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Carbon Realities in a Fragile Landscape: Rethinking Sustainability Pathways in Somalia

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ABSTRACT

Carbon dioxide (CO_2), the dominant greenhouse gas, poses major sustainability challenges for fragile economies such as Somalia. This study examines how energy consumption, foreign direct investment (FDI), economic growth, and population growth influence CO_2 emissions from 1990 to 2020 using the ARDL approach and Dynamic OLS for robustness. Results reveal that, in the long run, a 1% increase in energy consumption, FDI, and GDP raises emissions by 1.10%, 0.04%, and 0.28%, respectively, while population growth exerts an insignificant positive effect. In the short run, energy use, FDI, and GDP temporarily reduce emissions by 0.26%, 0.01%, and 0.09%, whereas population growth increases emissions by 0.04%. Granger causality indicates a bidirectional link between GDP and emissions, and one-way causality from emissions to energy use. These findings highlight that Somalia's current growth path is carbon-intensive and vulnerable to sustainability risks. The study recommends accelerating renewable energy adoption, enforcing environmental criteria for FDI inflows, integrating green growth into national economic planning, and promoting energy efficiency across sectors. By linking short- and long-run effects, this paper provides the first empirical evidence for designing low-carbon development strategies in Somalia's fragile context.

Keywords: Energy Consumption, Foreign Direct Investment, Economic Growth, Population Growth, Carbon Emissions, Environmental Sustainability
JEL Classifications: Q43, Q53, Q56, O55

1. INTRODUCTION

One of the most pressing challenges facing humanity today is reducing the harmful effects of global environmental pollution. Ecological problems have become global in both their impacts and their underlying causes. Global GHG emissions reached 59 $GtCO_2$-eq in 2019, a 54% increase since 1990, driven primarily by fossil fuel use, industrial activities, and land-use changes. Although renewable energy costs have dropped significantly and some countries have reduced their emissions, current global policies remain insufficient to meet international climate targets. High-emitting regions, particularly the top 10% of global households and major industrialized areas, contribute disproportionately to total emissions, while low-income countries contribute the least but are most vulnerable to climate impacts. Without rapid and large-scale mitigation efforts beyond 2030, global warming is likely to exceed the 1.5°C threshold, surpassing what is considered a safe climate boundary (IPCC, 2022). The rise in GHG emissions, largely driven by technological progress and increasing energy consumption, has drastically expanded the global carbon footprint. This presents both significant challenges and potential opportunities for advancing sustainability. Carbon dioxide (CO_2) alone accounts for roughly 60% of global warming and has remained a dominant contributor to climate change over the past two decades. If these emissions trends continue unchecked, global temperatures are projected to rise by 3 to 5 degrees Celsius by the end of the century, intensifying climate risks (Abdi and Muhumed, 2025).

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The complex relationships between energy consumption, CO_2 emissions, foreign direct investment (FDI), and economic growth have attracted substantial scholarly and policy interest. Industrial expansion, while boosting national output, has contributed significantly to environmental degradation, prompting global concern. These issues have been addressed at several major international forums, including Rio de Janeiro (1992), Stockholm (1979), Johannesburg (2002), Copenhagen (2009), and Durban (2011) (Muhammad and Khan, 2019). Industrialization, urbanization, and surging energy demands over recent decades have led to severe environmental degradation and widespread ecological disruption. These dynamics have significantly transformed the Earth's geographic and ecological balance, leading to heightened concern among environmentalists and global stakeholders (Abdi and Hashi, 2024). According to the Environmental Kuznets Curve (EKC), developing countries bear a disproportionate burden of environmental degradation. These countries frequently face a trade-off: choosing between immediate economic growth and long-term environmental sustainability. Economic priorities often dominate due to urgent developmental needs, with the hope that future increases in income will enable investment in environmental protection. Human activities, particularly fossil fuel combustion, have raised the average global temperature by about 1°C above pre-industrial levels. This increase has triggered more frequent and intense weather events such as droughts, heavy rainfall, heatwaves, and tropical storms, placing both ecosystems and human livelihoods at considerable risk (Hassan and Hussein, 2024). In the Sub-Saharan African context, energy poverty remains a critical issue. Somalia's energy access rate is currently estimated at just 15%, meaning around 10 million people remain without electricity. Access levels vary significantly by location, with about 33% of urban residents having electricity compared to only 4% in rural areas. Given an average household size of 5.9 people, this equates to roughly 1.7 million households lacking access to electricity across the country. Since the civil war, energy provision has largely been managed by the private sector, which now delivers over 90% of electricity in urban and peri-urban areas through locally operated private mini-grids.

