and deforested lands. The average annual crop waste produces 656,400 tonnes, with a potential energy of 2,706 GWh or 500 MW. The country can reduce its petroleum dependency by fermenting crops like sunflower seeds and Jatropha tree nuts to produce ethanol and biodiesel. However, the country faces environmental issues like deforestation, soil erosion, desertification, biodiversity loss, microclimatic change, and flooding. To combat global warming, the country needs to reduce energy consumption through increased renewable energy use or decreased consumption.

The location of Sierra Leone is perfect for solar power because of its strong solar radiation and abundance of sunshine. Solar PV systems are being installed in 14 districts, schools, hospitals, and growth centres, with a current capacity of 2.5 MWp in 2014. Low wind speed turbines are also being investigated, and wind speeds range from 3 to 5 m/s, with the possibility of 12 m/s in some places. Based on the neutrality theory, demand management and energy conservation measures might not affect economic expansion. However, in emerging nations, renewable energy consumption can be negatively impacted by mismanagement and significant investment, despite its environmental and future sustainability. The country must prioritize renewable energy access, particularly in off-grid and underserved communities, to improve sustainability and resilience, and invest in solar energy for schools, hospitals, and water supply systems.

Conclusion

This study analysed the relationship between renewable energy consumption and sustainable development in Sierra Leone using ARDL and Toda-Yamamoto causality approaches. The results confirmed the neutrality hypothesis, showing no causal link between renewable energy and economic growth, and that economic growth is negatively impacted by using renewable energy. However, the implications extend beyond GDP to the broader goals of social inclusion, environmental protection, and energy access. Sierra Leone's path to sustainable development requires a reorientation of energy policy to focus

on equity, accessibility, and environmental integrity. This involves scaling up investments in renewable technologies, expanding rural electrification, and integrating clean energy strategies into national development frameworks.

To realize the potential of renewable energy as a driver of sustainability, the government should also strengthen institutional coordination, foster private sector participation, and align interventions with the Sustainable Development Goals. With focused and inclusive policies, renewable energy can move from a neutral economic variable to a catalyst for transformative development. Although the cost of renewable energy is high for developing nations, and rising incomes encourage more usage, this study found a neutrality hypothesis for the relationship between economic growth and renewable energy consumption in Sierra Leone. Despite this, the study emphasizes why renewable energy is important for sustainable development and environmental conservation.

In addition to promoting investments through public-private partnerships, Sierra Leone seeks to diversify its energy resources and guarantee a consistent, reasonably priced, and equitable supply of renewable energy. The goal is to create a comprehensive, integrated renewable energy sector, foster international cooperation, and effectively use abundant energy resources for international promotion, despite renewable energy limitations not affecting economic growth.

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