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The Environmental Impact of Trade Openness on CO_2 Emissions: Empirical Evidence from Somalia

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ABSRACT

This research examines the effects of trade openness on carbon emissions in Somalia from 1980 to 2021. Somalia's economy is strongly dependent on exporting goods including cattle, charcoal, and raw agricultural products, which contribute to high carbon emissions. The study employed Autoregressive Distributed Lag (ARDL), full modified Ordinary Least Squares (FMOLS), dynamic Ordinary Least Squares (DOLS), and Canonical Co-integrating Regression (CCR) to analyze the immediate and long-term correlation between trade openness and carbon dioxide emissions in Somalia. When there are different types of variables, our approach, which includes the ADF unit root test, verifies that all variables show first-order integration (I (1)) and stationary behavior (I (0)). The ARDL-bound tests for co-integration reveal a durable connection between carbon emissions and several factors, including trade openness, gross domestic product (GDP), foreign direct investment (FDI), and population increase. The findings demonstrate a statistically significant and inverse relationship between trade openness and short-term carbon dioxide emissions. The heightened levels of trade openness have a noticeable detrimental effect on carbon emissions. Furthermore, there is a strong and statistically significant negative relationship between energy consumption, RGDP, and population increase with carbon emissions, except for RGDP which shows no significant impact. FDI exhibits a robust and meaningful correlation with carbon emissions in both the short and long term. In addition, Somalia's population is experiencing significant growth, making it one of the fastest-growing populations in the world. This growth leads to an increased demand for energy, land, and consumption, which in turn contributes to higher emissions. However, the research did not take into account other possible factors that could have an impact, such as technical advancements, global economic changes, climate change, and policy adjustments. The report advised that future research explore the possibilities of sustainable trade practices, improvements in energy efficiency, and the use of renewable energy as means to minimize CO_2 emissions.

Keywords: Trade Openness, CO_2 Emissions, ARDL, FDI, GDP, Somalia
JEL Classifications: C53, F43, O13, P28, Q53

1. INTRODUCTION

The increasing amount of global trade in goods resulted in a rise in economic efficiency and industrial operations. An exponential rise in global production involves more energy consumption, resulting in a corresponding surge in emissions of carbon dioxide (Murshed, 2022). The academic literature has suggested many mechanisms by which openness in trade can influence the environment, but empirical research on the association between trade openness and the environment has yielded conflicting results (Omri and Saadaoui, 2023; Raggad, 2020; Rahman and Ahmad, 2019). In addition, carbon emissions have significantly increased since the start of the industrial revolution and are a major contributor to the phenomena of global warming (Ansari et al., 2020). Regardless, climate scientists and environmental economists contend that global carbon emissions surged by 58% from 1990 to 2014. Concurrently, there was a noteworthy 425% increase in trading throughout this period. Nonetheless, a significant change happened in 2013-2014 when carbon emissions from developing countries overtook those from developed countries. Beyond that, projections show that emissions will skyrocket, going from 31.9 billion metric tons in 2012 to 43.2 billion metric tons in 2040, an increase of 34% throughout the predicted time frame. As a consequence of this, the excessive release of carbon emissions has become a

serious cause for concern, which has resulted in the requirement of immediate actions to address this urgent global crisis (Zuo et al., 2023). Not only that, but during the course of the past ten years, there has been a substantial rise in the degree of trade openness that exists between developed countries and emerging markets. This transformation has had a profound impact on the worldwide panorama. The substantial increase in commercial openness has resulted in a notable rise in the global trade balance, with the ratio of imports and exports growing from 10% in the 19th century to 50% in the current age. Conversely, China currently occupies the leading position as the largest global emitter of carbon dioxide (CO_2). Japan is ranked fifth and South Korea is ranked seventh. Collectively, these three nations accounted for around 34% of the total worldwide carbon dioxide emissions in the year 2019. Based on the substantial amounts of CO_2 emissions, the Chinese, Japanese, and Korean governments have begun to pay close attention to the problem of climate change and related phenomena, according to the British petrolium sustainability report (2020). The adoption of trade openness has greatly enhanced international trade among the three countries, leading to large energy consumption and a notable increase in CO_2 emissions. This phenomenon has given rise to environmental obstacles and has also played a role in fostering economic expansion (Dou et al., 2021).

In recent years, scholars have focused a great deal of emphasis on the problem of climate change, as well as the ramifications that this would have for countries in Africa. African economies have established trade ties not just with one another but also with the international community in order to fulfill their aim of improving the standard of living of their respective populations. The process of liberalizing economies to foreign trade, whether through Free Trade Areas (FTAs), Regional Economic Communities (RECs), or bilateral trade cooperations, does not always happen without environmental repercussions (Can and Gozgor, 2017; Opoku-Mensah et al., 2021). Furthermore, since 1990, Southern Africa has been the region on the African continent with the highest rate of deforestation thanks to the fact that it has been responsible for 31% of the total deforested area in the continent. Deforestation in member states of the Southern African Development Community (SADC) is accountable for 54% of the total biomass carbon losses in the continent. Deforestation and degradation, when combined, lead to carbon emissions that surpass the total emissions from all other sources by over fivefold (Abbas et al., 2022). The region is a suitable selection for this case study due to its prioritization of combating deforestation and minimizing CO_2 emissions as primary objectives for mitigating climate change in the area. The SADC region is notable for its proactive approach in implementing immediate strategies to effectively manage and conserve its forests. It has also enacted legislation to support communities in adapting to climate change and actively participates in campaigns to mitigate the impacts of rising global temperatures and minimize potential harm to the region (Udeagha and Breitenbach, 2023a).