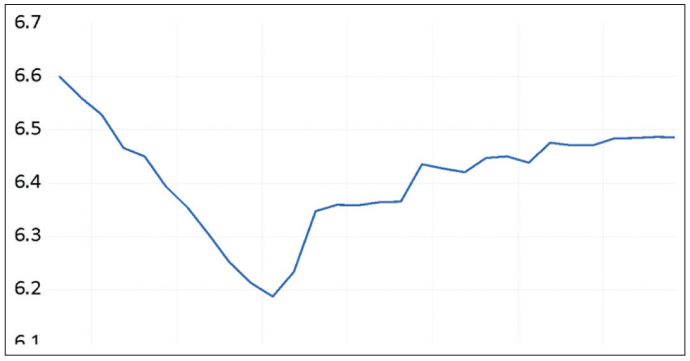
Economic growth is a universal policy goal, vital for enhancing living standards, reducing poverty, and promoting social well-being. Understanding the factors that drive economic growth is essential for crafting effective and sustainable development policies. However, the pursuit of economic advancement has significantly increased emissions of CO_2 and other GHGs, exacerbating global warming and climate instability (Hussein et al., 2024). All nations grapple with the challenge of achieving economic growth while safeguarding the environment. Traditional development models often emphasize rapid economic growth without fully accounting for long-term environmental consequences. The ecological footprint, a measure of the environmental impact of human consumption patterns, indicates that current rates of resource use far exceed Earth's capacity to regenerate them (Abdi et al., 2025). As economies expand and populations grow, energy consumption rises, leading to increased CO_2 emissions. Since the 1990s, newly industrialized countries have experienced a faster rise in CO_2 emissions compared to developed economies, further aggravating environmental stress. Environmental experts largely agree that energy consumption is the leading driver of CO_2 emissions, which accumulate in the atmosphere and drive global climate change (Abdi and Hashi, 2024).

Over the last two decades, FDI has increased significantly across nearly all global regions. This resurgence has revived academic debates about its economic benefits and environmental consequences. FDI can promote economic growth through capital inflows, technological transfers, improved productivity, and enhanced managerial expertise (Omri et al., 2014). However, its environmental impacts remain contested. Some studies support the Pollution Haven Hypothesis, which suggests that countries with weak environmental regulations, such as many in Africa, attract pollution-intensive industries from wealthier nations, resulting in greater environmental harm. Others argue in favor of the Pollution Halo Hypothesis, suggesting that FDI can bring cleaner technologies and higher environmental standards, thereby improving environmental quality (Paul et al., 2021).

Figure 1 shows the trend of log-transformed carbon dioxide emissions ($lnCO_2$) in Somalia from 1990 to 2020, highlighting three clear phases. From 1990 to 2000, emissions dropped significantly, from around 6.6 to 6.18, likely due to the ongoing civil conflict, economic collapse, and damage to infrastructure, which hindered industrial activity and reduced fossil fuel use. Between 2001 and 2010, emissions started to recover slowly, reflecting gradual economic stabilization, growth in the informal sector, and some limited reconstruction efforts. After 2010, the trend leveled off with a slight upward movement, showing modest increases in emissions driven by population growth, urbanization, and an increased reliance on diesel-powered generators and transport. Overall, even though Somalia's emissions are relatively low by global standards, the steady rise in recent years points to the possibility of future increases if economic development continues without proper environmental regulations or low-carbon alternatives.

