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Toward Environmental Sustainability: The Nexus between Agriculture, Renewable Energy, and Economic Growth in Mitigating CO_2 Emissions in Somalia

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ABSTRACT

This research investigates the intricate relationships between agriculture, renewable energy, economic growth, and carbon dioxide (CO_2) emissions in Somalia from 1991 to 2022. This study uses the autoregressive distributed lag (ARDL) model and Granger causality tests to understand their impact on environmental sustainability. ARDL results reveal a negative role of agriculture and renewable energy on CO_2 in the short and long term. The country's reliance on fossil fuels and biomass further intensifies CO_2 emissions. While economic growth is essential for improving living standards, it positively correlates with CO_2 emissions in the short and long term, emphasizing the challenge of decoupling economic development from environmental degradation. Domestic investment has a short-run relation only to CO_2 emissions. In Granger causality tests, the results indicated that Agriculture and domestic investment have bidirectional causality to carbon dioxide emissions. On the other hand, renewable energy, economic growth, and domestic investment have unidirectional causality to Agriculture in Somalia, while domestic investment has bidirectional causality to renewable energy and economic growth. The study recommends implementing comprehensive and integrated approaches to prioritize sustainable development strategies, clean energy alternatives, and efficient agricultural practices. Promoting economic growth while also focusing on capacity-building and awareness campaigns is essential. Collaborating with the international community on climate change mitigation and sustainable development initiatives can further support Somalia's journey toward environmental sustainability.

Keywords: Renewable Energy, CO_2 Emissions, Agriculture, Domestic Investment, Somalia
JEL Classifications: Q42, Q53, C22, O55

1. INTRODUCTION

The environmental challenges of climate change and escalating carbon dioxide (CO_2) emissions have engendered a global imperative for sustainable development. Amid this critical need, many nations, including Somalia, have recognised the urgency of addressing these issues to ensure the well-being of present and future generations. The relationship between agriculture, renewable energy, economic growth, and CO_2 emissions has emerged as a crucial domain for research and policy development in this context. The increasing concern about climate change and a sustainable environment has highlighted the rising importance of renewable energy sources. The global economy is shifting towards environmentally conscious renewable energy alternatives in response to the rapid depletion of fossil fuel reserves, including natural gas, coal, and oil gas. This transition aims to reduce reliance on traditional energy sources while maintaining and sustaining global economic productivity through renewable energy options (Raihan and Tuspekova, 2022b).

Somalia is facing many challenges related to environmental sustainability, most of which are caused by its susceptibility to climate change. This vulnerability is further compounded by the country's reliance on agriculture and fossil fuels. Agriculture is a crucial part of Somalia's economy but is also a significant contributor to greenhouse gas emissions, meaning the country's carbon footprint is relatively high. Agriculture is susceptible to the adverse effects of climate change, making it even more challenging for Somalia to adapt to changing climatic conditions.

In addition to its climate vulnerability, Somalia also suffers from a high susceptibility to natural disasters, a trend exacerbated by global climate change. The frequency and intensity of these events are increasing, with droughts being a particularly significant concern. Somalia has experienced about 14 major droughts on average once every 4 years since 1960. This worrying trend has made Somalia one of the most climate-vulnerable nations in the world. 018, the Center for Global Development ranked Somalia as the most climate-vulnerable nation out of 167 countries assessed (UN, 2015). Land use and forestry activities account for approximately twenty percent of the world's annual CO_2 emissions, making them the second-largest source of emissions and a prominent contributor to climate change, following energy usage (Raihan and Tuspekova, 2022a). In tandem, the lack of access to reliable energy sources further drives the use of biomass and fossil fuels, intensifying CO_2 emissions. At the same time, economic growth is indispensable for improving the standard of living and reducing poverty, but its conventional path often involves the unsustainable exploitation of natural resources.

In response to these challenges, there is growing recognition that a comprehensive and integrated approach is needed to achieve environmental sustainability. This approach entails understanding and harnessing the interconnections among agriculture, renewable energy, economic growth, and CO_2 emissions. In this context, the synergy between the agricultural sector and renewable energy sources presents an opportunity to transform traditional farming practices, reduce emissions from agricultural activities, and enhance energy access. Moreover, economic growth decoupled from carbon-intensive activities is essential for sustainable development. This aligns with the global commitment articulated in the United Nations' Sustainable Development Goals, particularly Goal 7, Affordable and Clean Energy, Goal 8, Decent Work and Economic Growth, and Goal 13, Climate Action (UN, 2015).

