International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(4), 576-587.

Assessing the Influence of Renewable Energy Consumption and Domestic Investment on Environmental Quality in Somalia

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Received: 01 Feburary 2025 **Accepted:** 26 May 2025 **DOI:** https://doi.org/10.32479/ijeep.19603

ABSTRACT

Environmental sustainability is a critical global issue, prompting initiatives to diminish emissions and alleviate the effects of climate change. This study examines the impact of renewable energy consumption and domestic investment on the environmental quality of Somalia from 1990 to 2020. The study used econometric methods, including the Pairwise Granger Causality Test and the ARDL model, to ascertain substantial correlations between environmental quality and variables such as population growth, renewable energy utilization, domestic investment, and economic growth. Research indicates a sustained positive link between population increase and environmental quality, but renewable energy utilization, domestic investment, and economic growth have a negative correlation with environmental quality. This research provides critical insights for policymakers in Somalia and beyond, highlighting the necessity of improving energy efficiency and decreasing emissions via investments in clean energy.

Keywords: Renewable, Domestic Investment, Environmental Quality, ARDL, Somali
JEL Classifications: Q56, Q42, Q53, Q58, O13, C32, F64

1. INTRODUCTION

Pollution, resource depletion, and climate change are environmental difficulties that have emerged as global issues. These concerns affect both industrialized and developing nations globally (Osobajo et al., 2020; Zafar et al., 2021). These challenges threaten ecosystems and have significant repercussions for public health, economic stability, and overall quality of life. In recent years, the need to reconcile economic growth with environmental sustainability has propelled initiatives like the Paris Agreement and the Kyoto Protocol (Radmehr et al., 2021). These initiatives seek to limit greenhouse gas emissions and promote the utilization of greener energy sources. Subpar air quality, associated with elevated death rates and higher health sensitivities, has emerged as a primary concern in this environment (World Health Organization, 2018). Thus, improving environmental quality is widely regarded as an essential objective in attaining sustainable development (Duodu, 2021).

In underdeveloped nations like Somalia, the stakes are exceptionally elevated. The environmental degradation in Somalia is intensified by a confluence of issues, including inadequate infrastructure, economic instability, and political insecurity (Hussein and Mohamed, 2024). The nation's dependence on conventional biomass for energy, owing to scarce alternatives, exacerbates deforestation, elevates air pollution, and intensifies carbon emissions (Warsame et al., 2022; World Bank, 2022). Conversely, Somalia has significant, unexploited potential in renewable energy, especially solar and wind power, which, if efficiently harnessed, might alleviate environmental strain while fostering economic development (Warsame, 2022). The shift to renewable energy in Somalia encounters considerable challenges, including inadequate regulatory frameworks, restricted investment, and insufficient infrastructure to provide sustainable energy solutions (Addis and Cheng, 2023).

Although there is widespread agreement on the significance of environmental quality and renewable energy, research explicitly

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investigating the impact of domestic investment on enhancing environmental outcomes in Somalia remains scarce. Policymakers aiming to foster sustainable development in fragile contexts should comprehend the interplay between domestic investment and renewable energy in shaping environmental quality, as this might yield significant insights (Ibrahiem, 2020).

This study seeks to address this gap by examining the synergistic effects of renewable energy use and domestic investment on environmental quality in Somalia from 1990 to 2020. This study aims to address the following problems using econometric techniques: What impact does the utilization of renewable energy have on environmental quality in Somalia? What is the significance of domestic investment in promoting environmental sustainability? How do these two elements combine to affect long-term environmental outcomes? The report aims to furnish policymakers with practical proposals for establishing an environmentally sustainable future for Somalia by answering these inquiries.

2. LITERATURE REVIEW

Comprehending the complex interplay between economic growth, renewable energy use, and environmental quality is essential for tackling modern environmental issues. This literature review examines significant research on these issues, focusing on the influence of economic growth on environmental quality, the importance of renewable energy, and the effects of domestic investment. This section finishes by pinpointing a research gap that this study intends to address.

2.1. Economic Growth and Environmental Quality

The correlation between economic growth and environmental quality has been extensively discussed by academics. Economic expansion is frequently sought to enhance living conditions and stimulate innovation. Nonetheless, it may also lead to environmental damage, especially in developing nations where industrial growth frequently compromises natural resources and air quality. Numerous studies illustrate how fast economic expansion may intensify environmental deterioration via heightened emissions and resource overuse. Khan (2019) analyzed Pakistan's economic growth from 1965 to 2015, revealing that CO_2 emissions increased with industrial production, illustrating how economic objectives can eclipse environmental concerns in lower-income countries. Kirikkaleli's (2020) study on China identified a significant correlation between economic growth and emissions, demonstrating that periods of economic expansion have traditionally resulted in increased air pollution due to heightened energy consumption.

Corroborating this perspective, Osobajo et al. (2020) documented a comparable tendency in the United Kingdom, where economic activities across 70 nations were examined, underscoring a strong correlation between economic expansion and elevated CO_2 emissions. The findings indicate a global trend where the desire for expansion frequently supersedes environmental preservation, particularly in nations with developing regulatory systems. Economic growth frequently yields immediate advantages such as employment generation and technical progress; nevertheless, the enduring environmental repercussions may surpass these benefits, especially if pollution mitigation regulations are insufficient.

The Environmental Kuznets Curve (EKC) theory posits a more hopeful perspective, indicating that the correlation between economic growth and environmental deterioration exhibits an inverted U-shape. This theory posits that environmental degradation first intensifies with economic expansion but later ameliorates when nations attain elevated income levels and invest in cleaner technology. Saboori et al. (2012) provided evidence for the Environmental Kuznets Curve (EKC) theory in Malaysia, observing that although economic expansion initially resulted in heightened CO_2 emissions, environmental quality commenced its improvement as national wealth climbed. This discovery corresponds with research conducted in Ethiopia and Ecuador, where analogous trends were noted (Adem et al., 2020; Alvarado and Toledo, 2016). These instances indicate that economic expansion, when accompanied by appropriate regulations, may effectively promote environmental sustainability, offering a reassuring outlook for emerging nations striving to reconcile growth with sustainability.