In Somalia, this tension between economic growth and environmental preservation is particularly acute. The country's environment has been severely degraded by deforestation, soil erosion, and land depletion, largely due to population growth, economic hardship, and resource exploitation. Charcoal production, in particular, is a critical example: it is both a primary domestic energy source and an export commodity. However, its production has caused widespread deforestation, with forest

Figure 1: $lnCO_2$ trends



cover dropping from 13% in 1990 to around 9.5% in 2020, a loss of approximately 2.2 million hectares (Osman et al., 2025). The ecological consequences of charcoal production are severe. Forest clearing has led to soil erosion, desertification, and biodiversity loss, which not only damage local ecosystems but also increase Somalia's vulnerability to climate-related disasters such as droughts and floods. As forests are destroyed, the carbon they once sequestered is released into the atmosphere, contributing to global warming. These environmental issues are closely tied to socioeconomic well-being, threatening agriculture, water availability, and food security for millions of Somalis (Osman et al., 2025). Overgrazing and unsustainable land use practices further exacerbate natural resource depletion. These activities degrade the soil, reduce vegetation cover, and contribute to long-term ecological instability. As Somalia's capacity to adapt to climate variability weakens, environmental pollution becomes a major concern, amplifying the country's exposure to climate shocks (Abdi et al., 2025).

Although previous studies have explored the individual effects of energy consumption, foreign direct investment (FDI), economic growth, and population growth on carbon emissions, both globally and in specific developing countries, there is a notable gap in the literature regarding their combined impact, particularly in the context of Somalia. Existing research often fails to capture the potential interactions and cumulative effects of these variables that may influence environmental outcomes such as CO_2 emissions. This fragmented understanding limits the ability to develop integrated policy responses aimed at balancing economic development with environmental sustainability. Therefore, this study seeks to fill this gap by examining the joint effects of energy consumption, FDI, economic growth, and population growth on carbon emissions in Somalia, providing a more holistic insight into the country's environmental challenges and informing evidence-based strategies for low-carbon development.

The structure of the study will be as follows: Section one: literature review. Section two: Methods. Section three: results and discussion. Section four: Conclusion and policy recommendation.

2. LITERATURE REVIEW

Recent research has been looking more closely at how macroeconomic factors in Somalia affect the environment. These studies uncover intricate and sometimes contradictory dynamics.

For instance, Hassan et al. (2024) investigated environmental sustainability in Somalia from 1991 to 2022 using the ARDL model, revealing that economic growth is positively linked to CO_2 emissions in both the short and long run, highlighting the difficulty in decoupling development from environmental harm.

Similarly, Ahmed et al. (2025) assessed the environmental impact of the agricultural sector's contribution to Somalia's economy using time series data from 1990 to 2020, employing ARDL, canonical cointegrating regression (CCR), dynamic ordinary least squares (DOLS), and fully modified ordinary least squares (FMOLS) techniques. The findings revealed a strong positive relationship between economic growth and environmental degradation, lending support to the environmental kuznets curve (EKC) hypothesis, which suggests that pollution increases with economic growth up to a certain point, after which it begins to decline as income levels rise. Furthermore, renewable energy consumption was found to significantly reduce environmental degradation, highlighting its potential role in sustainable development.

Alam et al. (2025) analyzed BRICS countries from 1985Q1 to 2021 Q4 using a quantile regression approach and found that renewable energy and natural resources reduce carbon emissions, while financial development and economic growth increase them, especially at higher emission levels.

Alam and Manigandan (2025) analyzed GCC countries from 1990 to 2021 and found that increases in natural resources, capital investment, and economic growth raise CO_2 emissions, while declines in these factors reduce them.

Manigandan et al. (2023) found that in BRICS countries, financial development and energy consumption boost economic growth but increase carbon emissions, while technological innovation enhances growth and reduces emissions, highlighting its role in sustainable development.

Abdulle and Mohamed (2024) studied trade openness and carbon emissions from 1980 to 2021 and showed that while GDP, energy consumption, and population growth generally negatively impact emissions, FDI significantly increases emissions in both timeframes.

Nor and Mohamad (2024) found that higher GDP per capita reduces emissions, especially in the short run, emphasizing the role of sustainable agriculture.