This article explores the nexus between agriculture, renewable energy, economic growth, and CO_2 emissions in Somalia, examining the potential for synergy and trade-offs. It synthesises existing research, analyses empirical data, and draws insights from experiences in other regions facing similar challenges. By investigating the complex relationships within this nexus, this study aims to provide a comprehensive perspective on the implications of various policy options for mitigating CO_2 emissions while fostering sustainable development in Somalia.

2. LITERATURE REVIEW

The relationship between Agriculture Renewable energy and economic growth and carbon dioxide (CO_2) emissions has been studied extensively in various countries, using different statistical methods to gain insights into this critical nexus. This literature review is divided into three sections: the first section is agriculture and CO_2 emissions, and the second section is renewable energy and CO_2 emissions. The last section is about economic growth and CO_2 emissions. We explore a series of such studies and their findings in each section.

2.1. Agriculture and Carbone Dioxide Emissions

Balsalobre-Lorente et al. (2019) examined the Environmental Kuznets Curve (EKC) hypothesis for Brazil, Russia, India, China, and South Africa (BRICS) from 1990 to 2014. They considered agricultural activities, energy use, trade openness, and mobile use the driving forces of environmental degradation. The study found that agriculture has an unfriendly impact on the environment, and agricultural activities have an additional pernicious effect. They used the Dynamic Ordinary Least Squares (DOLS) and the Fully Modified Ordinary Least Square (FMOLS) for long-run regression. Their results confirm that agriculture negatively impacts the environment in BRICS countries. Jebli and Youssef (2017) utilised panel cointegration techniques and Granger causality tests to investigate the dynamic causal links between agricultural value-added and carbon dioxide (CO_2) emissions for a panel of five North African countries from 1980 to 2011. The study found that agricultural value-added negatively affects CO_2 emissions. In Granger causality tests, they found the existence of bidirectional causality between CO_2 emissions and agriculture in the short run. In the long run, there is bidirectional causality between agriculture and CO_2 emissions (Ramakgasha et al., 2024).

Doğan (2018) analysed the relationship between agricultural production and carbon dioxide emissions in China over a long-term period, using annual data from 1971 to 2010. They estimated this relationship following the EKC hypothesis. To identify a long-term relationship, they employed the bounds test approach for cointegration and autoregressive distributed lag (ARDL), FMOLS, DOLS, and CCR. The study revealed that agriculture increases a country's long-term CO_2 emissions and that there is an inverse U-shaped agriculture-induced EKC curve for China. Mahmood et al. (2019) used the agriculture sector to test the existence of the EKC hypothesis in Saudi Arabia while considering energy consumption and agriculture share in income and analysing their effects on CO_2 emissions per capita. They confirmed that the EKC hypothesis validates agriculture's share in GDP and CO_2 emissions per capita with a turning point at 3.22% agriculture share in GDP. Further, they found that the agriculture sector negatively and significantly affects CO_2 emissions per capita. Prastiyo et al. (2020) examined the effects of agriculture, urbanisation, and manufacturing on carbon emissions in Indonesia to enhance the country's EKC research. The study confirmed the EKC hypothesis in Indonesia with a turning point of 2057.89 USD/capita. The study also demonstrated that agriculture affects the escalation of greenhouse gas emissions in Indonesia. Furthermore, the Granger causality analysis found a bidirectional causality relationship between emissions and the agricultural sector.

Aydoğan and Vardar (2020) investigated the dynamic links between agricultural value-added, renewable and non-renewable energy consumption, and CO_2 emissions. The goal was to examine the existence of the EKC hypothesis for a panel of E7 countries covering the period 1990-2014. The study found a positive relationship between CO_2 emissions and agricultural value-added in the long run. The results also support the inverted U-shaped EKC in these selected countries. Regarding the Granger causality analysis, bi-directional Granger causality exists between non-renewable energy consumption and CO_2 emissions in the long run. Yurtkuran (2021) conducted a study to examine the impact of agriculture, renewable energy production, and globalisation on CO_2 emissions in Turkey from 1970 to 2017. He used various statistical methods, including the Gregory-Hansen cointegration test, bootstrap ARDL approach, FMOLS, and DOLS long-run estimators. The study revealed a cointegration relationship between the variables and found that agriculture, renewable energy production, and economic globalisation contribute to environmental pollution. Therefore, Yurtkuran's examination confirms that these variables have an undesirable impact on CO_2 emissions.