Nevertheless, the EKC theory is not uniformly applicable. Shaari and Zainol Abidin (2021) investigated nine emerging nations in Asia and discovered a persistent correlation between economic expansion and environmental deterioration throughout the research period, with no notable reversal in pollution trends despite increasing incomes. The authors contended that local businesses' significant dependence on nonrenewable resources, together with insufficient regulatory control, perpetuated elevated emission levels, hence questioning the EKC's relevance in areas with emerging environmental legislation. These findings highlight the necessity for contextual strategies in economic growth and environmental management, since economic policies beneficial in one context may not be applicable in another.

2.2. Renewable Energy Consumption and Environmental Quality

The worldwide transition to renewable energy is considered a crucial approach for mitigating environmental damage. Renewable energy sources, including solar, wind, and hydropower, provide cleaner alternatives to fossil fuels, which contribute to elevated greenhouse gas emissions and considerable environmental damage. A substantial amount of evidence substantiates the notion that renewable energy utilization enhances environmental quality by decreasing CO_2 emissions and diminishing dependence on scarce natural resources.

Bölük and Mert (2015) analyzed Turkey's renewable energy policy and identified a robust negative correlation between renewable energy consumption and CO_2 emissions, indicating that augmenting the proportion of renewables in the energy mix might substantially alleviate environmental deterioration. Their findings correspond with those of Jebli et al. (2015), who noted that renewable energy usage across 25 OECD nations consistently associated with reduced emissions per capita, illustrating renewable energy's capacity to significantly alter environmental results.

Somalia exemplifies a distinctive scenario for renewable energy research, possessing ample renewable resources—especially sun and wind—yet encountering obstacles in harnessing these owing to political and economical limitations. Warsame's (2022) analysis indicated that, while Somalia's considerable potential for onshore wind energy generation, inadequate infrastructure and investment have hindered substantial progress. Studies demonstrate that the utilization of renewable energy, particularly from solar and wind sources, is crucial for enhancing environmental quality in the region (Warsame et al., 2022). Somalia's capacity to use its renewable energy resources is predominantly unutilized, representing a squandered opportunity that may provide significant economic and environmental advantages if bolstered by suitable investments and regulations.

Nonetheless, the research illustrates the intricacy of renewable energy deployment, since the environmental advantages of renewable energy vary across different places. Certain research indicate that insufficient infrastructure and poor technology may hinder the efficacy of renewable energy in enhancing environmental quality. McGee and Greiner (2019) discovered that in specific developing nations, ineffective renewable energy systems, along with inadequate maintenance, might add to environmental deterioration instead of mitigating it. This highlights the necessity for resilient infrastructure and regular technology enhancements to guarantee that renewable energy systems realize their intended advantages.

Addis and Cheng (2023) highlighted that the influence of renewable energy on environmental quality is contingent not only on the quantity of energy produced but also on the efficacy of its integration into the overall energy system. In areas with obsolete or poorly maintained electrical systems, renewable energy sources may not effectively lower emissions, potentially causing equivalent or more environmental damage compared to conventional energy sources. The findings indicate that substantial expenditures in supporting infrastructure and capacity building are necessary for renewable energy to realize its promise as an ecologically sustainable choice.

2.3. Domestic Investment and Environmental Quality

Domestic investment, especially in green infrastructure and sustainable initiatives, holds a potentially revolutionary capacity for improving environmental quality, however this study domain is little examined relative to economic development and renewable energy (Jiang et al., 2021; Martínez and Masron, 2020). Domestic investment may propel the advancement of sustainable infrastructure and renewable energy initiatives, offering a substitute for fossil fuel-dependent energy systems. Domestic investment may enhance energy efficiency, diminish emissions, and strengthen economic resilience by promoting ecologically sustainable initiatives (Sun et al., 2022; Taghizadeh-Hesary and Yoshino, 2019).

Research demonstrates that domestic investment in renewable energy infrastructure, including solar and wind farms, is favorably associated with environmental quality. Ibrahiem (2020) indicated that in North African nations, increased investment in renewable energy correlated with decreased CO_2 emissions. By emphasizing sustainable infrastructure, governments in these countries might foster economic development while preserving environmental integrity, therefore attaining a type of "green growth" that coincides with global sustainability objectives.

The renewable energy market in Somalia is nascent, necessitating immediate local investment to develop a reliable energy infrastructure. Warsame et al. (2022) observed that Somalia's renewable energy sector is being propelled by tiny, privately held enterprises managing hyper-local networks, characterized by little regulatory supervision and governmental backing. This decentralized energy sector has stimulated innovation and entrepreneurship, although it is inadequate to realize the nation's whole potential for renewable energy generation. Furthermore, in the absence of substantial governmental investment, private sector initiatives may find it challenging to expand sustainably. This analysis underscores the necessity for policies that promote domestic investment in Somalia's renewable energy sector, since these measures might diminish the country's dependence on conventional biomass and reduce total emissions.

The constraints confronting Somalia highlight a more extensive concern: Although private sector participation is advantageous, it frequently requires the support of government-backed domestic investment to guarantee that renewable energy initiatives are both scalable and sustainable. This strategy has been effective in nations with favorable regulations that encourage investment in renewable energy, including tax incentives or subsidies for environmentally friendly initiatives. In Somalia, external financing from international entities such as the World Bank or regional coalitions might augment local investment, facilitating the development of a robust and effective renewable energy infrastructure.

Although much research has been conducted on the effects of economic growth and renewable energy on environmental quality, there is a deficiency of studies that particularly investigate the joint implications of renewable energy consumption and domestic investment on environmental outcomes in Somalia. Current work predominantly examines the overall influence of economic expansion on environmental degradation, usually overlooking the distinct dynamics in developing countries where economic policies and environmental objectives sometimes conflict. Furthermore, whereas several studies have examined renewable energy as an isolated variable, few have investigated its synergistic relationship with domestic investment and the cumulative advantages this relationship may confer on environmental quality.

This study aims to address this gap by analyzing the relationship between renewable energy use, domestic investment, and their impact on environmental quality in Somalia. Somalia offers a distinctive scenario, characterized by plentiful renewable resources but lacking sufficient infrastructure and investment for their effective application. This research seeks to elucidate how developing nations, such as Somalia, might utilize domestic investment and renewable energy to attain sustainable development objectives by resolving existing gaps. The results are anticipated to provide practical advice for policymakers seeking to reconcile economic development with environmental sustainability.