Abdi et al. (2025) used ARDL and DOLS models on 1990-2020 data and confirmed that energy consumption and population density raise ecological pressure, and GDP's effect is insignificant in the short term but significant in the long term.

Osman et al. (2025) confirmed that GDP and population growth both increase environmental degradation.

Abdi and Hashi (2024) found that economic growth, energy consumption, and trade openness significantly contribute to pollution in both the short and long run.

Another study by Hassan et al. (2024) found that urban population growth increases environmental degradation in both time frames, while energy consumption shows a positive but insignificant link with CO_2 emissions.

Warsame et al. (2023) explored the roles of FDI, renewable energy, GDP, GDP^2, and population growth in Somalia between 1990 and 2019, revealing that renewable energy reduces emissions, while FDI and population growth exacerbate them.

Similarly, Mohamud and Mohamud (2023) analyzed the 1990-2020 period using ARDL, showing that in the short run,

renewable energy use raises emissions, while FDI and population reduce them; in the long run, renewable energy and GDP reduce emissions, while FDI and population increase them.

Globally, Omri et al. (2014) analyzed 54 countries and found bidirectional causality between FDI and emissions in most regions and unidirectional causality from emissions to growth worldwide.

Paul et al. (2021) used panel data from 200 countries and various econometric methods to show that FDI consistently increases CO_2 emissions.

Wang and Jiayu (2019) found a significant long-run link between FDI and emissions in Kuwait using ARDL and VECM Granger tests, confirming that FDI drives carbon emissions. In contrast, Shaari et al. (2014) used panel data from 15 developing countries and found no significant long-term effect of FDI on emissions using FMOLS, suggesting the impact of FDI may depend on country-specific factors such as environmental regulations and technological standards.

Collectively, these studies underscore the complex, sometimes contradictory interplay between macroeconomic variables and environmental outcomes in Somalia and beyond. Hence, this study investigates the impact of energy consumption, foreign direct investment (FDI), gross domestic product (GDP), and population growth on CO_2 emissions in Somalia between 1990 and 2020, using the autoregressive distributed lag (ARDL) bounds testing method, along with dynamic ordinary least squares (DOLS) for robustness, the analysis focuses on both short- and long-term relationships.

3. METHODS AND DATA

3.1. Measurements of the Variables and Sources of Data

This study investigates the nexus between energy consumption, foreign direct investment, gross domestic product, and population growth in Somalia, utilizing time series data from 1990 to 2020. The study uses data from the World Development Indicators, (WB, 2018), OUTWORLDINDATA, and SESRIC, as described in Table 1.

Table 1: Measurements of the variables and sources of data

Variable	Symbol	Description	Source
Carbon emissions	CO_2	Kilotons	WDI
Energy consumption	EC	primary energy consumption per capita	Our World in Data
Gross domestic product	GDP	GDP Constant 2015 Prices	SESRIC
Population growth	PG	Population growth (annual %).	WDI
Foreign direct investment	FDI	Foreign direct investment, net inflows (Bop, current US$)	WDI

3.2. Econometric Estimation

In our examination of the nexus between energy consumption, foreign direct investment, gross domestic product, and population growth in Somalia, we constructed the model by following Ahmed et al. (2024) and Abdulle and Mohamed (2024).To be careful with the heterogeneity issues, correct biased coefficient estimates, avoid nonlinear specification errors, and enable percentage interpretations, we adapted the study's variables into logarithmic form. Therefore, the model for the study is well-defined as follows:

$$lnCO2_t = \beta_0 + \beta_1 lnEC_t + \beta_2 lnFDI_t + \beta_3 lnGDP_t + \beta_4 lnPG_t + \varepsilon_t$$