2.2. Renewable Energy and Carbone Dioxide Emissions

Several studies have been conducted to evaluate the impact of renewable energy consumption and trade policy on environmental quality in Somalia. Warsame et al. (2022) analysed the effect of renewable energy on environmental degradation in Somalia using data from 1990 to 2017. They applied the ARDL model and Granger causality and found that renewable energy positively affects environmental quality in Somalia. In another study, Warsame (2023) researched the impact of energy consumption on carbon dioxide (CO_2) emissions in Somalia between 1990 and 2019. Analysing the data, he used two statistical methods - ARDL and FMOLS. The results showed that renewable energy hurts the environment in the long run. Additionally, the FMOLS analysis supported the idea of the EKC in Somalia. Mohamud and Mohamud (2023) conducted a study in 2023 to examine how renewable energy consumption affected environmental degradation in Somalia from 1990 to 2020. To do this, they employed ARDL and the Pairwise Granger Causality Test. Their findings showed a positive, significant relationship between renewable energy and environmental deterioration in the short term. However, in the long run, they discovered a negative, meaningful relationship between the use of renewable energy and environmental degradation. Therefore, their results indicate that using renewable energy is a crucial contributor to environmental degradation in Somalia in both the short and long term.

Similarly, various studies conducted in different countries have shown that renewable energy consumption positively impacts environmental quality. For instance, Usman et al. (2020) conducted a study in the United States between 1985Q1 and 2014Q4, and their findings confirmed that renewable energy consumption positively affects environmental quality. In Turkey, Karasoy and Akçay (2019) researched the impact of trade and renewable energy consumption on environmental pollution. They found that an increase in renewable energy consumption reduces CO_2 emissions in both the short and long run. Koengkan (2018) examined the effectiveness of renewable energy consumption in reducing environmental degradation in five MERCOSUR countries between 1980 and 2014 and found a negative association between renewable energy consumption and environmental degradation in the selected countries. Chien et al. (2021) studied the role of renewable energy in mitigating environmental degradation in Pakistan between 1980 and 2018. Their results showed that renewable energy sources hurt carbon dioxide emissions in the country. In Sub-Saharan African countries, Zandi and Haseeb (2019) examined the impact of renewable energy in mitigating environmental degradation between 1995 and 2017 using advanced panel data techniques. Their empirical findings concluded that green energy is environmentally favorable. Lastly, Ali et al. (2020) researched the correlation between renewable energy and CO_2 emissions in Malaysia for the period 1971-2019. The study employed wavelet tools to analyse these interconnections, and the findings revealed a negative coherence among various frequencies of renewable energy and carbon dioxide.

2.3. Economic Growth and Carbone Dioxide Emissions

The relationship between economic growth and CO_2 emissions has garnered significant attention worldwide. Several studies have investigated this relationship in different regions and countries. Kirikkaleli and Kalmaz (2020) investigated the relationship between economic growth and CO_2 emissions in Turkey from 1960 to 2016, using FMOLS and DOLS techniques. The study found a positive impact of economic growth on CO_2 emissions, consistent with the broader trend. Adebayo (2020) examined the relationship between economic growth and CO_2 emissions in Mexico from 1971 to 2016 using ARDL, FMOLS, and DOLS estimators. The results were consistent with previous studies, showing a positive correlation between economic growth and CO_2 emissions (Khamjalas, 2024).

In Asia, Prastiyo et al. (2020) focused on Indonesia, analysing data from 1970 to 2015 using the ARDL technique. The study found a positive impact of economic growth on CO_2 emissions, highlighting the importance of policies that promote green growth and sustainability. Liu and Bae (2018) conducted a study in China, one of the world's largest economies and carbon emitters, using the ARDL method. Their findings showed that economic growth has a positive effect on CO_2 emissions. You et al. (2022) investigated the relationship between economic growth and CO_2 emissions in Malaysia, a country at the intersection of economic development and environmental conservation. The researchers used a range of econometric techniques, including Maki co-integration, ARDL, FMOLS, and DOLS, and analysed the data from 1960 to 2018. The study revealed a positive correlation between economic growth and CO_2 emissions in Malaysia.