Somalia has had a protracted crisis lasting over three decades, marked by civil unrest and political instability. Consequently, this has led to substantial and detrimental ecological degradation, mainly due to deforestation and the exploitation of natural resources (Warsame et al., 2024). However, environmentally fragile regions such as Somalia have recently encountered frequent climate-induced disruptions, such as droughts, floods, and infestations of locusts. Climate change has the potential to exacerbate Somalia's vulnerability to poverty and food insecurity due to its economic dependence on natural resources and the detrimental effects of human activity, such as charcoal manufacture and overgrazing. The increased vulnerability to drought in rural Somalia results in a substantial reduction in consumption, thereby exacerbating poverty levels. The adverse impacts of climate change on impoverished communities will have extensive ramifications (IMF, 2022). Furthermore, the country has minimal historical or current accountability for the worldwide climate change, yet it faces an unequal share of the consequences from the climate crisis. Climate change-induced droughts, intermittent floods, and invasions of desert locusts lead to a decrease in livestock and agricultural production. These sectors make up more than 70% of the Gross Domestic Product (GDP) and provide employment for a significant number of individuals, both directly and indirectly. The depletion of primary sources of income in local communities is causing a rise in the number of people who are forced to leave their homes and leading to future humanitarian crises. Furthermore, in Somalia, the repercussions of climate change and unpredictability, along with conflicts, are intertwined, impacting the most susceptible demographics (particularly women and children) and communities reliant on natural resources (The Federal Republic of Somalia, 2021). Although Somalia has seen significant environmental degradation, its management of natural resources has deteriorated over time due to a mix of circumstances. The degradation has resulted from widespread deforestation, soil erosion, and decreasing water levels in important rivers. The insufficiency of water supply infrastructure and management has resulted in excessive grazing near water sources, which has expedited soil erosion (Okon and Osaji, 2023).

Given the intricate commercial and environmental conditions in Somalia. The ongoing empirical discourse over the correlation between trade openness and carbon dioxide (CO_2) persists without a conclusive resolution. The empirical studies analyzing the correlation between trade openness and CO_2 can be categorized into two major groups. One branch of research indicates that trade openness has a substantial and favorable impact on CO_2 levels in both the short and long run. Several researchers, such as (Dou et al., 2023; Tabassum et al., 2023; Meşter et al., 2023; Daly and Abdouli, 2023; Omri and Saadaoui, 2023; Udeagha and Breitenbach, 2023b; Sanusi and Dickason-Koekemoer, 2024) have contributed to this body of knowledge. In contrast, the second group indicates that there is a weak and non-significant correlation between trade openness and CO_2, which goes against what was expected. This is evidenced by numerous research studies, including those conducted by (Chhabra et al., 2023; Pata et al., 2023 and Derindag et al., 2023). By investigating this area of research that has not been thoroughly explored, academics and decision-makers can enhance their comprehension of the precise mechanisms by which the level of trade openness influences the release of CO_2 emissions in Somalia. Therefore, this knowledge may be used to guide the creation and execution of evidence-based policies that aim to encourage sustainable economic growth, support environmentally friendly trade practices, and facilitate

the shift towards a green economy in the country. In addition, performing comparison evaluations with other developing nations encountering comparable difficulties could offer significant viewpoints and understandings for Somali policymakers. Given the intricate economic terrain of Somalia, this scholarly pursuit carries substantial significance.

This research examines the impact of trade openness on CO_2 levels in Somalia. The following sections of this article are organized in the subsequent manner. The literature review is provided in Section 2, while Section 3 includes explanations of variables, data sources, and models. Section 4 focuses on the research findings and analyses. The final portion encompasses significant discoveries and the consequential results of the investigation.

2. LITERATURE REVIEW

2.1. Theoretical Review

A substantial amount of attention has been paid in academic study to the correlation between trade openness and carbon emissions. Numerous theoretical models and actual investigations have been conducted to investigate the probable connections between the two. This text provides an analysis of the core theoretical viewpoint.

A major concept that emerged in the early 1990s is the Environmental Kuznets Curve (EKC), which suggests a connection between environmental protection and free trade. The relationship between commerce and environmental degradation was initially investigated by trailblazing scholars, such as (Grossman and Krueger, 1995; Grossman and Krueger, 1991) were among the first to examine the connection between trade and the environment. Among the many notable contributions of Grossman and Krueger (1991) to our understanding of the environmental impacts of NAFTA is the theoretical framework they developed to explore the EKC hypothesis. Alternatively, the pollution haven hypothesis (PHH) put forth by Copeland and Taylor (2017) seeks to elucidate the environmental consequences of commerce. Businesses could be incentivized to relocate their operations to countries with less stringent environmental restrictions if said country has stringent environmental requirements. The abbreviation "PHH" refers to a collection of environmental policies that exhibit a relatively permissive attitude, granting specific countries a competitive edge and causing disruptions in global trade patterns. Trade liberalization can result in the transfer of pollution-intensive industries from developed to developing countries, as the latter have a competitive advantage in this sector. In general, the effect of global trade on pollution is still unclear. In order to gain a thorough understanding of the impact of free trade on the environment, it is crucial to take into account aspects such as the characteristics, extent, and technological methods used (Bhat and Tantri, 2023).

2.2. Empirical Review

A study conducted by (Dou et al., 2023) examines the impact of trade openness on the productivity of carbon dioxide (CO_2) emissions. This research was conducted. A dynamic nonlinear panel model is created by utilizing data from 76 nations covering the time period from 1990 to 2021. In addition to this, a mediation analysis is carried out in order to investigate the fundamental mechanisms that are responsible for the relationship between trade facilitation and carbon productivity. The entire sample is divided into four subsamples in order to investigate the regional differences that exist in the link between trade openness and carbon productivity. One important finding is that trade openness has a U-shaped relationship with carbon productivity, meaning it significantly affects the two variables. More precisely, carbon productivity initially declines and then improves after reaching a particular level of trade openness. (2) The association between trade openness and carbon productivity is found to be significantly mediated by energy intensity and the mix of energy consumption. (3) The relationship between trade openness and carbon productivity differs among countries.