(SEQ Equation*ARABIC 1)

where CO_2, EC, FDI, GDP, and PG denote carbon dioxide emissions, energy consumption, foreign direct investment, gross domestic product, and population growth, respectively. β_0 is the intercept term; β_1 to β_4 are the coefficients of the explanatory variables; ln denotes the natural logarithm; and ε_t is the error term. The ARDL bounds-testing approach developed by Pesaran et al. (2001) is used in this study to examine cointegration among the variables. The ARDL approach is particularly suitable for small samples and can accommodate variables integrated of order I(0) and I(1), provided none is I(2). Its single-equation structure simplifies estimation and interpretation, while allowing different lag lengths for individual variables (Abdi & Mohamed, 2025). The ARDL model is specified as follows.

$$\begin{aligned}\Delta lnCO2_t = {} & \alpha_0 + \varepsilon_1 lnCO2_{t-1} + \varepsilon_2 lnEC_{t-1} + \varepsilon_3 lnFDI_{t-1} \\ & + \varepsilon_4 lnGDP_{t-1} + \varepsilon_4 lnAlnPG_{t-1} \\ & + \sum_{i=1}^{p} \varepsilon_1 \Delta lnCO2_{t-i} + \sum_{i=1}^{q} \varepsilon_2 \Delta lnEC_{t-i} \\ & + \sum_{i=1}^{q} \varepsilon_3 \Delta lnFDI_{t-i} + \sum_{i=1}^{q} \varepsilon_4 \Delta lnGDP_{t-i} \\ & + \sum_{i=1}^{q} \varepsilon_4 \Delta lnPG_{t-i} + \varepsilon_t\end{aligned}$$

(SEQ Equation*ARABIC 2)

where α_0 denotes the constant term; β_i represents the long-run coefficients; φ_i and θ_i represent the short-run coefficients; Δ denotes the first-difference operator; p and q denote the selected lag lengths; and ε_t is the error term.

4. RESULTS AND DISCUSSIONS

4.1. Descriptive Summary

Table 2 displays the descriptive summary and correlation matrix of diverse investigative procedures. In section A, crucial indicators such as mean, Median, maximum, minimum, and standard deviation are described. Remarkably, gross domestic product exhibits the highest mean (21.845) and maximum value (22.616). Although population growth registers a mean value (1.936) and a minimum value (−0.992). Foreign direct investment shows the highest standard deviation (2.126), suggesting considerable variability, whereas carbon emission displays the lowest standard

deviation (0.099), indicating minimal variability around the mean. The data distribution shows a slight rightward skew, except for carbon emission, FDI, and population growth. The Jarque–Bera test indicates that all variables, except energy consumption and population growth, follow a normal distribution ($P > 0.05$). Additionally, section B displays the correlation among variables. Additionally, section B highlights that energy consumption and population growth have negative correlations with carbon emissions, while foreign direct investment and economic growth positively correlate with carbon emissions in Somalia.

4.2. Unit Root Tests

We assessed the integration order of the time-series variables by applying unit root tests, including the augmented dickey-fuller (ADF) and phillips-perron (PP) tests. Both tests assume the null hypothesis (H_0) of a unit root (non-stationarity) and the alternative hypothesis (H_1) of stationarity. As illustrated in Table 3, most variables exhibited non-stationarity at their level form but became stationary after first differencing [I(1)]. These findings justify the use of the ARDL framework, which accommodates variables integrated at different orders, such as I(0), I(1), or a combination of both.

4.3. Cointegration Assessment

The next step is to test for cointegration to determine if the variables share a long-term relationship. After selecting the optimal lag length and confirming the integration order, the Bounds testing approach was applied. The F-bounds test results, shown in Table 4, indicate that the calculated F-statistic of 9.175988 at the 1% significance level exceeds the upper bound critical value, confirming the existence of a long-run cointegration relationship among the variables.