3. METHODOLOGY AND DATA

This paper utilizes a robust econometric methodology to analyze the correlation between renewable energy use, domestic investment, and environmental quality in Somalia from 1990 to 2020. The discussion encompasses data sources, analytical methodologies, and model requirements to guarantee transparency and replicability. The methodology encompasses many econometric techniques, such as stationarity assessments, the Autoregressive Distributed Lag (ARDL) model for examining both short- and long-term associations, and robustness evaluations to corroborate results.

3.1. Data Sources and Parameters

Annual data for the research variables were sourced from reputable entities, including the World development indicator and the Organization of Islamic Cooperation (OIC), therefore assuring data correctness and consistency. The principal variables of concern comprise:

- Environmental Quality (EQ): Assessed by CO2 emissions, quantified in (kilotons) which acts as an indicator of environmental quality.
- Renewable Energy Consumption (REC): The percentage of total final energy consumption sourced from renewable resources.
- Domestic Investment (DI): Denoted by gross fixed capital formation, expressed in current prices.
- Economic Growth (EG): Assessed using per capita Gross Domestic Product (GDP) at constant prices, 2015.
- Population Growth (PG): Incorporated as a control variable, quantified as the yearly percentage increase of the total population.
- Agriculture production Cereals, Production.

To enhance interpretability, all variables were transformed into natural logarithms. This adjustment mitigates heteroscedasticity and enables the interpretation of coefficients as elasticities, hence enhancing the study of proportional changes.

3.2. Tests for Stationarity

In time-series analysis, stationarity is a crucial condition that guarantees the statistical features of data remain constant across time (Heaps, 2023). Non-stationary data may produce misleading conclusions, rendering stationarity testing an essential preliminary step. This research utilizes the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test to assess stationarity. The ADF test addresses autocorrelation by include lagged difference terms, but the PP test is resilient to heteroscedasticity and serial correlation, offering supplementary verification. Each variable was examined to ascertain its integration order at levels I(0) or first difference I(1), so confirming its appropriateness for ARDL bounds testing, as advised by Pesaran et al. (2001). The ADF and PP tests are commonly utilized; nevertheless, they may be susceptible to size distortions and exhibit poor power, especially in small sample sizes. Ng and Perron (2001) introduced improved unit root tests that integrate GLS detrending and optimum lag length selection utilizing information criteria to address these issues. Their methodology enhances the reliability of stationarity testing, guaranteeing more solid outcomes in empirical time-series analyses.

3.3. Model Selection: The Autoregressive Distributed Lag Approach

The autoregressive distributed lag (ARDL) model is employed for its adaptability in managing variables with mixed integration orders (I(0) and I(1)), which is beneficial in the small sample sizes commonly seen in datasets from developing nations (Pesaran et al., 2001). The ARDL limits testing method facilitates the concurrent investigation of short- and long-term relationships between dependent and independent variables. Accordingly, resilient in small sample sizes with a single long-term link between the underlying variables (Chandio et al., 2018)." Economic growth, domestic investment, the use of renewable energy, population increase, and agricultural output are independent factors, whereas carbon dioxide emissions act as the predictive variable. The following is an expression for observing the short-term and long-term relationships between the factors influencing environmental emissions.

$$LCO2t = \beta 0 + \beta 1LDIt + \beta 2LGDPt + \beta 3L\ REt + \beta 4LPOG\ t + B5LAGP + \mu t \quad (1)$$

In this case, ED for environmental quality is proxy of carbon dioxide emission, AGP for agricultural output, POP for population growth, REC for renewable energy consumption, DI for domestic investment, EG stands for economic growth and μt for error term. We converted every variable to a natural logarithm. Equation (2) is rewritten in ARDL form in order to assess the model's long-term relationship.

$$CO2_t = \alpha_0 + \beta_1 LCO2_{t-1} + \beta_2 LRE_{t-1} + \beta_3 LGDP_{t-1} + \beta_4 DI_{t-1} + \beta_5 LPOG_{t-1} + \beta_6 LAGP_{t-1} + \sum_{i=0}^{q} \Delta\alpha_1 LCO2_{t-k} + \sum_{i=0}^{p} \Delta\alpha_2 LRE_{t-k} + \sum_{i=0}^{p} \Delta\alpha_3 LGDP_{t-k} + \sum_{i=0}^{p} \Delta\alpha_4 LDI_{t-k} + \sum_{i=0}^{p} \Delta\alpha_5 LPOG_{t-k} + \sum_{i=0}^{p} \Delta\alpha_6 LAGP_{t-k} + \varepsilon_{t-k}$$

where α_0 is the constant, α_1-α_6 are the short-term variable coefficients, β_1-β_6 are the long-term parameter elasticities, q denotes the optimal lags of the explained, p denotes the explanators' optimal lags, Δ is the sign of the first difference in the short-term variables, and ε_t is the error term. Bounded testing is the first step in the ARDL cointegration technique.

Long-term variables are not cointegrated, according to the null hypothesis (H_0), which is $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = 0$. According to the alternative hypothesis (H_1), long-term variables are cointegrated if $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq \beta_7 \neq 0$. To evaluate the null hypothesis, the Wald-F statistics and critical values were used. The null hypothesis is rejected if the Wald-F statistics are greater than the upper bound critical values, suggesting that the variables are eventually related and vice versa.

3.4. Long-Term and Short-Term Projections

After establishing cointegration, the long-term coefficients and short-term dynamics are calculated. Long-term coefficients provide insights into the equilibrium linkages among renewable energy consumption, domestic investment, economic growth, and environmental quality. Simultaneously, short-term dynamics are examined using the error correction model (ECM), whereby the coefficient of the error correction term (η) signifies the rate at which deviations from the long-term equilibrium are rectified. A statistically significant negative coefficient for η indicates that any disequilibrium is rectified over time, restoring the system to long-term equilibrium.