This study, conducted by Dauda et al. (2021) examines the relationship between innovation and carbon dioxide (CO_2) emissions in nine (9) African nations from 1990 to 2016, using both panel and individual country data. The variables were shown to be stationary when the cross-sectional augmented Dickey Fuller (CADF) panel unit root test was applied. Westerlund and Johansen cointegration tests were used to identify enduring relationships among the variables. The study conducted its analysis by employing a fixed effect model and generalized technique of moments for the panel, and ordinary least squares for individual countries. The results confirmed the presence of a curvilinear relationship between innovation and CO_2 emissions at the panel level, particularly in Mauritius, Egypt, and South Africa. At the panel level, the implementation of renewable energy was discovered to decrease CO_2 emissions. Likewise, the existence of human capital was associated with a reduction in CO_2 emissions both at the panel level and in specific nations. Furthermore, the results substantiated the pollution refuge concept and pollution halo effect. Moreover, the Environmental Kuznets Curve was confirmed at the panel level in four out of the nine nations.

(Van Tran, 2020) examines the dynamic correlation between trade openness and environmental contaminants while taking into consideration potential factors that influence environmental quality in 66 developing nations from 1971 to 2017. The analysis makes use of the robust two-step generalized method of moments estimators with a finite sample adjustment in order to improve the accuracy of the analysis presented. The main empirical findings can be stated as follows: (1) Trade openness may have a negative effect on the environment, which aligns with the hypothesis of an environmental Kuznets curve. (2) An escalation in pollutants including carbon dioxide emissions, ambient particulate matter, and nitrous oxide emissions during the preceding period is associated with a rise in pollutants in the future. This suggests that if no measures are taken to decrease pollutants, environmental conditions may deteriorate. (3) Energy consumption, financial development, and industrialization are major factors that greatly contribute to environmental damage.

The data gathered from World Bank indices (Sun et al., 2020) was analyzed using a panel cointegration model to examine the link between carbon emissions, energy consumption, economic development, and trade openness in sub-Saharan African nations. The investigation uncovered a durable cause-and-effect

relationship between CO_2 emissions, energy usage, economic expansion, and trade accessibility. The study examined the existence of the Environmental Kuznets Curve (EKC) in the panel by including the squared trade openness element. It was found that increased trade openness has a detrimental impact, suggesting that environmental contamination in this area will decrease to some degree over time. The study findings indicate that in order to achieve sustainable growth in sub-Saharan Africa while reducing environmental difficulties, it is imperative to implement stringent policies and execute them effectively.

A study was conducted on 10 Asian economies between 1995 and 2018 to investigate the impact of characteristics such as energy efficiency, technological progress, trade openness, and institutional quality on environmental conditions. The objective of this study was to tackle the issue of rising pollution levels in spite of economic progress. Collaborative integration and cross-sectionally augmented autoregressive distributed lag models are some of the advanced statistical tools used in the study. The results indicate that greater trade openness and improved institutional quality are linked to a decrease in environmental quality. Conversely, enhanced energy efficiency and technical advancements are associated with a positive influence on environmental quality. Based on these results, Asian economies may better foster a sustainable environment by investing in technical innovations and improving the quality of their institutions. In order to improve environmental quality, the paper recommends implementing energy efficiency programs and trade-related environmental regulations (Wenlong et al., 2023).

Wang and Zhang (2021) conducted a study to assess the impact of protectionism, measured by trade openness, on the relationship between carbon emissions and economic development in 182 countries from 1990 to 2015. The findings reveal diverse effects of trade liberalization on carbon emissions across different socioeconomic groups. Countries with high and upper-middle incomes experience a reduction in carbon emissions due to increased trade openness. Nevertheless, the impact of increased trade on nations with lower-middle-income is little, and it actually exacerbates carbon emissions in countries with low-income. Moreover, the study demonstrates that the increase in individual incomes and population magnitude impedes the differentiation of economic growth from carbon emissions. However, the process of decoupling is strengthened in all nations as a result of the implementation of renewable energy and the existence of elevated oil prices.

The effect of trade liberalization on regional carbon emissions from 1970 to 2019 is examined in this research. The objective is to understand the underlying mechanisms that impact this association. The study provides vital insights into the intricate impact of trade openness on carbon emissions. It distinguishes the varied effects of imports and exports on emissions within specific countries. The findings reveal several significant observations. The research demonstrates a direct association between trade openness and carbon emissions, suggesting that greater levels of trade lead to a rise in greenhouse gas emissions. Nevertheless, the study indicates that there is a decline in influence once the trade agreement is put into place, indicating a possible method of controlling the environmental consequences of heightened trade (Dou et al., 2021).

The study examines the impact of economic variables, such as GDP growth, trade, and foreign direct investment (FDI), on carbon dioxide (CO_2) emissions in Latin American countries facing economic stagnation. It compares the effects of these outcomes with those in more affluent countries like Singapore, the United States, South Korea, and China. There is a strong and positive relationship between the Gross Domestic Product (GDP), Foreign Direct Investment (FDI), trade, and carbon dioxide (CO_2) emissions in wealthier countries. Nevertheless, this association is less prominent in countries that follow the MIT model. The study suggests that countries affiliated with the MIT group should focus on specific criteria to effectively navigate their development trajectory. Furthermore, research has established that foreign direct investment (FDI), growth in gross domestic product (GDP), and trade have the potential to improve environmental conditions by reducing carbon dioxide (CO_2) emissions. In contrast, sectors such as tourism and education have a minimal impact on the environment. This study provides valuable insights for policymakers aiming to develop sustainable and growth-focused strategies for nations categorized as MIT (Galvan et al., 2022).