4.4. Long-run and Short-run Results

Table 5 displays the long-run results of the coefficients valued using the ARDL method. The results show that all explanatory variables are statistically significant at the 1% level, demonstrating a robust connection between the independent variables and the dependent variable. More specifically, the investigation indicates that energy consumption, foreign direct investment, and gross

Table 2: Descriptive summary and correlation matrix

Section A: Descriptive summary					
Statistics	**lnCO$_2$**	**lnEC**	**lnFDI**	**lnGDP**	**lnPG**
Mean	6.413	5.706	17.200	21.845	1.936
Median	6.439	5.713	17.179	21.831	2.134
Maximum	6.600	6.365	20.105	22.616	2.302
Minimum	6.187	5.357	11.513	21.146	−0.992
Std. Dev.	0.099	0.186	2.126	0.484	0.665
Skewness	−0.615	1.109	−0.386	0.155	−3.576
Kurtosis	2.906	6.434	2.566	1.629	14.950
Jarque-Bera	1.966	21.585	1.014	2.549	250.530
Probability	0.374	0.000	0.602	0.279	0.000
Sum	198.808	176.877	533.207	677.197	60.029
Sum Sq. Dev.	0.297	1.033	135.573	7.018	13.252
Observations	31	31	31	31	31
Section B: Correlation matrix					
lnCO2	1				
lnEC	−0.007443	1			
lnFDI	0.463	−0.660	1		
lnGDP	0.383	−0.764	0.839	1	
lnPG	−0.422	−0.326	0.194	0.259	1

Table 3: Unit root tests

ADF Unit root test				
Variables	**Level**		**At first difference**	
	Intercept	**Intercept with trend**	**Intercept**	**Intercept with trend**
lnCO$_2$	−1.889	−2.674	−3.197**	−3.476*
lnEC	−3.979***	−6.913***	−11.255***	−10.697***
lnFDI	−1.439	−3.408*	−6.955***	−6.853***
lnGDP	0.7424	−3.156	−3.310*	−3.172*
lnPG	−3.022**	−3.266*	−6.260***	−6.253***
PP Unit root test				
Variables	**Level**		**At first difference**	
	Intercept	**Intercept with trend**	**Intercept**	**Intercept with trend**
lnCO$_2$	−1.990	−2.515	−3.130**	−3.479*
lnEC	−3.695***	−5.951***	−11.621***	−11.278***
lnFDI	−1.154	−3.382*	−10.782***	−13.319***
lnGDP	0.679	−3.378*	−4.825***	−5.090
lnPG	−2.701*	−3.144	−7.224***	−8.347***

*, **, ***Signify significance at 10%, 5% and 1%, in that order

Table 4: F-Bounds test

Model	F-statistic	Significant (%)	Bounds test critical values k=5		Decision
			I (0)	I (1)	
$LnCO_2$=lnEC, lnFDI, lnGDP, lnPG	9.176	1	3.29	4.37	Cointegration
		5	2.56	3.49	
		10	2.2	3.09	

Table 5: Long-run elasticities

Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnEC	1.103***	0.204	5.407	0.000
lnFDI	0.039***	0.011	3.481	0.003
lnGDP	0.284***	0.062	4.609	0.000
lnPG	0.068	0.039	1.715	0.104

domestic product have a significant positive effect on Somalia's carbon emissions, while population growth shows a positive but insignificant impact. By interpretation, a 1% surge in average energy consumption, FDI, and gross domestic product causes a 1.103%, 0.039887%, and 0.284 % surge in carbon emission, respectively, in Somalia.

Moreover, short-run results show that energy consumption, foreign direct investment, and gross domestic product have a significant negative effect on carbon emissions in Somalia. While population growth positively and significantly affects carbon emissions, as represented in Table 6. Taking to mean, a 1% increase in energy consumption, foreign direct investment, and gross domestic product causes a −0.257%, −0.007%, and −0.087% decrease in carbon emissions in the short run. On the other hand, a 1% surge in population growth brings a 0.035% rise in carbon emissions. In economic analysis, short-run effects do not appear immediately after a change occurs. Instead, they reflect transitional adjustments that take place over a limited period before long-term structural changes set in. This means that when variables such as energy consumption, FDI, or GDP change, their impact on carbon emissions may not be instantly visible and may take time. Additionally, the error correction term shows a statistical negative significance of 0.468, signifying the short-run convergence to equilibrium at a rate of 46.8%.

4.5. Diagnostic Tests

As indicated in Table 7, residual diagnostic tests were conducted, and the results confirm that the model meets all criteria, exhibiting normal distribution, absence of serial correlation, no heteroscedasticity, and the correct functional form.

