International Journal of Economics and Financial Issues

ISSN: 2146-4138

available at http: www.econjournals.com

International Journal of Economics and Financial Issues, 2025, 15(4), 135-143.

Impact of Economic Growth, Energy Consumption, and Industrialization on CO_2 Emissions: Evidence from Somalia

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Received: 04 December 2024 **Accepted:** 10 May 2025 **DOI:** https://doi.org/10.32479/ijefi.18928

ABSTRACT

This study analyzes the influence of economic growth, energy consumption, and industrialization on CO_2 emissions in Somalia, employing time series data from 1990 to 2019 and utilizing the Autoregressive Distributed Lag (ARDL) model to assess both short- and long-term interactions. This research offers empirical insights into the contribution of Somalia's emerging economy and limited industrialization to environmental deterioration. The results indicate that economic expansion and energy usage are the major contributors to CO_2 emissions in Somalia. A 1% increase in GDP per capita results in a 0.80% increase in CO_2 emissions, demonstrating a strong correlation between economic growth and environmental deterioration. A 1% increase in energy consumption leads to a 0.95% rise in CO_2 emissions, underscoring the nation's significant dependence on fossil fuels and suboptimal energy utilization. Nonetheless, industrialization does not demonstrate a statistically significant effect on CO_2 emissions, indicating that Somalia's industrial sector is undeveloped and has not substantially contributed to pollution levels. The short-run dynamics indicate that energy consumption significantly and immediately affects CO_2 emissions, but economic expansion does not have a direct short-term influence. The error correction term (ECT = −0.2655, $P < 0.01$) indicates that deviations from long-run equilibrium rectify at a rate of 26.55% annually, so affirming the stability of the link among economic development, energy consumption, and environmental deterioration. These findings highlight the pressing necessity for Somalia to implement sustainable energy regulations, enhance industrial efficiency, and limit CO_2 emissions. Policy proposals encompass investing in renewable energy, enhancing environmental governance, and incorporating green industrial practices to reconcile economic development with environmental sustainability. This study offers essential information for policymakers seeking to formulate sustainable economic policies while alleviating climate change effects.

Keywords: CO_2 Emissions, Economic Growth, Energy Consumption, Industrialization, Environmental Sustainability
JEL Classifications: O44, Q43, O14, Q53, C32

1. INTRODUCTION

The global warming issue, mainly driven by carbon dioxide (CO_2) emissions, remains a crucial challenge in the world. Since the arrival of industrial revolution, economic activities like production, consumption, and energy usage, have had been leading contributors to greenhouse gases (GHGs) emissions. Particular potential and challenges arise from the relationship between industrialization, energy consumption, economic growth, and CO_2 emissions in emerging nations like Somalia, where industry is still in its infancy. Although a lot of research has been done on these links in larger, more developed economies, less focus has been placed on less developed countries with distinct socioeconomic problems, like Somalia. This study attempts to close that gap by examining the combined and separate impacts of industrialization, energy use, and economic growth on CO_2 emissions in Somalia.

The present study establishes numerous theoretical frameworks and empirical evidence to examine the effects of economic growth on environmental degradation. The Environmental Kuznets Curve (EKC) hypothesis, for instance, posits that CO_2 emissions initially rise with economic growth but decline once a country reaches a certain income threshold, primarily due to the adoption of cleaner technologies. However, studies applying this framework often focus on countries with well-established industrial bases and advanced economies (Dogan and Inglesi-Lotz, 2020; Beşe and Kalayci, 2021). On the other hand, country like Somalia with its fragile economy and heavy reliance on biomass and petroleum products, offers a distinct case where traditional growth patterns and energy reliance may not follow the standard EKC trajectory. Present research contributes the existing literature by examining whether EKC hypothesis holds in a country with limited industrialization and high dependence on non-renewable energy sources.

Furthermore, number of studies has interrogated the energy-consumption nexus however, the energy mix in Somalia, characterized by heavy dependence on biomass and less access to modern and cleaner energy sources, remains unexplored in prior studies. Prior work on the Sub-Saharan Africa by Mentel et al. (2022) and Namahoro et al. (2024), underscore the role of renewable energy sources in mitigating CO_2 emissions. Similarly, Hassan, Mohamed, Mohamed, and Osman (2024) emphasize that Somalia's increasing urbanization and energy use—largely sourced from non-renewable biomass—pose significant challenges to environmental sustainability. Nonetheless, fewer studies have explicitly focused on how Somalia's energy consumption patterns have influenced the CO_2 emissions over time. By focusing on Somalia's energy consumption trends and their environmental implications, present study aims at offering critical insights into regions energy emissions and informing policy measures for sustainable energy development.