3.5. Validation Assessments

This study performs many diagnostic tests to guarantee the robustness and trustworthiness of the data, including:

- Normality Test (Jarque-Bera): Assesses whether the residuals are normally distributed, a key assumption in regression analysis (Bai and Perron, 2003).
- Serial Correlation (Breusch-Godfrey Test): Checks for the presence of autocorrelation in the residuals, ensuring that the ARDL model specification is correctly capturing the time dynamics of the variables.
- Heteroscedasticity (Breusch-Pagan Test): Evaluates if the variance of residuals is constant, confirming the homoscedasticity assumption for valid inference.
- CUSUM and CUSUMSQ Tests: These cumulative sum tests assess the stability of the ARDL model coefficients over the sample period, with stable models indicating reliable parameter estimates (Pesaran and Shin, 1999).

3.6. Approach of Data collection and Analysis

3.6.1. Robustness checks

Robustness checks are performed to ascertain the model's dependability and the assumptions' validity. These encompass:

- Normality (Jarque-Bera Test): Ensures that the residuals are normally distributed.
- Serial Correlation (Breusch-Godfrey Test): Detects any autocorrelation in the residuals.
- Heteroscedasticity (Breusch-Pagan Test): Checks for constant variance in residuals.
- Stability Tests (CUSUM and CUSUMSQ): Assess the stability of model parameters over time.

In summary as shown in above Table 1, this systematic methodology, when enhanced by robust diagnostic assessments, provides a definitive and replicable analytical framework for examining the impact of renewable energy and domestic investment on environmental quality in Somalia.

Table 1: Summary of analytical approach

Step	Methodology component	Specific test/technique
1. Stationarity Tests	ADF and PP Tests	Determines integration order
2. Model Selection	ARDL Model	Establishes lag structure and model choice
3. Cointegration Test	ARDL Bounds Testing	F-statistic and critical values for cointegration
4. Estimation	ECM and ARDL for short- and long-term effects	Long-term coefficients and error correction term
5. Robustness Checks	Diagnostic Tests	Jarque-Bera, Breusch-Godfrey, Breusch-Pagan, CUSUM, and CUSUMSQ

4. EMPIRICAL EXAMINATION AND RESULTS

The empirical analysis conducts a comprehensive examination of the data, emphasizing descriptive statistics, stationarity, cointegration, and model estimations to elucidate the relationships among economic growth, population, renewable energy, domestic investment, agricultural production, and environmental quality in Somalia. This part seeks to elucidate the characteristics of the data, identify any inherent correlations, and analyze the consequences of the results.

4.1. Descriptive Analysis

Descriptive analysis is an essential phase in comprehending the attributes of the dataset and the distribution of significant variables. This first evaluation offers insight into the core trends, variability, and asymmetry of the data, so laying the groundwork for further statistical analysis. Table 2 displays descriptive data for the study's principal variables: economic growth (GDP), population growth (POG), renewable energy consumption (RE), environmental quality (EQ), domestic investment (DI), and agricultural production (AGP). These data facilitate the identification of overarching patterns and variability within each variable, establishing a foundation for investigating the potential relationships between these characteristics and environmental quality across time.

The average values for these variables are: GDP (21.90), population (16.13), renewable energy (4.52), environmental quality (6.41), domestic investment (19.97), and agricultural production (12.49). Domestic investment (22.92) and economic growth (21.08) have the greatest maximum values, signifying considerable variance in these variables across the research period.

All variables, except for economic growth, have negative skewness, indicating asymmetry in the data distribution. Domestic investment exhibits the biggest standard deviation (0.61), signifying considerable fluctuation around its mean. The elevated standard deviation indicates that, on average, domestic investment levels exhibit considerable variability within the sample, with several findings markedly below or above the mean.

4.2. Correlation Analysis

The correlation analysis offers a first examination of the correlations between environmental quality and the principal variables of interest in this study: Economic development, population growth, renewable energy consumption, domestic investment, and agricultural production. Upon analyzing the correlation matrix in Table 3, we discern both positive and negative relationships that provide insight into the potential links between these factors and environmental quality in Somalia.

Economic growth demonstrates a moderate positive link with environmental quality (r = 0.3999), suggesting that as the economy develops, CO_2 emissions generally rise. This favorable correlation indicates that economic activity in Somalia may be exacerbating environmental deterioration, perhaps owing to dependence on fossil fuels and other resource-intensive methods. Population growth exhibits a positive connection (r = 0.2227) with environmental quality, suggesting that an increasing population

Table 2: Descriptive statistics and trends

Stats	lCO_2	lDI	lGDP	lPOG	lRE	LAGP
Mean	6.4131	19.9709	21.9087	16.1372	4.5285	12.4929
Medium	6.4388	19.9388	21.8305	16.1637	4.5358	12.4893
Maximum	6.6000	21.0879	22.9246	16.6211	4.5591	12.9987
Minimum	6.1874	18.6619	21.1460	15.6762	4.4578	11.6858
Std dev	0.0994	0.6155	0.5787	0.2894	0.0247	0.3495
Skewness	−0.6151	−0.1179	0.4448	−0.0395	−1.2846	−0.4018
Jarque _bar	1.9666	0.2329	2.5364	1.9137	9.8406	1.4866
p-value	0.3740	0.8900	0.2813	0.3840	0.0072	0.4755

Table 3: Correlation coefficient

	lCO_2	lDI	lGDP	lPOG	lRE	lAGP
lCO_2	1					
lDI	0.0205	1				
lGDP	0.3999	0.8405	1			
lPOG	0.2227	0.8907	0.9670	1		
lRE	−0.2227	0.8487	0.7677	0.8790	1	
lAGP	−0.3775	−0.2872	−0.4226	−0.3049	−0.1656	1

may be associated with heightened environmental stress, possibly due to augmented energy consumption and land utilization. The detected positive association between domestic investment and environmental quality, however small (r = 0.0205), suggests that heightened investment may be associated with marginal increases in CO_2 emissions, potentially indicative of expenditures in sectors that have yet to achieve environmental optimization.

In contrast, the usage of renewable energy exhibits a negative connection with environmental quality (r = −0.2277). This negative correlation indicates that increased use of renewable energy correlates with diminished CO_2 emissions, reinforcing the notion that renewable energy sources may significantly mitigate environmental damage. This discovery corresponds with worldwide trends advocating renewable energy as a cleaner substitute for fossil fuels, hence endorsing environmental sustainability. Agricultural output exhibits an inverse correlation with environmental quality (r = −0.3775), suggesting that increased agricultural productivity may lead to environmental degradation. This correlation may be ascribed to sustainable farming techniques or enhanced production, which diminishes the necessity for more deforestation and land degradation.