In Africa, by applying the vactor error correction model kernelised reqularised least squeres, Machine learning method estimators using annual time series data spanning from 1085 to 2016, Warsame et al. (2023) found that economic growth has positive effects on CO_2 emissions in Somalia. Adebayo and Beton Kalmaz (2021) conducted a similar investigation into the relationship between economic growth and CO_2 emissions in Egypt from 1971 to 2014, using ARDL, FMOLS, and DOLS methods. The findings again showed a positive relationship between economic growth and CO_2 emissions. Nondo and Kahsai (2020) explored the interplay between economic growth and CO_2 emissions in South Africa, analysing data from 1970 to 2016 using the ARDL approach. The study found a positive effect of economic growth on CO_2 emissions. Odugbesan and Adebayo (2020) investigated the relationship between economic growth and CO_2 emissions in Nigeria from 1981 to 2016, using ARDL, FMOLS, and DOLS methods. The study revealed a positive correlation between economic growth and CO_2 emissions. These studies collectively highlight the critical need for sustainable development strategies that address the environmental consequences of economic growth. The positive relationship between economic growth and CO_2 emissions, observed across various countries and regions, underscores the global scope of this challenge.

3. METHODOLOGY

3.1. Data

This paper analyzes time series data from 1991 to 2022 to determine the level of environmental pollution, focusing on carbon dioxide emissions as the dependent variable. The study considers agriculture, renewable energy, economic growth, and domestic investment as independent variables. Agriculture is measured by assessing the value added to current prices, while renewable energy is measured by determining the percentage of final energy consumption. Economic growth is evaluated by GDP in current prices, and domestic investment is measured by determining the gross fixed capital formation in current prices. To ensure accuracy, detailed sources of data and their unit measurements are presented in Table 1.

3.2. Model Specification

This study was accomplished by using the ARDL model. ARDL bond testing has several benefits over conventional cointegration tests. First, it can be used regardless of whether the underlying variables are I (0), I (1), or a combination of the two (Pesaran et al., 2001). Second, ARDL tests capture the data generation process by allowing for a suitable number of lags within the general to specific modeling frameworks. Third, short-run corrections can be integrated with a long-run equilibrium in ARDL by deriving the error correction mechanism (ECM) through a simple linear transformation without relying on long-run information. Fourth, the ARDL approach outperforms the Johansen and Juselius approach in small sample sizes. In theory, environmental degradation is associated with agriculture and renewable energy. Assuming the market clearing condition of Friedman (1949), this study states that carbon dioxide emissions equal agricultural and renewable energy and the Marshallian demand function can be written as follows.

$$CO_{2t} = f(AVT_t, RE_t) \quad (1)$$

Where CO_{2t} is carbon dioxide emissions at time series t, AVT_t is the percentage of agriculture value added at time series t, and REt is renewable energy consumption at time series t.

In Equation 1, we extended the influence of economic growth and domestic investment on Somalia's environmental degradation. So it can be specified as follows:

$$CO_{2t} = f(AVT_t, RE_t, EG_t, DI_t) \quad (2)$$

Where EG_t is economic growth at time series t, DI_t is domestic investment at time series t. In the econometric model, the relationship between environmental degradation, agriculture, renewable energy, economic growth, and domestic investment can be specified as follows:

$$CO_{2t} = \beta_0 + \beta_1 AVT_t + \beta_2 RE_t + \beta_3 EG_t + \beta_4 DI_t + u_t \quad (3)$$

Where β_0 is the intercept of the model, 1, 2, 3, and 4 are coefficient measures of explanatory variables on the dependent variable. To avoid issues related to heteroscedasticity and autocorrelation, we transform the data into a logarithmic form since this study uses the ARDL model for assessing short and long-run cointegration between regressand and regressors variables based on the empirical study of (Warsame et al., 2023), the mathematical expressions of ARDL can be written as follow.

$$\Delta LCO2_{t-1} = \beta_0 + \beta_1 LCO2_{t-1} + \beta_2 LAVT_{t-1} + \beta_3 LRE_{t-1} + \beta_4 LEG_{t-1} + \beta_5 LDI_{t-1} + \sum_{i=1}^{\rho} \alpha_1 \Delta LCO2_{t-i} + \sum_{i=1}^{\rho} \alpha_2 \Delta LAVT_{t-i} + \sum_{i=1}^{\rho} \alpha_3 \Delta LRE_{t-i} + \sum_{i=1}^{\rho} \alpha_4 \Delta LEG_{t-i} + \sum_{i=1}^{\rho} \alpha_5 \Delta LDI_{t-i} + u_{t-i} \quad (4)$$

Where Δ is the first deference operator, ρ indicates the optimal leg length of the estimated variables. β_1, β_2, β_3, β_4, and β_5 are coefficient measures of estimated variables' long-run effects. While 1, 2, 3, 4, and 5 are coefficient measurements of the short-run effect of estimated variables.