Another crucial component of present study is the role of industrialization. Although industrialization is a well-recognized contributor of CO_2 emissions, its impact in Somalia, however, differs from that in more industrialized countries. Research by Liu and Bae (2018) and Hanif (2018) focus on economies with prominent industrial outputs and well-established manufacturing sector. Contrary to this, Somalia being at early stage of industrialization, its economy heavily relies on agriculture and small-scale manufacturing. This study addresses the gap in the literature by examining how early-stage industrialization, driven by sectors like construction and small-scale manufacturing, impacts CO_2 emissions in a low-income, resource-constrained context.

By bridging these gaps, present study provides a comprehensive analysis of effects of economic growth, energy consumption, industrialization on CO_2 emissions in Somalia. This not only contributes to growing body of literature on the impacts of development on environment in Sub-Saharan Africa but also offers policy insights for fostering sustainable development in fragile economies.

2. LITERATURE REVIEW

Hanif (2018) investigates the relationship between economic growth, urbanization, and energy consumption (both renewable and nonrenewable) on carbon emissions in Sub-Saharan Africa, focusing on the environmental impacts in developing economies over a period from 1995 to 2015. By utilizing a system generalized method of moment (GMM) approach on a panel of 34 emerging economies, the paper highlights significant contributions of fossil and solid fuel consumption, as well as urban expansion, to carbon dioxide emissions and air pollution, while also identifying an environmental Kuznets curve (EKC) in the region.

Liu and Bae (2018) investigate the causal linkage among CO_2 emissions per capita, energy intensity, real GDP per capita, industrialization (share of industrial value added in GDP), urbanization, and share of renewable energy consumption in China over the period from 1970 to 2015. They employ autoregressive distributed lag (ARDL) model and apply the vector error correction model (VECM) to analyze the directional causality variables. The estimates of long-run parameters ensure the positive relationship among variables indicating that increase in energy intensity, urbanization, real GDP, industrialization increases CO_2 emissions. Moreover, Long-run feedback Granger causalities exist among emissions, real GDP, and industrialization.

Shaari et al. (2021) using the data from 1990 to 2015 of nine developing countries explore the impacts of rural population growth, energy consumption, and economic growth on CO_2 emissions. The panel ARDL technique is used to analyze the data and the findings reveal while, rural population does not directly affect the CO_2 emissions in short-run, however energy consumption and economic growth can have negative short-term impact on environment.

Sikder et al. (2022) have examined the combined effects of energy usage, industrialization, GDP growth, and urbanization on CO_2 emissions for 23 developing countries over the period of 1995-2018. Through employing the panel autoregressive distributed lag (ARDL) model and the heterogeneous causality test, the results reveal that increase in energy use, economic growth, industrialization, and urbanization result in greater CO_2 emissions. Following this, the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) results confirm the influence of GDP growth, energy use, industrialization, and urbanization on CO_2 emissions, in case of developing countries. Furthermore, the panel causality analysis identified a bidirectional causal relationship between energy use, GDP growth, and urbanization, industrialization, and CO_2 emissions.

Mentel et al. (2022) in their paper explore the relationship between industry value added, renewable energy, and CO_2 emissions of 44 Sub-Saharan African countries over the period 2000-2015. Using a two-step system GMM estimator, they find that the share of industry in GDP has a significant positive impact on CO_2 emissions, while renewable electricity output reduces CO_2 emissions.

Raihan et al. (2022) empirically examine the nexus among Malaysia's energy consumption, agriculture land expansion, deforestation, and CO_2 emissions. Utilizing data ranging from 1990 to 2019 and using bound testing (ARDL) approach followed by Dynamic OLS (DOLS) method, their findings show a significant positive relationship between energy consumption and CO_2 emissions. Moreover, agriculture land expansion has also positive relationship with CO_2 emissions sustaining the notion of detrimental effects of agriculture land expansion and deforestation on environment.

Warsame et al. (2023) investigate the relationship between energy consumption, carbon dioxide emissions, and macroeconomic variables in Somalia with data spanning from 1990 to 2019 using ARDL model. The study finds a negative long-run relationship between carbon dioxide emissions and energy consumption in Somalia. The study also found that rising industrial value-added had a significant positive impact on energy consumption.

Hussein et al. (2023) study the relationship between economic growth, energy consumption, and environmental degradation in Kenya. Using Autoregressive Distributed Lag model (ARDL) from 1990 to 2019 they find that energy consumption and economic growth increase CO_2 emissions both in the short- and long-run in Kenya except for economic growth which is inconsequential in the short run.

Abdi and Hashi (2024) establish a significant relationship between energy consumption and economic growth, highlighting the importance of understanding this relationship for enhancing economic efficiency and reducing energy consumption. Using vector error correction model (VECM) they investigate the combined effects of energy consumption, industrialization, and urbanization on environmental sustainability in Somalia from 1990 to 2020. In addition, by using the bound-testing approach and the ARDL model, the paper shows that on one hand, economic growth, energy consumption, and trade openness contribute to environmental damage while, on the other hand, industrialization and urbanization tend to mitigate theses affects. The study indicates that energy consumption significantly exacerbates environmental pollution in Somalia, highlighting a critical nexus between energy use and economic growth. The Granger causality analysis reveals a unidirectional causality from energy consumption to environmental degradation, suggesting that as energy consumption increases, it contributes to environmental challenges.