These findings offer a preliminary comprehension of the interconnections between economic growth, population increase, domestic investment, renewable energy, and agricultural practices concerning environmental quality in Somalia. Although economic growth, domestic investment and population increase appears to strain environmental quality, renewable energy use and possibly sustainable agriculture methods appear to provide advantageous outcomes. This approach establishes a basis for subsequent econometric testing to assess causal links and long-term effects.

4.3. Unit Root Test Analysis

The unit root test is an essential procedure in time series analysis, specifically for assessing the stationarity of each variable, as non-stationary variables may result in false regression outcomes. This study employed the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests to evaluate the stationarity of each variable, as shown in Table 4. These tests determine the integration order of the data series, which is crucial for selecting the suitable econometric model, especially when employing an Autoregressive Distributed Lag (ARDL) methodology.

Table 4 indicates that certain variables are stable at levels [I(0)], whilst others attain stationarity just after initial differencing [I(1)]. The ADF and PP tests demonstrate that economic growth (GDP), population growth (POG), and renewable energy (RE) attain stationarity at the level [I(0)], since their test statistics are significant and exceed the critical values at several significance levels. These findings indicate that variations in these variables remain generally stable over time without necessitating differencing.

In contrast, several variables, such as environmental quality (CO_2 emissions, EQ), domestic investment (DI), and agricultural production (AGP), exhibit non-stationarity at their levels but attain stationarity upon initial differencing. This indicates that the means and variances of these variables fluctuate with time when examined in their original forms. Upon conversion to their initial differences, the variables achieve stability, satisfying the stationarity requirements essential for rigorous regression analysis.

The heterogeneous integration order of the variables, with some stationary at levels and others at first differences, warrants the application of the ARDL model. ARDL modeling is appropriate in this context since it accommodates both I(0) and I(1) variables without necessitating their integration to a uniform order. The results further demonstrate that none of the variables are integrated at the second difference [I(2)], hence validating the model's premise that the variables are either I(0) or I(1).

The unit root test findings establish a fundamental basis for subsequent study. By confirming that the data satisfy stationarity criteria, we can confidently utilize ARDL to investigate the short-term and long-term interactions among renewable energy, domestic investment, population growth, and environmental quality in Somalia. The results of the unit root tests substantiate the methodological approach, affirming that the selected econometric approaches are suitable for examining the relationships within this dataset.

4.4. Cointegration Test Analysis

The F-bound test is performed to evaluate the existence of a long-term relationship (cointegration) between environmental quality (EQ) and the independent variables: economic growth (GDP), population growth (POG), renewable energy consumption (RE),

Table 4: Unit root test

Variable	T-statistics	
	PP	ADF
lCO_2	−2.6742	−2.5153
lDI	−3.4809	−2.9009
lGDP	−3.6715**	−3.3497*
lPOG	−3.9779**	−4.2624**
lRE	−5.8572***	−5.8572***
LAGP	−4.2484	−4.2735
D (lCO_2)	−3.4754*	−3.4784*
D (lDI)	−5.7448***	−5.7457***
D (lGDP)	−4.1488**	−4.1488**
D (lPOG)	−3.8162**	−4.6576***
D (lRE)	−3.6816***	−3.6681**
D (AGP)	−8.3943	−17.9964

domestic investment (DI), and agricultural production (AGP). The cointegration test findings presented in Table 5 offer essential insights into the stability of the equilibrium connection among the variables across time.

The findings reveal that the Wald F-statistic is 24.15, much above the upper bound critical value of 3.79 at the 5% significance level. Given that the computed F-statistic exceeds the necessary upper bound value, we may reject the null hypothesis of no cointegration, so affirming the presence of a long-term equilibrium link between environmental quality and the explanatory variables.

The F-bound test findings indicate that environmental quality in Somalia is cointegrated with the chosen economic and environmental components, signifying a long-term link among these variables. This discovery establishes a foundation for subsequent study of the ARDL model to elucidate both short-term variations and long-term modifications in environmental quality as affected by renewable energy, domestic investment, population expansion, economic growth, and agricultural practices.

4.5. Long-Run and Short-Run ARDL Model Analysis

The ARDL model provides significant insights into the long-term and short-term links between environmental quality (CO_2 emissions) and critical factors: Domestic investment (DI), economic growth (GDP), renewable energy consumption (RE), population growth (POG), and agricultural production (AGP). The calculated coefficients for these associations, shown in Table 6, demonstrate the unique effects of each variable on environmental quality over several time frames.

Over time, domestic investment exhibits a substantial beneficial impact on environmental quality, shown by a coefficient of −0.0989. This research indicates that a 1% rise in domestic investment correlates with a 0.0989% enhancement in environmental quality, suggesting that more investment—potentially allocated to infrastructure and sustainable practices—facilitates a reduction in CO_2 emissions. Economic expansion negatively impacts environmental quality, as evidenced by a correlation of −0.2880, signifying that a 1% rise in GDP correlates with a 0.288% increase in CO_2 emissions. This result indicates the environmental expenses linked to economic growth, implying that industrial and other resource-intensive activities facilitating economic development

Table 5: F-bound test

Wald f statistics	Level of significant (%)	Bounds test critical values	
		significance M (6)	
		1 (0)	1 (1)
24.15	1	3.41	4.68
	5	2.62	3.79
	10	3.41	4.68

Table 6: Long run and short run

Variable	Coefficient	Probability
LDI	−0.0989***	0.0009
LGDP	−0.2880***	0.0036
LRE	−14.1812***	0.0000
LAGP	−0.0018	0.9022
LPOG	1.8982***	0.0000
Short-run impact		
D ($LCO2_{t-1}$)	−0.0297	0.6889
D ($LCO2_{t-2}$)	−0.3270***	0.0005
D (LDI)	−0.0427***	0.0009
D (LDI_{t-1})	0.0373***	0.0099
D (LGDP)	−0.0218	0.5379
D (LPOG)	4.0561***	0.0000
D ($LPOG_{t-1}$)	−0.7759***	0.0004
ECT(−1)	−0.678***	0.0000

in Somalia may be exacerbating environmental deterioration. This corresponds with the Environmental Kuznets Curve (EKC) concept, which posits that initial economic expansion may exacerbate pollution prior to the adoption of cleaner practices and technology.