The study conducted by (Zafar et al., 2019) examines the division of energy consumption between renewable and nonrenewable sources and assesses its impact on carbon dioxide (CO_2) emissions. Additionally, it takes into account the impact of trade openness on this correlation by utilizing the framework of the environmental Kuznets curve (EKC). The analysis centers on the categorization of developing economies from 1990 to 2015 based on the Morgan Stanley Capital International (MSCI) classification. This study utilizes a cross-sectional dependence (CD) test and a second-generation panel unit root test to provide precise estimation. The Pedroni and Westerlund panel cointegration tests are utilized to examine the condition of long-term equilibrium. The study employs the Continuously Updated Fully Modified (CUP-FM) and Continuously Updated Bias-Corrected (CUP-BC) methods to examine long-term output elasticities. In addition, the Vector Error Correction Model (VECM) is used to identify the causal relationships between the variables. The data suggest that the utilization of renewable energy contributes to an increase in CO_2 emissions, while the utilization of nonrenewable energy leads to a decrease in CO_2 emissions. The study also offers evidence in favor of the Environmental Kuznets Curve (EKC) hypothesis. Trade openness has a detrimental effect on CO_2 emissions, which play a vital role in these nations' pursuit of globalization. Moreover, there exists a direct correlation between the long-term usage of renewable energy and economic growth, as well as the emission of CO_2, the use of nonrenewable energy, and the degree of trade openness. Renewable energy has a causal effect on short-term economic growth, while economic growth has a causal effect on nonrenewable energy. In addition, the study conducted by (Muhammad et al., 2022) investigates the influence of carbon emissions, real oil prices, income inequality, economic growth, and trade openness on the adoption of sustainable energy in twenty-three (23) OECD nations. In order to verify the existence of a long-term equilibrium, the investigation makes use of the

Westerlund panel cointegration methodology. Additionally, the Augmented Mean Group (AMG) estimator is utilized in order to investigate the long-term correlation among the factors, taking into account variations in slopes and interconnections among varied sectors. Furthermore, the Dumitrescu and Hurlin (DH) panel causality analysis is employed to assess the causative relationship between the variables. Our research findings demonstrate a clear correlation between the consumption of renewable energy (REC) and economic advancement, actual oil prices, disparity in wealth, and the level of trade openness in member countries of the Organization for Economic Cooperation and Development (OECD). However, a negative correlation is shown between renewable energy consumption (REC) and carbon dioxide (CO_2) emissions in these countries. Furthermore, it has been observed that there is a unidirectional relationship between GDP per capita and the adoption of sustainable energy, while a reciprocal relationship exists between economic disparity and the utilization of renewable energy.

A noteworthy finding is the validation of the Environmental Kuznets Curve (EKC) hypothesis in Turkey, India, China, and South Korea. This suggests the presence of a non-linear relationship between economic progress and environmental degradation in these countries. At the outset, when there is an increase in economic prosperity, there is a corresponding decline in environmental quality. However, once a certain threshold of economic development is reached, the quality of the environment begins to enhance. These findings provide policymakers with vital knowledge to design sustainable strategies for reducing carbon emissions and promoting economic growth in less developed countries. Policymakers can effectively devise solutions to tackle environmental issues and foster economic growth by understanding the elements and mechanisms that impact CO_2 emissions.

3. METHODOLOGY

3.1. DATA

The research utilizes yearly data spanning from 1980 to 2021. Data was gathered from a variety of sources, including the World Bank's World Development Indicators (WDI) and SESRIC from the OIC (Table 1). The study uses the to assess the causes of carbon dioxide emission as the dependent variable. It also incorporates independent variables like trade openness, energy consumption, foreign direct investment (FDI), gross domestic product (GDP), and population growth to explore their relationships with the dependent variable. Trade openness reflects the level of economic integration with the global market which include export and imports. FDI inflows represent foreign investment received by the country, while GDP indicates economic production at current prices. Energy consumption represents energy consumption (% of total energy consumption. FDI investment in assets like machinery and equipment and the yearly population growth rate is another way to measure population growth.

3.2. Econometrics Technique

The Augmented Dickey-Fuller (ADF) test was employed to carry out the unit root test. An assessment was made on the outcomes of the constant and probability examinations. The unit root estimation encompass analyzing both the hypothesis of a unit root and the alternative hypothesis of a stationary (or trend stationary) time series (Zabri and Abu Bakar, 2022).

Table 1: Data and sources

Symbols	Variables	Measurements	Sources
CO_2	Carbon emissions	Kilotons	SESRIC data
TOP	Trade Openness	P trade (% GDP)	SESRIC data
ENERGY-CON	Energy consumption	Renewable energy consumption (% of total energy consumption)	World Bank
RGDP	Real Gross Domestic Products	Constant 2015 Prices, annual change	World Bank
FDI	Foreign Direct Investment	Millions of dollars	World Bank
POP-GROWTH	Population growth	Growth Rate of Population, Annual %	SESRIC data

Sources: Computed by authors (2024)

Following this, the co-integration test is utilized to evaluate the determined connection among the variables. As outlined in the cointegration theory proposed by Engle and Granger (1987), the ability to integrate non-stationary variables in a linear fashion to produce stationary variables allows for the establishment of a linkage between said variables. Shahbaz et al. (2015) have highlighted criticisms regarding the traditional methodologies. These criticisms suggest that these methods exhibit a tendency to favor not rejecting the null hypothesis, lack homogeneity when handling variables with varying integration orders, yield very deceptive outcomes, and are extremely inaccurate when used to small sample sizes. Therefore, it is essential to create an adjustment for fundamental principles. Therefore, to improve the effectiveness of test power, a more powerful co-integration method called autoregressive distributed lag (ARDL) bounds testing is used.