Hassan et al. (2024) in their study analyze the impact of urban population growth and energy consumption on environmental degradation in Somalia, utilizing the ARDL model and Granger causality test with data spanning from 1989 to 2021. Highlighting the relationship between increasing urbanization and domestic investment, both of which contribute to environmental harm through higher carbon dioxide emissions their findings reveal a causal relationship exists among them, as well as a bidirectional causal effect between urbanization and energy consumption.

Namahoro et al. (2024) have empirically examined long-run effects of energy intensity, economic growth, and renewable energy consumption on CO_2 emissions across regions and income levels of 50 African countries from period of 190 to 2018. Study employs panel estimators, causality test, impulse response and variance decomposition analysis and reveals that energy intensity does promote emissions across regions and income levels, and at the African level, while renewable energy consumption contributed to mitigating CO_2 emissions. Additionally, economic growth affects CO_2 emissions negatively at the African level but the effect is mixed across regions and income levels.

Huang and Ren (2024) The study investigates the relationship between the utilization of natural resources, economic growth, and energy consumption patterns on CO_2 emissions in 160 developing countries, using panel data from 2001 to 2022. It aims to understand the environmental implications of these factors in a global context. The findings reveal a positive correlation between the effective use of natural resources and increased CO_2 emissions, while the impact of economic growth on emissions varies depending on the type of energy sources utilized, highlighting the contrasting effects of renewable energy versus fossil fuels on environmental outcomes.

Kirikkaleli (2020) focuses on china, considered to be largest carbon emitter in the world. This study focuses time-frequency dependency of economic growth and CO_2 emissions in China from 1950 to 2016. To investigate long-run and short-run causal links, wavelet coherence approach has been utilized. The findings of this study reveal that there is long-run co-integration linkage between economic growth and CO_2 emissions in China and economic growth in China has an important power for predicting CO_2 emissions over the selected study period, especially in the short-term and medium-term.

3. METHODOLOGY AND DATA

3.1. Data and Sources

The Impact of Economic Growth, Energy Consumption, and Industrialization on CO_2 Emissions: Evidence from Somalia in this study. The World Bank, SESRIC, and World Data provided a time series of data from 1990 to 2019. The study used three variables: GDPPC (economic growth, measured by GDP per capita constant 2015 prices); IND (industry, value added, 2015 US$), which is a proxy for industrialization; CO_2 (Carbon dioxide emissions, kt); and EC (energy consumption, measured in kilograms of oil equivalent per capita).

Equation (1) represents the linear relationship between economic growth, energy consumption, and industrialization on CO_2 emissions in Somalia:

$$\ln CO2_t = F(\ln EC_t, \ln IND_t, \ln GDPPC_t) \quad (1)$$

To ensure data stability and variance consistency, all variables—CO_2 emissions (CO_2), energy consumption (EC), industrialization (IND), and GDP per capita (GDPPC)—are transformed using the natural logarithm as follows:

$$\ln CO2_t = F(\ln EC_t, \ln IND_t, \ln GDPPC_t) \quad (1)$$

The empirical model can be specified as:

$$\ln CO2t = \beta_0+\beta_1 \ln EC_t+\beta_2 \ln IND_t+\beta_3 \ln GDPPC_t+\varepsilon_t \quad (2)$$

where ln $CO2_t$ is the dependent variable, ln EC_t, IND_t and $GDPPC_t$ are explanatory variables at time tεt represents the error term, and β_0,β_1,β_2,\beta$_0$, \beta$_1$, \beta$_2$, β_0,β_1,β_2, and β_3\beta$_3\beta_3$ denote the elasticities to be estimated.

The initial phase of assessing cointegration is analyzing the sequence of integration of the variables. The Phillips-Perron (PP) test and Augmented Dickey-Fuller (ADF) test are utilized to assess the stationarity of the series. Upon confirming stationarity and determining the suitable lag order, further analysis is performed to ascertain any cointegrating correlations among the variables.

Numerous cointegration tests exist to evaluate long-term equilibrium connections among model variables. The Engle and Granger test, extensively examined in the literature, is applicable just to variables with the identical order of integration. Nonetheless, other methodologies have been established, such as the Phillips and Ouliaris test, the Johansen and Juselius test, and the Structural Error Correction Model introduced by Boswijk (1994). Furthermore, Banerjee et al. (1998a) proposed a t-test methodology for the null hypothesis, but Johansen's Error Correction Cointegration technique offers a more adaptable and resilient framework compared to the Engle and Granger method.

These conventional methods have been criticized for their apparent unreliability in small samples, inconsistency with different-order integrated variables, and propensity to produce skewed and deceptive results when the null hypothesis is rejected (no-cointegration).