The usage of renewable energy demonstrates the most significant beneficial impact on environmental quality, shown by a coefficient of −14.1812. Table 6 indicates that a 1% increase in renewable energy consumption correlates with a substantial 14.18% decrease in CO_2 emissions. This pronounced negative correlation highlights the potential of renewable energy as a pivotal element in mitigating environmental deterioration, reinforcing the perspective that transitioning energy sources from fossil fuels to renewables may yield significant environmental advantages. Population growth exhibits a substantial positive correlation with environmental quality, indicated by a coefficient of 1.8982. This data indicates that a 1% rise in population growth correlates with a 1.90% enhancement in environmental quality, a somewhat paradoxical outcome. This may suggest that population expansion in Somalia correlates with heightened environmental consciousness or a transition to cleaner behaviors; nevertheless, additional investigation is necessary to elucidate the particular processes underlying this phenomenon.

Agricultural productivity, meanwhile, does not have a substantial correlation with environmental quality over the long term, as seen by an insignificant value of −0.0018 in Table 6. This suggests that agricultural techniques in Somalia now exert minimal impact on CO_2 emissions, perhaps due to the country's comparatively low levels of industrial agriculture.

The ARDL model indicates that, in the short run, domestic investment exerts a beneficial effect on environmental quality, evidenced by a coefficient of −0.0427. This conclusion indicates that heightened domestic investment provides prompt environmental advantages, maybe via rapid implementation projects in cleaner technology or enhanced practices. Nevertheless, economic expansion seems to exert a negligible effect on environmental quality in the short run, evidenced by a coefficient of −0.0218. This implies that transient variations in economic development may not substantially influence CO_2 emissions, signifying that the environmental repercussions of economic activities require a longer duration to manifest.

Population increase, in accordance with long-term findings, demonstrates a substantial positive effect on environmental quality in the short term, with a coefficient of 4.0561. This link highlights the atypical positive correlation between population expansion and enhancements in environmental quality in Somalia, however comprehending the precise determinants of this relationship may necessitate more inquiry.

The error correction term (ECT), with a coefficient of −0.678, is statistically significant, signifying an adjustment speed of around 67.8% annually. The negative ECT value indicates that any short-term divergence from the long-term equilibrium among these variables is rectified rapidly, confirming the stability of the long-term link between environmental quality and the independent variables.

The findings of the ARDL model shown in Table 6 demonstrate that and domestic investment are key determinants of enhancing environmental quality in Somalia in both the long and short term. In contrast, economic expansion presents a sustained challenge to environmental quality, highlighting the necessity for policies that mitigate the environmental costs of development. The positive correlation between population growth and environmental quality indicates a noteworthy trend that may signify a transition towards sustainable practices. These results underscore the necessity of advancing renewable energy and sustainable investment to attain long-term environmental goals in Somalia.

4.6. Robustness Checks Analysis

To validate the dependability of the ARDL model outcomes, we performed several robustness assessments utilizing the Fully Modified Ordinary Least Squares (FMOLS) approach, as illustrated in Table 7. The FMOLS method provides an alternative estimation that aids in confirming the stability and consistency of the relationships identified between environmental quality and key variables such as domestic investment, economic growth, renewable energy consumption, population growth, and agricultural production.

Table 7: Diagnostic check

Test statistic	Probability
Jarque-Bera normality test	0.1588
Breusch-Godfrey serial correlation test	0.0715
Breusch-pagan Hetroskedasticity test	0.8325
R-square	0.947

The results in Table 7 closely correspond with the long-term outcomes of the ARDL model, so validating the validity of the initial study. Domestic investment (DI) exhibits a notable negative correlation with environmental quality, reflected by a coefficient of −0.0706, signifying that a 1% rise in domestic investment correlates with a 0.0706% enhancement in environmental quality (a decrease in CO_2 emissions). This conclusion aligns with the ARDL results, indicating that domestic investment, likely in green and sustainable industries, favorably impacts environmental outcomes in Somalia.

Renewable energy consumption (RE) demonstrates a significant negative impact on environmental quality, evidenced by a coefficient of −6.5818 in the FMOLS assessment. This outcome validates the significant environmental advantage of renewable energy demonstrated in the ARDL model, indicating that a 1% rise in renewable energy consumption results in a 6.58% decrease in CO_2 emissions. The uniformity among methodologies underscores the vital importance of renewable energy in enhancing environmental quality and diminishing dependence on fossil fuels.

Population growth (POG) exhibits a notable positive effect on environmental quality, shown by a coefficient of 0.5349. This finding corresponds with the positive correlation between population growth and environmental quality in the ARDL model, indicating that population growth in Somalia may be linked to sustainable practices or heightened environmental awareness, although additional research may be required to comprehensively elucidate this relationship.

The Jarque-Bera normality test yields a $P = 0.1588$, suggesting that the residuals exhibit normal distribution, given the non-significant result ($P > 0.05$). The Breusch-Godfrey serial correlation test produces a $P = 0.0715$, indicating an absence of significant serial correlation in the residuals, hence satisfying the independence requirement. The Breusch-Pagan heteroscedasticity test yields a $P = 0.8325$, signifying homoscedasticity and corroborating the assumption of constant variance in the residuals. Finally, the model's R-squared value of 0.947 indicates a robust model fit, with 94.7% of the variance in environmental quality accounted for by the independent variables.

In the FMOLS model, both economic growth (GDP) and agricultural production (AGP) are statistically insignificant, with coefficients of 0.0838 and −0.0337, respectively. The results align with the ARDL model findings, suggesting that economic growth and existing agricultural methods may not substantially influence CO_2 emissions in Somalia. The absence of importance indicates that economic activity and agricultural output may not exert a direct or immediate impact on environmental quality in this setting.

The FMOLS model has an R-squared value of 0.88, indicating robust explanatory power, as 88% of the variance in environmental quality is accounted for by the model's independent variables. This result, together with the ARDL model's elevated R-squared, signifies that the chosen elements are dependable indicators of environmental quality.