The study employs the Autoregressive Distributed Lag (ARDL) model, which was introduced by Pesaran et al. (2001) and is more efficient than previous cointegration methods (Menyah and Wolde-Rufael, 2010; Panopoulou and Pittis, 2004). The ARDL model is appropriate for examining the enduring connections and immediate fluctuations between variables. The unit root test was employed to confirm that no variable surpassed the level of integration, which is essential to prevent wrong regression (Dickey and Fuller, 1979). The ARDL model incorporates both stationary and non-stationary variables in the analysis, utilizing the ADF unit root test to establish stationarity. The Autoregressive Distributed Lag (ARDL) model is a widely used econometric method for examining the correlation between variables in both the short and long term. It is especially beneficial for rational selection of this method is when the variables being examined are integrated at different orders, such as I (0) or I (1). Below is a systematic method for the logical selection and estimation of an ARDL model. This makes it well-suited for analyzing time series data. The study utilized an ARDL model, which may be described in the following manner.

$$\Delta LCO2_t = \alpha_0 + \beta_1 LTOP_{t-1} + \beta_2 LENERGY - CON_{t-1} + \beta_3 LRGDP_{t-1} + \beta_4 LFDI_{t-1} + \beta_5 POP - GROWTH_{t-1} + \sum_{i=0}^{q} \Delta\alpha_1 LTOP_{t-k} + \sum_{i=0}^{p} \Delta\alpha_2 LTOP_{t-k} + \sum_{i=0}^{p} \Delta\alpha_2 ENEGGY - CON_{t-k} + \sum_{i=0}^{q} \Delta\alpha_3 LRGDP_{t-k} + \sum_{i=0}^{q} \Delta\alpha_3 LFDI_{t-k} + \sum_{i=0}^{q} \Delta\alpha_4 POP - GROWTH_{t-k} \varepsilon_{t-k}$$

Where α_0 is the constant, α_1-α_3 are the coefficient of the short-run variables, β_1, β_2, β_3, β_4 and β_5 are the elasticities of long-run parameters, q indicates the explained optimal lags, p shows the optimal lags of the explanators, Δ is the first difference sign showing short-run variables, and εt is the error term.

The ARDL co-integration method begins with bound testing and subsequently undergoes regression analysis using Ordinary Least Squares (OLS). The null hypothesis, denoted as H0: $\beta_1=\beta_2=\beta_3=\beta_4$, posits that the variables do not exhibit co-integration in the long term, while the alternative hypothesis, denoted as H1: $\beta_1\neq\beta_2\neq\beta_3\neq\beta_4\neq\beta_5\neq0$, suggests that the variables are co-integrated in the long term. The null hypothesis was evaluated by employing the Wald-F statistics and critical values. If the Wald F statistics exceed the upper bound critical values, the null hypothesis is rejected, indicating a long-term connection between the variables. Conversely, if the Wald F statistics do not surpass the upper bound critical values, the null hypothesis is accepted, implying the absence of a long-term connection between the variables. Additionally, this study utilizes Fully Modified OLS (FMOLS), Dynamic OLS (DOLS), and Canonical Cointegrating Regression (CCR) to confirm the long-term findings of the ARDL model, as seen in previous research.

The empirical specifications for the model can be quantified as:

$$LCO_{2t} = \beta_0 + \beta_1 LTOP_t + \beta_2 ENG\text{-}CON + \beta_3 LRGDP_t + \beta_4 LFDI_t + \beta_5 POP_t + \varepsilon_t$$

Where LCO_{2t} the dependent variables, where $LTOP_t$, ENG-CON $_t$, $LRGDP_t$, $LFDI_t$, and POP-G_t the explanatory variables in year t, ε_t is the error term, and β_0, β_1, β_2, β_3, β_4 and β_5 are the elasticities to be estimated.

LCO_2 represents the natural logarithmic representation of carbon dioxide emissions at time t. LTOP represents the natural logarithmic representation of trade openness at time t. LRGDP represents the natural logarithmic representation of Gross domestic product at time t. LFDI represents the natural logarithmic representation of foreign direct investment inflow at time t, population growth rate at time t.

4. RESULTS AND DISCUSION

4.1. Descriptive Statistics

A comprehensive analysis of the properties of the data series was carried out by means of descriptive statistics, which are described in Table 2. As shown in Table 2, the average values for carbon emissions (13.35), trade openness (4.14), energy consumption (3.61), real gross domestic product (21.36), FDI (15.28), and population growth (2.79). Significantly, Foreign Direct Investment (FDI), Local and Regional Gross Domestic Product (LRGDP), and Carbon Dioxide (CO_2) exhibit the most elevated peak values, reaching 22.81, 21.70, and 13.81, correspondingly. Carbon dioxide, energy consumption, and LFDI display positive skewness, indicating a distribution with a longer tail on the right side. On the other hand, trade openness, LRGDP, and population growth demonstrate negative skewness, suggesting a distribution with a longer tail on the left side. Moreover, trade openness, foreign direct investment, population growth, and carbon dioxide in Somalia are negatively correlated, according to Table 3's correlation analysis. Conversely, variables encompass energy usage, while RGDP demonstrates a positive correlation with carbon dioxide emissions.