The model's long-term relationship is assessed by rewriting equation (2) in ARDL form.

$$\Delta CO2t = \alpha_0 + \beta_1 \ln CO2_{t-1} + \beta_2 \ln EC_{t-1} + \beta_3 \ln GDPPC_{t-1} + \beta_4 \ln IND_{t-1} + \sum_{i=0}^{q} \Delta\alpha_1 \ln CO2_{t-k} + \sum_{i=0}^{p} \Delta\alpha 2 \ln EC_{t-k} + \sum_{i=0}^{p} \Delta\alpha_3 \ln GDPPC_{t-k} + \sum_{i=0}^{p} \Delta\alpha_4 \ln INDI_{t-k} + \varepsilon_{t-k}$$

where α_0 is the constant term, α_1-α_4 are the coefficients for short-term variables, and β_1-β_3 are the long-run parameter elasticities. The variable q signifies the ideal lags for the variables that are explained, p indicates the ideal lags for the variables that are explanatory, Δ is the initial difference sign that illustrates short-run variables, and εt is the error term. Bound testing is the first step in the ARDL cointegration process. Ordinary Least Squares (OLS) regression is then applied. The alternative hypothesis (H_1): $\beta_1 \neq \beta_2 \neq \beta_3 \neq 0$ implies that there is long-term cointegration among variables, while the null hypothesis (H_0): $\beta_1 = \beta_2 = \beta_3 = 0$ asserts that there is no cointegration over the long term. Critical values and Wald-F statistics are used to evaluate the null hypothesis. In the long term, the variables are linked if the null hypothesis is rejected, as demonstrated by Wald-F statistics above the upper bound critical values, and vice versa.

3.2. Granger Causality in the Error Correction Model

Once cointegration has been confirmed by the Johansen and ARDL bound tests, Granger causality can be included in a vector error correction modeling framework. We formulate the error correction equation as follows in order to estimate the error correction model:

$$\Delta CO2_t = \alpha_0 + \sum\Delta B_1 \ln CO2_{t-k} + \sum\Delta B_2 \ln EC_{t-k} + \sum\Delta B_3 \ln GDPPC_{t-k} + \sum\Delta B_4 \ln INDI_{t-k} + ECM_{t-1+}\varepsilon_t$$

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The computed F-statistic beyond the upper critical value indicates a long-term co-integration link among the variables. If the F-statistic is below the lower critical value, the null hypothesis of no co-integration remains unrefuted. When the calculated F-statistic falls between the upper and lower critical values, the result is indeterminate, requiring further testing to ascertain the presence of a co-integration connection. In these instances, an alternate method is analyzing the error-correction term, which offers additional confirmation of co-integration by evaluating the rate at which discrepancies from equilibrium rectify with time.

3.3. Granger Causality in the Error Correction Model

Upon verifying co-integration using the Johansen test and the ARDL limits test, Granger causality may be examined within the context of a vector error correction model (VECM). The error correction model (ECM) is utilized to evaluate the short-term and long-term dynamics of the relationships among the variables. The formula for the error correction model is articulated as follows:

$$CO2_t = \beta_0 + \sum_{i=1}^{q} \beta_1 \Delta CO2_{t-k} + \sum_{i=1}^{p} \beta_2 \Delta LGDP_{t-k} + \sum_{i=1}^{p} \beta_3 \Delta LFDI_{t-k} + \sum_{i=1}^{p} \beta_4 \Delta LURPOP_{t-k} + \sum_{i=1}^{p} \beta_5 \Delta LRE_{t-k} + \lambda ECM_{t-1} + \varepsilon_t$$

ECM is the error correction term, which reflects the rate at which discrepancies from the long-term equilibrium are rectified over time.

The computed F-statistic beyond the upper critical value validates a long-term co-integration link among the variables. If the F-statistic is below the lower critical value, the null hypothesis of no co-integration remains unrefuted. When the F-statistic is between the higher and lower critical thresholds, the outcome is indeterminate, requiring more examinations to confirm the existence of co-integration.

The error correction term (ECT) is essential for confirming co-integration. For the ECM to accurately capture short-term modifications while preserving long-term equilibrium, the ECT must be statistically significant and negative. This guarantees that departures from equilibrium self-correct over time, so enhancing the stability of the co-integrated connection.

4. RESULTS AND DISCUSSION

4.1. Descriptive Analysis and Correlation Matrix

The stationarity unit root test, the ARDL model's long-term relationship as established by the limits F-test, the short- and long-run coefficients, the error correction term, and the quality of the data as assessed by diagnostics and structural stability tests are all covered in this part.