4.6. Casualty Test

To assess the causal relationships among the variables, we conducted a Granger causality test as exhibited in Table 8. The results indicate a unidirectional Granger causality from carbon emissions to energy consumption, suggesting that past values of carbon emissions help predict energy consumption. Similarly, there is unidirectional causality from energy consumption to population growth, and from gross domestic product (GDP) to population growth, indicating that both energy consumption and economic growth influence population trends. Moreover, a

Table 6: Short-run and ECM

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D (lnEC)	0.077	0.075	1.02	0.318
D (lnEC(-1))	−0.257***	0.059	−4.304	0.000
D (lnFDI)	0.006**	0.003	2.257	0.037
D (lnFDI(-1))	−0.007**	0.003	−2.357	0.029
D (lnGDP)	−0.087*	0.047	−1.841	0.082
D (lnPG)	0.035***	0.009	3.863	0.001
ECTt-1	−0.468***	0.057	−8.273	0.000

Table 7: Diagnostic test

Test type	Statistic
Normality	1.485 (0.476)
Serial correlation	0.230 (2.938)
Heteroskedasticity	12.365 (0.261)
Ramsey reset test	1.443 (0.246)

Table 8: Granger causality

Null hypothesis	Obs.	F-Statistic	Prob.
lnEC → $lnCO_2$	29	0.535	0.593
$lnCO_2$ → lnEC		3.408	0.049
lnFDI → $lnCO_2$	29	1.820	0.184
$lnCO_2$ → lnFDI		0.191	0.827
lnGDP → $lnCO_2$	29	4.169	0.028
$lnCO_2$ → lnGDP		4.725	0.019
lnPG → $lnCO_2$	29	0.269	0.766
$lnCO_2$ → lnPG		0.904	0.418
lnFDI → lnEC	29	1.395	0.267
lnEC → lnFDI		2.079	0.147
lnGDP → lnEC	29	2.034	0.153
lnEC → lnGDP		1.858	0.178
lnPG → lnEC	29	0.467	0.633
lnEC → lnPG		35.076	8.E-08
lnGDP → lnFDI	29	4.672	0.019
lnFDI → lnGDP		0.035	0.965
lnPG → lnFDI	29	0.051	0.951
lnFDI → lnPG		0.093	0.912
lnPG → lnGDP	29	10.993	0.000
lnGDP → lnPG		0.359	0.702

bidirectional Granger causality exists between GDP and carbon emissions, implying a mutual influence between economic growth and carbon emissions. The analysis also shows unidirectional causality from GDP to foreign direct investment (FDI), suggesting that economic expansion attracts foreign investment. Conversely, no Granger causality was found among the following pairs: FDI and carbon emissions, population growth and carbon emissions, FDI and energy consumption, GDP and energy consumption, and population growth and FDI. These findings underscore the directional interdependence among economic, environmental, and demographic factors.

4.7. Robust Analysis

To underscore our long-run ARDL results, we have conducted dynamic ordinary least squares (DOLS) as a robustness evaluation, as displayed in Table 9. The long-run findings of DOLS reveal that energy consumption, foreign direct investment, and gross domestic product have a significant positive impact on carbon emission in Somalia, while population growth exhibits an insignificant positive effect, similar to those of the ARDL model. Interpreting a 1% rise in energy consumption, foreign direct investment, and gross domestic product, carbon emissions will increase by 0.569, 0.031, and 0.163, respectively, in the long run.