4.2. Unit Root Tests

The following Table 3 displays the outcomes of unit root tests, potentially Augmented Dickey-Fuller tests, conducted on a set of variables in both their original form and their initial changes. These evaluations are conducted both with and without trends being incorporated into the context. Here is an analysis of the outcomes. In addition, the results of the ADF unit root test indicate that the t-statistics for variables such as level, trade openness, energy consumption, LRGDP, and LFDI do not surpass the critical thresholds required to reject the null hypothesis of a unit root. This suggests that these variables are non-stationary, as evidenced by their high P-values exceeding 0.05. The variables of CO_2 emission and population increase show significant t-statistics (−4.1477 and −4.4113, −4.0557 and −4.3703) with corresponding P-values of 0.0058 and 0.0064. In addition, following the application of first differencing, all variables exhibit statistically significant t-statistics and possess P-values that are below 0.05. This indicates that it is possible to reject the null hypothesis of a unit root. Therefore, it may be inferred that these variables achieve stationarity following a single differencing operation. Overall, the outcomes of the ADF test indicate that, with the exception of rainfall, the variables are not stationary at their original levels but become stationary after the initial differencing. Differencing is necessary to ensure stationarity in all variables, which is a crucial prerequisite for doing time series analysis.

4.3. Long Run Cointegrations Tests

This study examines an unconstrained model by employing the ARDL co-integration test. The evaluation utilizes the F-statistics test to evaluate the collective hypothesis that all coefficients within the lagged long run are equivalent to zero. The results are presented in the table provided below. The results offer empirical proof that supports the statistical verification of the long-term co-integration of the variables. The results indicate that the computed F-statistics of 15.284685 surpass the threshold value of 3.38 at a significance level of 5% (Table 4). The findings demonstrate a significant and enduring correlation between carbon dioxide emissions, trade openness, energy consumption, foreign direct investment, real gross domestic product, and population increase within the setting of Somalia.

Table 2: Descriptive statistics and correlation

Variables	LCO_2	LTOP	ENG-CON	LRGDP	LFDI	POP-G
Mean	13.3551	4.14907	3.61467	21.365	15.280	2.7992
Median	13.3296	4.32860	3.41059	21.529	14.556	3.4621
Maximum	13.8191	4.80128	5.91506	21.705	22.818	8.9400
Minimum	12.5238	2.91017	2.25315	19.831	9.2103	−4.5200
Standard Deviation	0.23546	0.51934	1.02945	0.4938	3.4888	2.3038
Skewness	0.437410	−0.978293	0.75449	−2.4389	0.5882	−1.1824
Kurtosis	5.509901	2.76546	2.76058	7.5826	2.8199	6.1591
Jarque-Bera	12.36360	6.79566	4.08511	78.388	2.4786	27.253
Probability	0.002067	0.03344	0.12969	0.0000	0.2895	0.0000
Correlation						
L CO_2	1					
LTOP	−0.22837	1				
ENG-CON	0.27079	0.17192	1			
LRGDP	0.078818	−0.22570	−0.09346	1		
LFDI	−0.09584	0.52564	−0.15487	−0.59513	1	
POP-G	−0.33428	0.20205	0.04924	−0.14963	0.04153	1

Sources: Computed by Authors (2024)

Table 3: ADF unit root test results

At level				
	With constant		With constant and trend	
Variables	*T*-Statistic	Prob	*T*-Statistic	Prob
LCO_2	−4.1477	0.0023	−4.4113	0.0058
LTOP	−2.2838	0.1818	− 2.3257	0.4112
LENG CON	−1.5565	0.4953	−1.2733	0.8806
LRGDP	−0.9063	0.7763	−1.6320	0.7626
LFDI	−1.1909	0.6693	−1.9082	0.6321
LPOP-G	−4.0557	0.0029	−4.3703	0.0064
At first difference				
Variables	*t*-Statistic	Prob.	*t*-Statistic	Prob.
d (L CO_2)	−4.5659	0.0008	−4.2410	0.0095
d (LTOP)	−6.8732	0.0000	−6.8760	0.0000
d (ENG CON)	−6.3064	0.0000	−6.5589	0.0000
d (LRGDP)	−6.6287	0.0000	−6.9333	0.0000
d (LFDI)	−5.9810	0.0000	−5.9985	0.0001
d (POP-G)	−6.3063	0.0000	−6.2162	0.0000

Sources: Computed by authors (2024)

Table 4: F-bounds test

Model: LCO_2=f (L TOP, ENERGY-CON, LRGDP, LFDI, POPGROWTH)		K=5	
Test Statistic	Value	Significant	I (0)	I (1)
F-statistic	15.284685,	1%	3.06	4.15
		5%	2.39	3.38
		10%	2.08	3

Sources: Computed by Authors (2024)

4.4. ARDL Results

The ARDL results displayed in Table 5 provide useful insights into the long- and short-term correlations among the variables examined in this research endeavor. The coefficients provide insight into the relationship between the dependent variable (carbon emissions) and the independent factors over a prolonged duration. The statistical significance of the coefficients for carbon dioxide and trade openness, which are 0.18 and 0.0167 respectively at a significance level of 0.05, indicates that a one percent increase in trade openness results in an 18% rise in carbon emissions. In contrast, the coefficient of the real gross domestic product (RGDP) in Somalia shows a statistically insignificant negative correlation

Table 5: Long and short run results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LTOP	0.188055	0.073586	−2.555590	0.0168
ENE CON	−0.174234	0.073137	−2.382305	0.0248
LFDI	0.134038	0.056407	2.376241	0.0271
LRGDP	−0.000582	0.012622	−0.046120	0.9637
POP-G	−0.227175	0.040003	5.678949	0.0296
ECM (-1)	−0.640562	0.174813	−3.664271	0.0011
Short Run				
D (LTOP)	−0.066145	0.022629	−2.923051	0.0087
D (ENE CON)	−0.192606	0.034375	−5.603085	0.0000
D (LFDI)	0.018863	0.005459	3.455246	0.0027
D (LRGDP)	−0.027523	0.088426	−0.311248	0.7581
D (POP-G)	−0.019602	0.006164	−3.180157	0.0049
C	7.895686	1.455722	5.423899	0.0000
R2	0.980			