Table 1 offers a thorough summary of the descriptive statistics for important factors in a study looking at "the impact of economic growth, energy consumption, and industrialization on CO_2 Emissions: Evidence from Somalia." The natural logarithms of carbon dioxide emissions ($\ln CO_2$), energy consumption (lnEC), industrialization (lnIND), and economic growth (lnGDPPC) are among the variables. The average values of these variables show central tendencies: $lnCO_2$ is 6.4129, lnEC is 5.7173, lnIND is 18.1040, and lnGDPPC is 2.4991. A comparatively symmetric distribution is shown by the median values, which stand for the midway point of the data, being near the means. Furthermore, the table sheds light on the distribution and form of the data. The comparatively tiny standard deviations for $lnCO_2$, lnGDPPC, and lnEC indicate little variation around the mean. However, lnIND's standard deviations are higher, suggesting greater industrialization unpredictability. The distribution's asymmetry is measured by skewness; $lnCO_2$ and lnIND have a minor negative skewness, whereas lnEC and lnGDPPC have a positive skewness. The normality of the data distribution is revealed by the Jarque-Bera statistic and related P-values. Significantly low P-values for lnEC indicate a departure from normalcy, which could have an impact on statistical analysis. In the framework of the study's main research topic, these descriptive statistics help to provide a thorough grasp of the important variables and their distributions, laying the groundwork for more in-depth analyses and interpretations.

The correlation matrix shows how the variables in the study on "the impact of Economic Growth, Energy Consumption, and Industrialization on CO_2 Emissions: Evidence from Somalia "relate to one another. It is noteworthy that there is a moderately positive association between lnIND (industrialization), lnGDPPC (economic growth), $lnCO_2$ (carbon dioxide emission) and lnEC (energy consumption). Table 2 shows a positive correlation between economic expansion, industrialization, and carbon dioxide emissions. On the other hand, there is a negative correlation between Carbon dioxide emissions and energy usage.

4.2. Unit Root Test

When modeling time series, it is crucial to ensure unit root features, particularly when using autoregressive distributed lag (ARDL) analysis. The Philips Perron (PP) and Augmented Dickey-Fuller (ADF) tests were therefore used to lower the possibility of inaccurate regression results. While the other series exhibit a unit root, Table 3's unit root analysis reveals that the natural logarithm of energy consumption (lnEC) is stationary at the level (I[0]). Furthermore, Table 3 demonstrates that only lnEC is integrated at (I[0]), whereas the majority of the series are integrated at the First difference (I[1]). At the second difference (I[2]), none of the variables exhibit stationarity, hence the analysis proceeded to estimate the limits test for cointegration.

4.3. Cointegration Test

The results of the F-bounds test for cointegration, which is crucial for evaluating the long-term relationship between variables, are shown in the table 4. Critical values are compared to the F-statistic of 9.3744 at different significance levels (1%, 5%, and 10%). The alternative hypothesis in this case asserts that cointegration occurs, but the null hypothesis asserts that cointegration does not. The null hypothesis is rejected and cointegration is demonstrated if the F-statistic is greater than the critical value. The critical values of the boundaries test provide standards for varying degrees of importance. At the 1%, 5%, and 10% significance levels, the null hypothesis is rejected in this case since the F-statistic is greater than all crucial values. As a result, the results suggest a long-term correlation between the factors that were studied.

4.4. Diagnostic Check

Table 6 demonstrated According to the results of the diagnostic examination, the ARDL model does not have serial correlation, heteroscedasticity, model misspecification, or normality constraints. The CUSUM and CUSUM-square tests also show that the ARDL model's coefficients remained constant over the course of the sample period; the test results are shown in Figures 1 and 2, respectively.

Table 1: Descriptive statistics and trends

Stats	LCO_2	LEC	LNIND	LGDPPC
Mean	6.4129	5.7173	18.1040	2.4991
Medium	6.4377	5.7173	18.2140	2.4616
Maximum	6.5930	6.3652	19.0327	2.7556
Minimum	6.1944	5.4274	17.1177	2.3409
Std dev	0.1009	0.1768	0.6278	0.1294
Skewness	−0.5143	1.3927	−0.1433	0.7790
Jarque _bar	1.4463	31.0476	2.5087	3.3043
p-value	0.4852	0.0000	0.2852	0.1916

Table 2: Correlation

	LCO_2	LEC	LIND	LGDPPC
LCO_2	1			
LEC	−0.0041	1		
LIND	0.2502	−0.7721	1	
LGDPPC	0.5760	−0.6686	0.8686	1

Table 3: Unit root test

Variable	T-statistics	
	ADF	PP
$lnCO_2$	−2.6578	−2.3435
lnIND	−2.2516	−2.2305
lnGDPPC	−2.7191	−2.0214
LEC	−7.4709***	−6.2445***
D (lCO_2)	−3.4250*	−3.4618*
D (lnIND)	−5.9256***	−5.8817***
D (lnGDPPC)	−3.6702**	−5.0208***
D (lnEC)	−10.7008***	−11.4089***

Table 4: F-bound test

Wald f statistics	Level of significant Significance (%)	Bounds test critical values M (6)	
		1 (0)	1 (1)
9.3744	1	4.29	5.61
	5	3.23	4.35
	10	2.72	3.77