4. RESULTS AND DISCUSSIONS

4.1. Descriptive Analysis

Table 2 presents descriptive data that highlight the information flow. Specifically, LCO_2 is distinguished by having a smaller group (mean 13.320) than the busy crowds around LAVT, LRE, LEG, and LDI (means ranging from 3.714 to 6.050). Surprisingly, the median values nearly resemble the means, indicating that everyone in each group is somewhat similar to their neighbor in terms of

Table 1: Data measurement and its sources

Variables	Description	Measurement	Source
CO_2	Carbon dioxide emissions	Per capita CO_2 emissions	WDI
AVT	Agriculture total value added	Current price USD	SESRIC
RE	Renewable energy consumption	% of total final energy consumption	WDI
GDP	Gross domestic products	Current price USD	WDI
DI	Domestic investment	Gross fixed capital formation (current US$)	WDI

value. Think of them as calm observers in the center. In this way, people are arranged inside each group. With everyone clustered near the average (low standard deviation), LCO_2 appears to be a well-organized group. This is not the case for LEG, where people are more dispersed, suggesting a higher degree of variability in their values (significant standard deviation). By gently tilting the lens, we can discern the general form of each population in the distribution shape. We may view each variable's overall shape in the distribution shape. LCO_2 has a modest rightward tilt (positive skewness), indicating that many individuals may be on the high end. Conversely, LRE exhibits a leftward dip (negative skewness), suggesting the possibility of outliers towards the lower values. However, the tails of all the crowds are fatter than the average bell curve (kurtosis >1), which suggests that there may be more people at the periphery than a normal distribution would indicate. Correlations between the estimated variables in this study interact, as shown in the back of Table 2; LCO_2 has negative correlations to most other variables. Imagine it as an inverse movement where the others quietly move in one direction while LCO_2 moves in the opposite direction. For instance, LCO_2 and LRE have a correlation of −0.530, which means that as LCO_2 confidently moves to the right, LRE moves to the left.

Table 2: Descriptive statistics

Variables	LCO_2	LAVT	LRE	LEG	LDI
Mean	13.320	3.714	4.527	5.603	6.050
Median	13.318	3.624	4.536	5.662	6.099
Maximum	13.766	4.289	4.559	6.135	7.126
Minimum	13.082	3.145	4.455	4.875	4.917
SD	0.123	0.337	0.028	0.357	0.546
Skewness	0.734	0.190	−0.264	−0.426	−0.199
Kurtosis	1.047	1.693	1.768	2.080	2.397
Jarque-Bera	2.860	2.548	2.593	2.165	0.718
Probability	0.285	0.280	0.268	0.339	0.699
Correlation					
LCO_2	1.000				
LAVT	−0.129	1.000			
LRE	−0.530	−0.675	1.000		
LEG	−0.263	−0.846	0.947	1.000	
LDI	−0.097	−0.795	0.871	0.951	1.000

LAG: Lag of the agricultural, LRE: Lag of renewable energy, LDI: Lag domestic investment, LEG: Lag economic growth, SD: Standard deviation

Non-stationary data can be difficult to analyze, and differencing is often used to achieve stationarity (Hassan & Mohamed, 2024). The results in Table 3 present the unit root tests for the five estimated variables in this study using both the Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF) tests at both the level and first difference. At the level, the carbon dioxide and renewable energy variables are stationary, as indicated by their highly significant t-statistics (1%) across most specifications, allowing us to reject the null hypothesis of non-stationarity for these variables. However, agriculture's total value added, economic growth, and domestic investment show non-stationarity, as their t-statistics are insignificant, except in specific cases such as the constant trend PP test for economic growth. At the first difference, all the variables become stationary, with significant t-statistics at either the 1% or 5% levels, indicating that these variables are integrated of order 1 [I(1)]. Most variables require first differencing to achieve stationarity, which is typical in time series analysis.