Sources: Computed by Authors (2024)

of -0.000582 at a significance level of 0.05. This highlights the significant influence of economic growth on carbon emissions, resulting in a long-term detrimental effect of 0.058%. Similarly, the correlation between energy consumption and population growth in Somalia shows that as population increases, there is a negative effect on carbon emissions and environmental sustainability in the long term. This means that even small increases of one percent in energy consumption and population growth result in declines of 17% and 0.22% in carbon emissions, respectively. The repercussions of these factors, which involve the prevalent utilization of conventional biomass sources like firewood and charcoal, accounting for over 90% of Somalia's total energy consumption, substantially contribute to its emissions profile. The Somali economy is currently undergoing a period of recuperation and expansion, mostly driven by carbon-intensive sectors such as agriculture, cattle, and fishing. Nevertheless, this expansion is concurrently generating an increased need for energy, which is projected to exacerbate emissions unless there is a transition towards sustainable energy sources.

Furthermore, the coefficient associated with foreign direct investment (FDI) exhibits a somewhat significant positive correlation of 0.13 at a significance level of 0.05. This suggests

that there is a correlation between a rising trend in foreign direct investment and a very small 13% rise in Somalia's carbon emissions over a period of time. In the long term, there is a significant and strong negative relationship between the coefficient of population growth rate and carbon emissions. The findings underscore the substantial impact of population expansion in Somalia on carbon emissions.

The Error Correction Mechanism (ECM) coefficient, shown as -1, quantifies the rate at which a system reestablishes its long-term equilibrium after a disruption. The presence of a significant negative coefficient of -0.64 indicates that the system is actively moving towards a state of equilibrium, and any deviations from this equilibrium are gradually being corrected. The short-term analysis reveals a positive correlation between the coefficients of the D(LFDI) variable and carbon dioxide emissions in Somalia. This implies that a rise in foreign direct investments results in a temporary increase in carbon emissions by 1.88%. In contrast, the inverse relationship between trade openness, energy consumption, real GDP, and population growth and carbon dioxide emissions in the short term context of Somalia is indicated by the negative coefficients. Specifically, a rise in these variables will result in a drop in carbon dioxide emissions by 6.6%, 19%, 2.7%, and 1.9% respectively. The statistical significance of the intercept term (C) indicates that it represents the fundamental level of carbon dioxide emissions when all independent variables are at zero. Finally, the coefficient of determination (R2) is 0.98, indicating that the model accounts for 98% of the variability in the dependent variable.

4.5. Diagnosis Tests

According to the results of the diagnostic assessment in Table 6, the Normality test produces a value of 0.4786 and a corresponding probability of 0.3057. This indicates that the mistakes in the model appear to follow a normal distribution. The heteroscedasticity test yields a result of 2.403844, with a probability of 0.3006, suggesting that there is not significant evidence to support the presence of homoscedasticity in the model. In the same way, the assessment of autocorrelation yields a value of 0.831 and a probability of 0.4468, indicating that there is no evidence of serial correlation within the errors. The Ramsey RESET test yields a value of 1.2442, accompanied by a probability of 0.2793. The stability results demonstrate that the model is stable and exhibits a good match. Based on the CUSUM and CUSUM square graph shown in Figure 1, there is no significant evidence of omitted variables in the model. Overall, the diagnostic checks provide solid evidence for the reliability and suitability of the model used in this work, allowing for confident inferences to be made about the correlation between trade openness and carbon emissions in Somalia. The outcomes of the normality, heteroscedasticity, autocorrelation, and Ramsey RESET tests suggest that the model is accurately defined and does not have any serious statistical problems. This ensures that the findings may be relied upon to influence policy and economic decisions with confidence.

Table 6: Diagnosis tests

Diagnostic check	Value	Probability
Normality Test	0.4786	0.3057
Heteroscedasticity test	2.403844	0.3006
Autocorrelation LM test	0.831	0.4468
Ramsey RESET test	1.2442	0.2793

Sources: Computed by authors (2024)

4.6. Cointegration Analysis

The results of the Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR) analyses are displayed in Table 7. The long-term relationships among the variables, namely trade openness (LTOP), energy consumption (ENR CON), real GDP (LRGDP), foreign direct investment (LFDI), population growth (POP-G), and a constant (C), are determined using the following methodologies.

The results shown in Table 7 depict the coefficients and corresponding probability of FMOLS, DOLS, and CCR models, which examine the relationships between trade openness and carbon emissions. In the FMOLS model, the coefficient associated with trade openness is −0.09, indicating that a 1% increase in trade openness leads to a 0.09% decrease in CO_2 emissions. Similarly, the coefficient for population growth is −0.035, indicating a negative correlation with carbon dioxide emissions. This suggests that a 1% increase in population leads to a 0.035% decrease in CO_2 emissions. The coefficients for energy consumption, RGDP, and FDI in FMOLS are 0.107, 0.080, and 0.083, respectively. This suggests that these factors have a positive impact on CO_2 emissions. The coefficients seen in DOLS and CCR typically display a comparable pattern to FMOLS, albeit with slightly different magnitudes. The coefficient associated with trade openness is estimated to be approximately −0.161663 in DOLS and −0.100174 in CCR. This indicates a significant negative impact on CO_2 emissions, consistent with FMOLS. In Somalia, the coefficients for energy consumption, RGDP (Real Gross Domestic Product), and FDI (Foreign Direct Investment) have a strong positive effect on CO_2 emissions. This is shown in both DOLS (Dynamic Ordinary Least Squares) and CCR (Cointegrated Vector Regression) models, which are parallel to FMOLS (Fully Modified Ordinary Least Squares). The study's cointegration estimators highlight the long-lasting relationships between trade openness and CO_2 emissions in Somalia. The R-squared values (0.954 for FMOLS, 0.993 for DOLS, and 0.972 for CCR) indicate that these models effectively explain a large portion of the variation in carbon dioxide emissions by considering trade openness and other factors. This highlights the reliability of the cointegration estimators in accurately capturing the long-lasting relationships between the variables.