Table 5: Long run and short run

Variable	Coefficient	SE	T-Statics	Probability
LEC	0.9562**	0.3993	2.3943	0.0256
LGDPPC	0.8069**	0.1361	1.5754	0.0301
LIND	0.2145	0.3479	2.3189	0.1294
Short-run impact				
Variable	Coefficient	SE	T-Statics	Probability
D (LEC)	0.1599***	0.0496	3.2239	0.0039
D (LGDPPC)	−0.2324	0.1625	−1.4299	0.1668
ECT(−1)	−0.2655***	0.0406	−6.5277	0.0000

4.5. Robust Analysis

Table 7 shows a study that supports the long-term findings from the ARDL model shown in Table 5 by using Fully Modified Ordinary Least Squares (FMOLS). It is confirmed by this study that Somalia's carbon dioxide emissions are significantly impacted by economic growth. However, the evidence indicates that industrialization and energy use have no discernible impact on carbon dioxide emissions. The findings show that there is a predicted 0.86% increase in carbon dioxide emissions for every 1% increase in economic development.

4.6. Causality Test

Table 8 shows the results of a Granger causality test, which shows that there are four possible outcomes for the following variable, all of which are unidirectional. Both carbon dioxide emissions (CO_2) to energy consumption (EC), economic growth (GDPPC) to carbon dioxide emissions (CO_2), and industrialization (IND) to economic growth (GDPPC) are causally related in a one-way fashion. An additional component that has become a bidirectional indicator is the relationship between industrialization (IND) and CO_2.

4.7. Model Specification Test

To ensure that the estimated ARDL model is correctly specified and does not suffer from omitted variable bias, an omitted variables test using the squares of fitted values was conducted. This test evaluates whether any important nonlinear components or interactions have been excluded from the model specification.

The result from Table 9 demonstrated, the null hypothesis indicate that there are no omitted variables. The F-statistic is 0.1141, suggesting that the model adequately accounts for the variables included, supporting the assertion that no important variables have been omitted from the analysis."

Figure 1: Normality and Serial Correlation Diagnostic Results

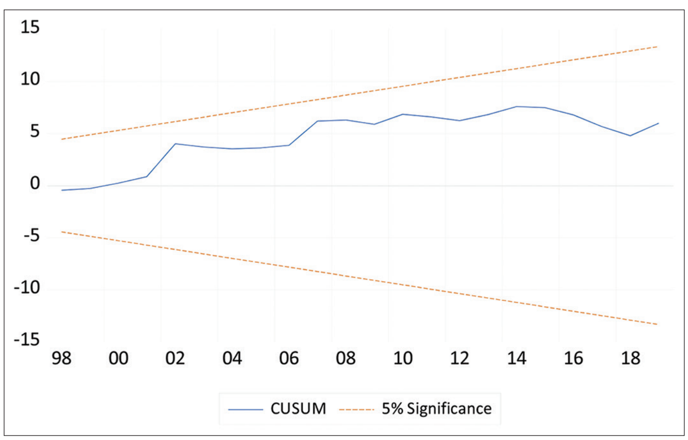
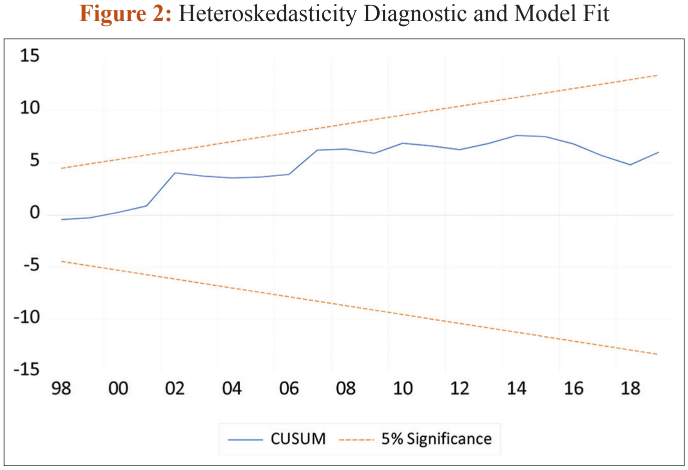


Figure 2: Heteroskedasticity Diagnostic and Model Fit



5. DISCUSSION OF FINDINGS

The empirical findings of the study underscore notable correlations among economic growth, energy consumption, industrialization, and CO_2 emissions in Somalia, exhibiting differing levels of statistical significance. Although economic expansion and energy consumption were shown to significantly influence CO_2 emissions, industrialization lacked statistical significance over the long term. These findings offer essential insights into Somalia's distinctive economic and industrial framework and its environmental consequences.