The FMOLS results shown in Table 8 corroborate the robustness of the ARDL model findings. The adverse effects of domestic investment, Population growth and renewable energy use on CO_2 emissions are substantial and uniform across models, highlighting the ecological advantages of investing in sustainable behaviors and renewable energy. The restricted impact of economic expansion and agricultural output on environmental quality is corroborated, indicating that these sectors may not significantly influence environmental outcomes in Somalia under present circumstances.

Table 8: FMOLS method

Variable	Coefficient	Probability
LDI	−0.0706**	0.0340
LPOG	0.5349**	0.0335
LGDP	0.0838	0.3455
LRE	−6.5818***	0.0001
LAGP	−0.0337	0.2357
C	27.5857***	0.0000
R-Square	0.88	

4.7. Granger Causality Test Analysis

The Granger causality test was performed to analyze the directional links between environmental quality (EQ) and several variables, including economic growth (GDP), population growth (POG), renewable energy consumption (RE), domestic investment (DI), and agricultural production (AGP). Table 9 displays the findings of the Granger causality test, revealing both unidirectional and bidirectional causal links among these variables.

Table 9: Granger causality test

Null hypothesis tests	Obs	F-statistics	obs
LDI→LEQ	29	2.6787	0.0891
LEQ→LDI		1.7584	0.1938
LGDP→LEQ	29	3.4438	0.0484
LEQ→LGDP		2.3705	0.1150
LPOG→LEQ	29	3.7161	0.0393
LEQ→LPOG		0.1555	0.8568
LRE→LEQ	29	2.1770	0.1353
LEQ→LRE		2.2664	0.1254
LNAGP→LEQ	29	0.1149	0.8919
LEQ→LNAGP		3.8927	0.0343
LGDP→LDI	29	3.8274	0.0361
LDI→LGDP		2.0334	0.1528
LPOG→LDI	29	3.7690	0.0377
LDI→LPOG		4.2689	0.0259
LRE→LDI	29	0.9284	0.4089
LDI→LRE		2.1113	0.1430
LNAGP→LDI	29	1.1177	0.3435
LDI→LNAGP		0.7222	0.4959
LPOG→LGDP	29	6.4981	0.0056
LGDP→LPOG		0.5485	0.5849
LRE→LGDP	29	6.1062	0.0072
LGDP→LRE		1.5707	0.2285
LNAGP→LGDP	29	4.7436	0.0184
LGDP→LNAGP		2.0513	0.1505
LNAGP→LRE	29	1.5921	0.2242
LRE→LNAGP		0.4565	0.6388
LNAGP→LPOG	29	0.6091	0.5520
LPOG→LNAGP		2.9674	0.0705
LRE→LPOG	29	1.7524	0.1948
LPOG→LRE		2.7999	0.0807

The Granger causality test findings in Table 9 indicate many substantial unidirectional causal links. Economic growth (GDP) Granger-causes environmental quality (EQ), evidenced by an F-statistic of 3.4438 (P = 0.0484), indicating that variations in GDP anticipate alterations in CO_2 emissions. This research indicates that economic activities affect environmental outcomes, reinforcing the idea that economic growth in Somalia has environmental consequences. Population growth (POG) Granger-causes environmental quality (EQ) with an F-statistic of 3.7161 (P = 0.0393), signifying that demographic alterations significantly influence CO_2 emissions. This outcome may indicate the heightened demand for resources and energy linked to a burgeoning population, hence impacting environmental quality.

Economic growth (GDP) Granger-causes domestic investment (DI), evidenced by an F-statistic of 3.8274 (P = 0.0361), indicating that economic expansion stimulates domestic investment. Agricultural production (AGP) Granger-causes economic growth (GDP), evidenced by an F-statistic of 4.7436 (P = 0.0184), signifying the agricultural sector's significant impact on Somalia's economic activity. Moreover, environmental quality (EQ) Granger-causes agricultural production (AGP), evidenced by an F-statistic of 3.8927 (P = 0.0343), suggesting that environmental circumstances, potentially via resource availability or climatic considerations, influence agricultural output.

Renewable energy consumption (RE) has a unidirectional causal link with economic growth (GDP), supported by an F-statistic of 6.1062 (P = 0.0072). This research indicates that renewable energy consumption is a significant catalyst for economic activity, possibly fostering sustainable growth. Population growth (POG) Granger-causes economic growth (GDP), evidenced by a substantial F-statistic of 6.4981 (P = 0.0056), highlighting the correlation between demographic shifts and economic development.

The Granger causality test indicates a bidirectional causal link between domestic investment (DI) and population growth (POG), evidenced by F-statistics of 3.7690 (P = 0.0377) and 4.2689 (P = 0.0259). This bidirectional causation indicates a dynamic relationship in which investment levels impact population growth, while changes in population subsequently influence domestic investment requirements. The relationship between investment and population growth underscores the interdependence of economic and demographic elements in Somalia's developmental framework.

The Granger causality test results indicate that economic expansion, population increase, renewable energy use, and agricultural output exert directional effects on environmental quality and on one another. Economic activities and demographic trends are key catalysts of environmental changes, whereas renewable energy use is demonstrated to bolster economic growth, so underscoring its critical role in sustainable development. The causality findings offer significant insights for policymakers, highlighting the necessity to account for both direct and indirect effects while pursuing environmental and economic objectives in Somalia.

5. DISCUSSION OF THE RESULTS

This study's findings offer significant insights into the correlation between environmental quality and many socio-economic parameters in Somalia, such as domestic investment, economic growth, renewable energy consumption, population increase, and agricultural productivity. This work, utilizing an ARDL model, has elucidated both short-term and long-term dynamics that highlight the intricacies of balancing environmental sustainability with economic and demographic pressures. This discussion section analyzes these findings within the context of Somalia and pertinent literature, while also addressing the implications for policy and future study.

The beneficial effect of renewable energy usage on environmental quality is highlighted as a key finding. Both the ARDL model and FMOLS robustness checks reveal a significant negative connection between renewable energy and CO_2 emissions, corroborating global research that recognizes renewable energy as an effective strategy for mitigating environmental deterioration. Research conducted by Bölük and Mert (2015) and Jebli et al. (2015) also indicates that heightened utilization of renewable energy results in significant emission reductions, corroborating our findings in Somalia. This outcome underscores the necessity for policies that promote investment in renewable energy infrastructure, especially considering Somalia's potential for solar and wind energy. Increasing the use of renewable energy may diminish dependence on fossil fuels, thereby reshaping Somalia's energy framework and promoting environmental and economic advantages.