Once we have identified the presence of a unit root and chosen the most suitable lag model, our analysis focuses on doing the F-bound test to evaluate the long-term cointegration between the variables in the estimated model. Table 4 displays the F-statistics and their corresponding critical values. The critical values obtained from Pesaran et al. (2001) are considered unsuitable for our investigation due to the limited sample size, which consists of just 32 observations. Instead, we use Narayan's critical values, which are considered appropriate for small sample sizes ranging from 31 to 81 observations (Narayan, 2004). The results of our research indicate a long-term cointegration link between Agriculture Value Added, Renewable Energy, Economic Growth, Domestic Investment, and Carbon Dioxide Emissions. Therefore, we reject the null hypothesis, which implies the absence of cointegration, and do not reject the alternative hypothesis, which suggests the presence of cointegration. The presence of cointegration between the dependent variable and the explanatory factors is confirmed by our Wald F-statistic of 6.03, which exceeds the threshold value of 5.06 at a 1% significance level.

Table 5, presented below, shows the results of an ARDL model, a statistical technique used to investigate the relationship between a dependent variable, CO_2, and four independent variables:

Table 3: Unit root test

	AV Level			
	PP		ADF	
Variables	With constant, T-statistic	With constant and trend, T-statistic	With constant, T-statistic	With constant and trend, T-statistic
LCO2	−4.380***	−4.962***	−5.000***	−2.212
LATV	−1.501	−1.703	−1.501	−1.703
LRE	−5.055***	−3.249*	−4.818***	−4.760***
LEG	−4.381***	−3.150	−2.143	−0.428
LDI	0.417	−6.954***	3.759	−7.984***
		At first difference		
d(LCO2)	−6.242***	−6.232***	−6.363***	−6.327***
d(LATV)	−6.207***	−6.129***	−2.754*	−6.339***
d(LRE)	−3.135**	−4.255**	−3.114**	−4.184**
d(LEG)	−3.265**	−3.578**	−2.924*	−2.702
d(LDI)	−17.641***	−17.100***	−9.681***	−4.957***

*Significant at the 10%; **Significant at the 5%; ***Significant at the 1%.
PP: Phillips-Perron, ADF: Augmented Dickey-Fuller

Table 4: F-bounds test

Bound test critical values				
Model $LnCO_2$=f (ln AGV, ln RE, ln EG, ln DI)			K=4	
Test statistic	F-statistic	Significance (%)	I (0)	I (1)
F-statistic	6.025912	1	3.74	5.06
		5	2.86	4.01
		10	2.45	3.52

K represents a number of parameters, and the Critical Values are based on Narayan (2004)

Table 5: Autoregressive distributed lag long and short run autocomes

Variable	Long run		Short run and ECM_{t-1}	
	Coefficient	T-statistic	Coefficient	T-statistic
LAVT	−0.418***	−3.635	−0.087*	−1.808
LRE	−5.061*	−1.778	−7.979***	−7.368
LEG	0.606*	1.782	0.307*	1.942
LDI	−0.448	−1.504	0.343***	3.379
ECM_{t-1}			−0.506***	−6.013
Diagnostic tests				
Normality test	1.902 (0.386)			
LM test	3.666 (0.160)			
Hetro test	8.470 (0.583)			
RESET test	2.511 (0.021)			
Adjusted R^2	0.939 (0.000)			

*Significant at the 10%; **Significant at the 5%; ***Significant at the 1%. LAG: Lag of the agricultural, LRE: Lag of renewable energy, LDI: Lag domestic investment, LEG: Lag economic growth

Agriculture, renewable energy, economic growth, and domestic investment. It provides the short and long-term effects of estimated variables on the CO_2. The long-term results reveal that agriculture and renewable energy negatively impact carbon dioxide emissions, while economic growth has a positive significance. For example, an increase in the lag of the agricultural value added (LAG) by one unit is linked to a decrease in carbon dioxide emissions of 0.418 units. This means agriculture has a negative relation to CO_2 in the long run. Similarly, the lag of renewable energy (LRE) exhibits a long-term negative association with CO_2; this implies that a one-unit increase in the lag of LRE results in a decrease of 5.061 units of CO_2 in the long run, while an increase in the lag of economic growth by one-unit results in an increasing 0.61 units of CO_2 in the long run period, The positive relationship between economic growth and carbon dioxide emissions emphasizes the challenge of decoupling economic development from environmental degradation. Supported studies conducted by (Khan et al., 2020; Leitão et al., 2022) have shown a strong correlation between economic growth and carbon dioxide emissions. The researchers have revealed as our study revealed that as economies grow, their carbon footprints also grow, increasing carbon dioxide emissions. The short-term coefficients demonstrate that agriculture and renewable energy have a negative significance relation to CO_2. In contrast, domestic investment and economic growth positively and significantly affect carbon dioxide emissions (CO_2). The Error Correction Mechanism (ECMt-1) at −0.506 with a t-statistic of −6.013 signifies the speed of adjustment towards long-run equilibrium after a short-run deviation. This means that if there is a deviation from the long-term equilibrium, the error correction mechanism will push the dependent variable back toward the equilibrium at a rate of 0.506 units per period. To evaluate the model's reliability, various diagnostic tests were performed. The normality, LM (Breusch-Godfrey), Heteroskedasticity, and RESET tests provide insights into the model's adequacy. The p-values for the normality, LM, and Heteroskedasticity tests exceed 0.05, suggesting no evidence against normality, serial correlation, or heteroskedasticity. This implies that the model is reliable and adequately captures the relationship between the dependent and independent variables. However, the RESET test yields a P = 0.21, indicating that the model is correctly specified. Overall, the model explains approximately 93.9% of the variation in carbon dioxide