A key conclusion is the positive and substantial correlation between economic growth (GDP per capita) and CO_2 emissions, indicating that a 1% increase in GDP per capita results in a 0.80%

Table 6: Diagnostic check

Diagnostic Test	Value	Probability
Jarque-Bera Normality test	5.5628	0.0619
Breusch-Godfrey serial correlation test	5.6594	0.0590
Breusch-pagan Hetroskedasticity test	9.9944	0.1249
R-square	0.6452	

Table 7: FMOLS method

Variable	Coefficient
LEC	0.1347 (0.5986)
LIND	−0.0634 (−1.1635)
LGDPPC	0.8602 (3.4149)***
C	4.6399 (2.3404)***

Table 8: Granger causality test

Null hypothesis tests	Obs	F-statistics	Obs
LEC→LCO_2	28	1.2201	0.3136
LCO_2→LEC		3.6995	0.0405
LIND→LCO_2	28	5.3305	0.0125
LCO_2→LIND		3.4703	0.0482
LGDPPC→LCO_2	28	5.3861	0.0121
LCO_2→LGDPPC		1.8529	0.1794
LIND→LEC	28	1.0382	0.3701
LEC→LIND		2.0335	0.1537
LGDPPC→LEC	28	2.4204	0.1112
LEC→LGDPPC		3.5644	0.0448
LGDPPC→LIND	28	2.5391	0.1008
LIND→LGDPPC		4.7337	0.0190

Table 9: Omitted variables: Squares of fitted values

Test Statistic	Value	df	Probability
t-statistic	1.6486	21	0.1141
F-statistic	2.7180	1.21	0.1141

increase in CO_2 emissions. This outcome is consistent with prior studies by Shahbaz and Du (2024), Aytekin et al. (2022), and Abdi and Hashi (2024), indicating that economic growth, especially in developing nations, typically leads to heightened energy demand, augmented transportation, and expanded industrial activities, all of which exacerbate environmental degradation. In Somalia, economic growth is primarily driven by urbanization, rising consumption, and investments, resulting in increased reliance on fossil fuels and elevated transportation emissions. This illustrates the Environmental Kuznets Curve (EKC) concept, which asserts that CO_2 emissions initially increase with economic expansion until sustainable development initiatives and technology progress ultimately result in environmental enhancements. Nonetheless, Somalia's deficiency in robust environmental legislation and alternative energy resources may impede this transformation.

A notable discovery is the robust and considerable correlation between energy usage and CO_2 emissions. The findings demonstrate that a 1% increase in energy consumption results in a 0.95% increase in CO_2 emissions, affirming that energy utilization significantly contributes to environmental deterioration. The results correspond with the findings of Petruska et al. (2023) and Abdi and Hashi (2024), indicating that fossil fuel-based energy use is a primary contributor to carbon emissions in rising countries. The significance of this connection in Somalia highlights the necessity of implementing energy-efficient techniques and shifting to renewable energy sources. Somalia's significant dependence on biomass, charcoal, and fossil fuels underscores the necessity for clean energy regulations, investments in renewable energy infrastructure, and incentives for energy efficiency to alleviate the environmental impacts of rising energy demand.

The analysis indicates that industrialization does not exert a statistically significant effect on CO_2 emissions over the long term. This indicates that Somalia's industrial sector is still undeveloped and does not substantially contribute to pollution levels, in contrast to more industrialized countries. The correlation study indicates a moderate positive association between industrialization and CO_2 emissions (0.21%), implying that as Somalia's industries develop, emissions are likely to rise incrementally. Nonetheless, the absence of statistical significance suggests that present industrial operations are inadequate to generate extensive pollution. The results align with research conducted by Warsame and Abdi (2023), Zhu et al. (2017), and Aslam et al. (2021), indicating that in economies with nascent industrial expansion, the effect on carbon emissions may be less significant than in highly industrialized countries. This outcome underscores the necessity of including sustainable industrial strategies at the outset of Somalia's economic path to guarantee that as industrialization advances, eco-friendly practices and cleaner technology are used to avert excessive pollution.

The short-term dynamics of the ARDL model elucidate the impacts of economic development and energy consumption on CO_2 emissions. In the short term, economic growth (D(lnGDPPC)) exerts a negative although statistically negligible effect on emissions, indicating that variations in GDP may not promptly result in heightened carbon emissions. Nonetheless, energy consumption persistently has a substantial beneficial impact on emissions, underscoring the necessity for prompt measures to enhance energy efficiency and sustainability. The error correction term ($ECT = -0.2655$, $P < 0.01$) indicates a long-run equilibrium connection, signifying that short-term fluctuations in CO_2 emissions will ultimately revert to the long-term trend at an annual rate of 26.55%. This underscores the persistence of the correlation among CO_2 emissions, economic growth, and energy consumption, emphasizing the enduring significance of sustainable energy policies and economic strategies.

The findings highlight the essential influence of economic expansion and energy consumption on CO_2 emissions in Somalia, but industrialization is comparatively little due to the nation's restricted industrial advancement. These findings underscore the pressing necessity for legislative measures that reconcile economic growth with environmental sustainability. The findings indicate that Somalia ought to prioritize investments in renewable energy, enact carbon-reducing legislation, and guarantee that industrial expansion adheres to ecologically friendly practices. Enhancing regulatory frameworks, fostering energy efficiency, and advocating for green industrial strategies will be essential in mitigating CO_2 emissions while maintaining economic advancement.