Economic growth, meanwhile, poses a multifaceted issue. The ARDL model findings demonstrate that economic expansion adversely affects environmental quality, leading to heightened CO_2 emissions over the long term. This finding aligns with the Environmental Kuznets Curve (EKC) hypothesis, which posits that although economic growth initially deteriorates environmental quality, a threshold may be attained where increased income facilitates investments in cleaner technologies and sustainable practices (Saboori et al., 2012). However, this pivotal moment may not be readily achievable for developing nations such as Somalia, whose economic expansion is predominantly fueled by resource-intensive sectors and constrained regulatory structures. Consistent with the research of Khan (2019) and Kirikkaleli (2020), our findings underscore the necessity for a balanced strategy for economic growth that incorporates sustainability factors. Policymakers in Somalia must to contemplate frameworks that facilitate green growth, including the promotion of clean industrial technology and the incentivization of ecologically sustainable behaviors.

The correlation between population increase and environmental quality is notably compelling in this context. Contrary to conventional beliefs, population expansion seems to positively influence on environmental quality in Somalia, indicating that an expanding population may be associated with heightened environmental awareness or enhanced resource efficiency. This outcome diverges with observations in other areas, where population expansion generally exacerbates environmental strain due to heightened consumption and waste generation. Osobajo et al. (2020) recorded the detrimental environmental effects of population expansion in the United Kingdom and other wealthy nations. The distinctive discovery in Somalia may indicate cultural or economic processes wherein population increase prompts alterations in community-driven environmental practices or necessitates the adoption of sustainable measures. This outcome necessitates more investigation to elucidate the processes underlying this association and ascertain its long-term viability.

Domestic investment significantly impacts environmental quality. Over the long run, domestic investment correlates with a decrease in CO_2 emissions, indicating that heightened investment—potentially in infrastructure and technology advancements—facilitates positive environmental results. This is consistent with the findings of Ibrahiem (2020) and Martínez and Masron (2020), which indicate that green investment may enhance sustainable development through the promotion of energy efficiency and cleaner technology. Somalia's situation underscores the necessity of directing domestic investment towards sustainable industries, including renewable energy and environmentally friendly infrastructure, to optimize beneficial environmental outcomes. Policies that promote environmentally advantageous investments and emphasize sustainable infrastructure may be crucial for realizing both economic and environmental objectives in Somalia.

The little influence of agricultural output on long-term environmental quality may indicate the current condition of Somalia's agricultural sector, which is comparatively small-scale and lacks industrial intensity. This differs with research in more developed nations, where agriculture, especially industrial farming, significantly affects the environment owing to elevated emissions from fertilizers, technology, and alterations in land usage. Research conducted by Adem et al. (2020) and Alvarado and Toledo (2016) indicates that industrial agriculture frequently results in substantial CO_2 emissions. Nonetheless, Somalia's mostly traditional and subsistence-based farming methods may explain the little impact reported in this study. As Somalia's agricultural sector advances, it is imperative for policymakers to prioritize sustainable farming techniques that safeguard environmental integrity while promoting food security and economic development.

6. CONCLUSION AND POLICY IMPLICATIONS

This paper provides a comprehensive examination of the determinants affecting environmental quality in Somalia, emphasizing the impacts of domestic investment, economic growth, renewable energy utilization, population increase, and agricultural output. The ARDL model findings indicate both short-term and long-term interactions, offering an extensive understanding of the influence of various socio-economic factors on environmental quality.

A notable discovery is the beneficial effect of renewable energy use on environmental quality. The findings indicate that renewable energy is crucial for decreasing CO_2 emissions, underscoring the pressing necessity for policies that promote investment in renewable energy infrastructure. Incentives including subsidies, tax incentives, and favorable regulatory frameworks might expedite the adoption of renewable energy, providing significant environmental advantages while addressing Somalia's energy requirements.

Economic growth, meanwhile, presents a problem in reconciling development with sustainability. The findings indicate that economic expansion, as it already exists, correlates with heightened CO_2 emissions, illustrating the environmental repercussions of industrial and resource-heavy practices. This discovery corresponds with the Environmental Kuznets Curve (EKC) concept, which posits that first phases of economic expansion frequently accompany environmental deterioration. Policymakers in Somalia should implement measures for green growth that include sustainable practices into the economy to alleviate these consequences. This may involve advocating for cleaner technology, instituting environmental rules for companies, and fostering environmentally responsible activities across many sectors.

Domestic investment Negatively influences environmental quality, indicating that when allocated to green industries, it may significantly contribute to sustainable development. Policies that emphasize environmentally sustainable investments—such as tax incentives for green projects, government-supported financing choices, and incentives for private-sector investment in sustainable infrastructure—could further improve environmental quality. Investment in renewable energy, clean technologies, and sustainable infrastructure would optimize environmental advantages while concurrently fostering economic growth.

The correlation between population increases and environmental quality is a fascinating and rather unforeseen discovery. It posits that population expansion may correlate with enhancements in environmental quality, maybe attributable to heightened awareness, community-driven activities, or transitions towards sustainable resource utilization in reaction to population demands. Policymakers ought to cultivate this link by endorsing eco-friendly urban development, advocating sustainable behaviors within communities, and incorporating environmental education into public initiatives to leverage this beneficial trend.

This study underscores the significance of renewable energy, domestic investment, and sustainable policies in attaining environmental objectives while bolstering economic resilience in Somalia. Policymakers are urged to implement a balanced strategy that fosters economic growth via green investments and renewable energy, while mitigating the environmental consequences of industrial operations. These findings enhance the research on drivers of environmental quality and establish a basis for Somalia's sustainable development policies. Future study might investigate the processes behind these associations and examine supplementary elements that may affect environmental results, like government, education, and foreign assistance. By emphasizing sustainable practices, Somalia may attain economic growth that is congruent with environmental sustainability, so securing a resilient and prosperous future.

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