Table 6: Pairwise granger causality tests

Null hypothesis	F-statistic	P
LATV→LCO_2	3.64781	0.0401
LCO_2→LATV	5.91838	0.0076
LDI→LCO_2	2.63771	0.0906
LCO_2→LDI	5.47376	0.0104
LRE→LAG	9.12541	0.001
LATV→LRE	1.56129	0.2289
LEG→LATV	11.3753	0.0003
LATV→LEG	1.09562	0.3493
LDI→LATV	3.95985	0.0315
LATV→LDI	1.16915	0.3264
LEG→LRE	2.57671	0.0953
LRE→LEG	0.11516	0.8917
LDI→LRE	3.0578	0.0642
LRE→LDI	4.34495	0.0236
LDI→LEG	5.275	0.0119
LEG→LDI	3.16874	0.0587

Figure 1: CUSUM test

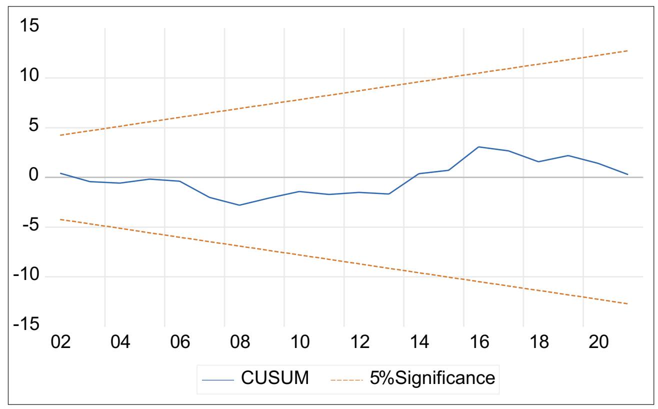
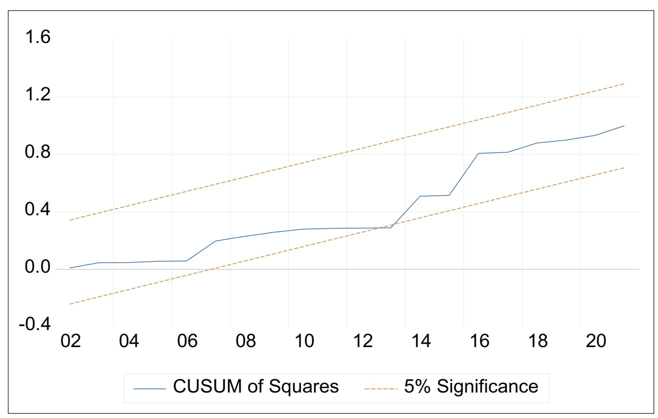


Figure 2: CUSUM squares test



emissions, as indicated by the adjusted $R^2 = 0.939$. Furthermore, the stability of ARDL model coefficients over the observed period is confirmed through the CUSUM and CUSUM-square tests, as visually displayed in Figures 1 and 2.