6. CONCLUSION AND POLICY RECOMMENDATIONS

6.1. Conclusion

This research investigates the effects of economic growth, energy consumption, and industrialization on CO_2 emissions in Somalia, utilizing time series data from 1990 to 2019 and employing the ARDL model to assess both long-term and short-term correlations. The results indicate that economic development and energy consumption are the principal factors influencing CO_2 emissions, however industrialization has a negligible effect on emissions due to Somalia's undeveloped industrial sector.

A 1% increase in GDP per capita results in a 0.80% increase in CO_2 emissions, indicating a strong correlation between economic growth and environmental deterioration. A 1% rise in energy consumption leads to a 0.95% rise in emissions, underscoring the significant reliance on fossil fuels and suboptimal energy utilization. Nonetheless, industrialization is statistically negligible in affecting CO_2 emissions, suggesting that Somalia's economic activities are not yet substantially dependent on extensive industrial output.

The short-term dynamics indicate that economic expansion does not instantaneously result in increased emissions; yet, energy consumption remains a substantial contributor to CO_2 emissions. The error correction term ($ECT = -0.2655$, $P < 0.01$) indicates that deviations from long-term equilibrium are rectified at a rate of 26.55% annually, underscoring the enduring influence of economic expansion and energy use on environmental deterioration.

These findings underscore the pressing necessity for Somalia to formulate policies that foster economic growth while guaranteeing environmental sustainability. In the absence of deliberate action, ongoing economic growth and increasing energy use may exacerbate environmental circumstances, hindering Somalia's capacity to fulfill sustainable development goals (SDGs) and climate obligations.

6.2. POLICY RECOMMENDATION

To alleviate the adverse environmental impacts of economic growth and energy consumption while fostering sustainable development, Somalia must embrace a holistic strategy for policy execution.

A vital measure is the shift to renewable energy sources by diminishing reliance on fossil fuels and biomass through investments in solar, wind, and hydroelectric energy initiatives. The government ought to implement incentive programs to draw private-sector investment in green energy initiatives and advocate for energy efficiency measures to reduce waste and foster sustainable consumption.

Implementing methods for the reduction of carbon emissions is of similar significance. Carbon taxes or cap-and-trade policies can be implemented to incentivize industry to reduce emissions. Moreover, implementing stringent environmental rules on energy generation and fuel use will assist in reducing excessive emissions. To enhance sustainability, the promotion of low-carbon transportation options, like electric automobiles and upgraded public transit networks, is essential.

With the expansion of Somalia's industrial sector, it is imperative to formulate sustainable industrialization laws that mandate the use of environmentally friendly technology and practices by enterprises. Promoting sustainable manufacturing practices and assisting enterprises that utilize renewable energy in production would mitigate the environmental effects of industrialization. Additionally, financial incentives and concessions must to be granted to enterprises that adhere to sustainability criteria and proactively diminish their carbon emissions.

Improving energy efficiency and conservation is an essential approach. This necessitates public awareness initiatives to inform customers about energy saving and efficiency strategies. The government should promote the utilization of energy-efficient appliances and industrial equipment via subsidies or tax incentives. Regulatory frameworks must be established to mandate the integration of energy-efficient technology in new constructions and manufacturing facilities to reduce their environmental impact.

To guarantee successful policy execution, environmental governance and climate policies require enhancement. This can be accomplished by enhancing environmental monitoring via entities tasked with monitoring CO_2 emissions and implementing rules. National environmental plans must correspond with international climate obligations, including the Paris Agreement and Sustainable Development Goal (SDG) 13 concerning Climate Action. Additionally, a national carbon reduction strategy must be formulated to align environmental policies with Somalia's long-term economic objectives.

Advancing research and innovation in green technology is crucial for sustainable development. Investing in research for alternative energy sources and carbon capture technology will enable the shift to greener energy. Promoting collaboration between academic institutions and industry to develop sustainable energy solutions, while providing grants and financial support to startups focusing on climate-friendly inventions, will stimulate innovation in the renewable energy sector.

Ultimately, regional collaboration on environmental sustainability is essential. Fortifying collaborations with regional organizations may augment climate resilience initiatives and facilitate the exchange of best practices. Somalia ought to engage proactively in transnational energy infrastructure initiatives, including the East African renewable energy grid, to enhance access to greener energy sources. Moreover, partnering with global funders and organizations might provide funding for climate adaption initiatives, guaranteeing enduring sustainability.

Through the implementation of these policies, Somalia may harmonize economic growth with environmental sustainability, so assuring enduring development that is both resilient and cognizant of climate considerations. Investing in renewable energy, sustainable industrialization, and carbon mitigation measures would not only diminish emissions but also provide new economic prospects and enhance overall environmental quality.

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