4.8. Discussion

The findings indicate that there's a significant positive connection between energy consumption and carbon emissions in Somalia. In simpler terms, as we use more energy, our carbon emissions tend to climb as well. This happens mainly because a lot of our energy comes from fossil fuels like coal, oil, and natural gas, which are known to be major contributors to greenhouse gas emissions. This situation underscores the strong relationship between our energy needs and the degradation of the environment, suggesting that our current energy sources aren't sustainable. This aligns with the study of Abdi and Hashi (2024). FDI also appears to significantly and positively influence carbon emissions in Somalia, signifying that when foreign investment increases, pollution levels tend to rise. This could happen if those investments flow into sectors that are heavy on energy use and pollution, like manufacturing, mining, or construction. Without strong environmental regulations in place, foreign companies might focus more on profits than on sustainability. Therefore, even though FDI plays a crucial role in driving economic growth, it can have negative effects on the environment if not managed carefully. This study is supported by Warsame (2023) and Wang and Jiayu (2019). Similarly, the analysis shows a positive and significant link between GDP and carbon emissions in Somalia. In straightforward terms, as the economy expands, emissions tend to rise as well. This trend is particularly noticeable in developing countries, where economic growth often goes hand-in-hand with industrialization, increased transportation, and greater energy demands. This finding suggests that the current economic growth model may be contributing to environmental harm and could become unsustainable over time unless we adopt greener growth strategies. This finding aligns with studies by Osman et al. (2025) and Hassan et al. (2024). In contrast, population growth shows a positive but statistically insignificant effect on carbon emissions. This implies that while a larger population might lead to a slight uptick in emissions, the impact isn't particularly strong or consistent. This result is reinforced by the study of Abdi et al. (2025) and Hassan et al. (2024).

Table 9: Long-run of DOLS result

Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnEC	0.569	0.184	3.089	0.010
lnFDI	0.031	0.011	2.759	0.019
lnGDP	0.163	0.041	4.013	0.002
lnPG	0.036	0.104	0.347	0.735

5. CONCLUSION AND POLICY RECOMMENDATIONS

This study investigates the nexus between energy consumption, foreign direct investment, gross domestic product, population growth, and carbon emissions in Somalia. The findings reveal that energy consumption, foreign direct investment, and gross domestic product have a significant positive impact on carbon emissions in Somalia, while population growth shows an insignificant positive effect. In the short run, however, energy consumption, foreign direct investment, and gross domestic product exhibit a significant negative effect on carbon emissions, whereas population growth positively and significantly affects emissions. Granger causality analysis indicates unidirectional causality from carbon emissions to energy consumption, from energy consumption to population growth, and from GDP to population growth. Furthermore, there is bidirectional causality between GDP and carbon emissions, and unidirectional causality from GDP to foreign direct investment, while no causality is found among other variable pairs.

First, since energy consumption is a major contributor to carbon emissions, Somalia should realistically focus on shifting toward cleaner and more efficient energy systems. This includes promoting renewable energy sources such as solar, wind, and hydro power, improving energy efficiency, and expanding access to off-grid renewable solutions. In the future, Somalia could establish smart-grid systems, adopt digital energy monitoring tools, and develop regional energy-sharing initiatives to ensure sustainable and resilient energy access. Second, regarding foreign direct investment (FDI), the government should enforce strict environmental regulations to direct investments toward sustainable sectors. Offering incentives for green technologies and mandating environmental impact assessments can ensure that foreign investments contribute to both economic growth and environmental protection. From a futuristic standpoint, Somalia can aim to become a regional hub for green investment, leveraging digital platforms to attract climate-smart investors and establishing green certification systems for FDI projects. Third, given the positive relationship between GDP growth and emissions, it is essential to adopt sustainable development strategies that balance economic progress with environmental protection. Realistically, this includes implementing carbon pricing mechanisms, investing in eco-industrial zones, and promoting innovation in sustainable industries. In the long run, Somalia could integrate circular economy principles and climate-smart technologies into its development agenda to achieve low-carbon, inclusive growth. Fourth, while population growth currently shows an insignificant impact on emissions, proactive measures are needed to ensure long-term sustainability. Realistically, this means promoting environmental education, public awareness campaigns, and sustainable consumption habits.

Looking ahead, Somalia could adopt urban green planning, smart city frameworks, and sustainability-oriented population policies to align demographic trends with environmental goals. In conclusion, embedding sustainability into national planning and investment frameworks is crucial for Somalia's transition toward a low-carbon

and resilient economy. Realistic short-term policies supported by visionary, future-oriented strategies will enable Somalia to achieve sustained economic growth while safeguarding environmental integrity.

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