The results in Table 6 display the Granger Causality Tests performed on our study's different pairs of agricultural value added, renewable energy, domestic investment, and economic growth variables to assess whether the values of one variable significantly cause the other. In this case, the null hypothesis assumes no causality exists between the variables. The table presents the F-statistic and corresponding P-values for each pair of variables. The test results revealed a bidirectional causation between carbon dioxide emissions (LCO_2) and agriculture (LAVT). The bidirectional causality between agriculture and carbon dioxide emissions demonstrates the critical need for sustainable agricultural practices to address the environmental impacts of food production. Studies conducted by Chandio et al. (2020) and Ridzuan et al. (2020) have provided robust evidence supporting the idea that agricultural practices significantly impact carbon emissions. This evidence reinforces the importance of improving farming methods to reduce the environmental impact of agriculture while still meeting the demands of a growing population. By adopting sustainable farming practices, farmers can reduce the carbon track of their operations while also protecting the environment and preserving natural resources for future generations. Another important finding was that domestic investment (LDI) has a bidirectional relationship with carbon dioxide emissions, meaning that both variables significantly influence each other. This implies that domestic investment significantly impacts carbon dioxide emissions and vice versa. Furthermore, the tests showed that renewable energy (LRE) significantly causes agriculture, indicating that renewable energy substantially impacts agriculture. This significant impact of renewable energy on agriculture implies that the shift towards renewable energy sources could positively impact the agriculture sector. The findings suggest that economic growth (LEG) also significantly causes agriculture, meaning that economic growth significantly impacts agriculture. This implies that economic growth can lead to increased agricultural production; conversely, a decline in economic growth may lead to a decline in agricultural production. Finally, renewable energy was found to significantly cause domestic investment, indicating that renewable energy has a significant impact on domestic investment. This finding implies that the shift towards renewable energy sources can positively impact domestic investment. The results of the Granger Causality Tests provide valuable insights into the dynamic interactions among the examined environmental factors. The findings shed light on the potential causal relationships over the observed period, which is crucial for policymakers, researchers, and decision-makers to make informed decisions.

5. CONCLUSION

This study has explored the intricate relationships among agriculture, renewable energy, economic growth, and carbon dioxide (CO_2) emissions. This study uses secondary data from 1991 to 2022, the ARDL model, and the Granger causality test to fully understand these dynamics. In the ARDL model, the results of this study revealed a negative impact of agriculture and renewable energy on CO_2 emissions in the short and long term. The country's reliance on fossil fuels and biomass further intensifies CO_2 emissions. While economic growth is essential for improving living standards, it positively correlates with CO_2 emissions in the short and long term, emphasizing the challenge of decoupling economic development from environmental degradation. Domestic investment has a short-run relation only to CO_2 emissions. In Granger causality tests, the result of this study indicated that Agriculture and domestic investment have bidirectional causality to carbon dioxide emissions. On the other hand, renewable energy, economic growth, and domestic investment have unidirectional causality to Agriculture in Somalia, while domestic investment has bidirectional causality to renewable energy and economic growth. However, the study identifies a potential synergy between agriculture and renewable energy sources, offering opportunities to transform traditional farming practices, reduce emissions, and enhance energy access.

The study's findings suggest that addressing environmental challenges in Somalia requires a comprehensive and integrated approach that considers sustainable development strategies, prioritizes clean energy alternatives, and employs efficient agricultural practices that can help transform the country's economy while minimizing environmental degradation. Policymakers need to prioritize initiatives that encourage the adoption of renewable energy sources in Somalia. Investing in renewable energy infrastructure, such as solar and wind power, can help reduce CO_2 emissions and improve energy access, which can mitigate the reliance on fossil fuels. Sustainable agricultural practices are essential for reducing the environmental footprint of the agriculture sector. This includes promoting efficient water use, agroecological methods, and precision farming to enhance productivity while minimizing emissions. Diversifying the energy mix by incorporating various renewable sources can contribute to a more resilient and sustainable energy system. This can involve a combination of solar, wind, hydropower, and other clean energy alternatives to meet the country's energy needs.

Policymakers should explore avenues for promoting green economic growth by emphasizing industries and sectors that are environmentally friendly. This can involve incentives for clean energy projects, green technology development, and sustainable practices within the business sector. Initiatives for capacity building and awareness campaigns can empower local communities, farmers, and businesses to adopt environmentally sustainable practices. Education on the benefits of renewable energy, sustainable agriculture, and the long-term consequences of CO_2 emissions is crucial for fostering a culture of environmental responsibility. Given the global nature of environmental challenges, Somalia should actively engage in international collaborations and initiatives focused on climate change mitigation and sustainable development. Accessing funding, technology transfer, and expertise from the international community can bolster Somalia's efforts towards environmental sustainability.

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