4.7. Results and Discussions

Our analysis discovered a favorable and enduring correlation between trade openness and environmental quality, indicating that heightened trade is likely to have harmful consequences. Greater trade openness in Somalia can result in unregulated exploitation of natural resources, including overfishing and deforestation for charcoal production. This can also lead to the transfer of polluting carbon emissions, posing a significant risk to the country's natural assets and ecological systems. In the absence of effective regulation, the growth of commercial farming for the purpose of exporting goods may result in the devastation of natural habitats, degradation of soil, and scarcity of water resources. In the lack

Figure 1: CUSUM and CUSUM square

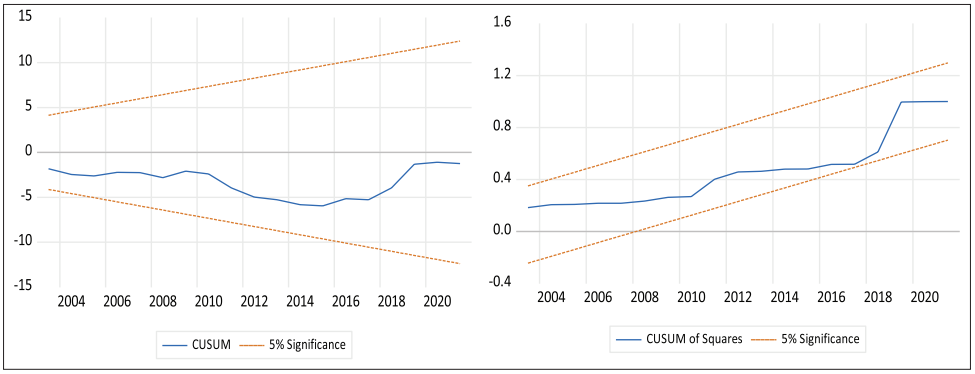

Table 7: FMOLS, DOLS, and CCR results

Variable	FMOL		DOLS		CCR	
	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob
LTOP	0.099378	0.2195	0.161663	0.008	0.100174	0.2493
ENR CON	0.107476	0.0037	0.105786	0.003	0.097851	0.0060
LRGDP	0.080823	0.3529	0.116602	0.024	0.076588	0.4002
LFDI	0.083240	0.0000	0.022274	0.019	0.017805	0.2484
C	11.46888	0.0000	10.86632	0.000	11.61326	0.000
R2	0.954		0.993		0.972	

Sources: Computed by Authors

of sufficient environmental protections, the growth of industrial activities and urbanization caused by commerce may exacerbate pollution of the air, water, and soil. However, trade liberalization has the potential to promote the adoption of environmentally friendly technologies and sustainable management practices, leading to improved resource efficiency and reduced environmental consequences. These findings are consistent with the studies conducted by (Wang et al., 2024; Safi et al., 2023; Liu et al., 2021;Wen et al., 2020; Essandoh et al., 2020). In addition, the study discovered a long-term inverse correlation between carbon dioxide (CO_2) emissions and energy consumption. This implies that higher levels of energy consumption worsen the effects of climate change, negatively impacting the quality of the environment in the long term. This finding aligns with the research conducted by Adebayo et al. (2022), who indicated that energy usage had a negative impact on CO_2 emissions in Sweden. Moreover, the research demonstrates a persistent negative correlation between economic growth and carbon emissions in Somalia over an extended period of time. This critical topic has a major effect on both the sustainability of the environment and economic policies. The intricate relationship between environmental degradation and economic progress is shaped by multiple factors, such as the agricultural consequences of climate change. Somalia, which heavily relies on agriculture and livestock, is particularly affected by this. Additionally, Somalia's reliance on inefficient and carbon-intensive energy sources exacerbates the negative impacts of CO_2 emissions on the economy. The results demonstrate a negative association between these two factors. These findings align with Olaoye (2024), research, which shown that higher GDP levels have negative effects on environmental quality, particularly in terms of increased carbon dioxide emissions in certain African countries. In contrast, foreign direct investment has a favorable long-term effect on CO_2 emissions, highlighting the essential importance of sufficient FDI in maintaining environmentally friendly nations. This finding corroborates the research conducted by Boubacar et al. (2024), which demonstrated a positive correlation between increased foreign direct investment (FDI) and carbon dioxide emissions in Africa. Furthermore, there is a negative correlation between the growth of the rural population (RP) and environmental quality in Somalia. This suggests that as the rural population increases, there is a corresponding increase in carbon emissions. This corroborates the findings of Ayompe et al. (2020), who emphasized the possibility of rural population growth leading to adverse environmental productivity due to escalated energy use, deforestation, and nomadic practices.

In the near term, the detrimental impact of D(LTOP) on CO_2 emissions implies that international trade has a temporary deleterious effect on CO_2 emissions. This may be attributed to exports that involve cattle and charcoal, as well as imports of fossil fuels, which contribute to continued growth in CO_2 emissions. Nevertheless, the immediate benefits are probably offset by enduring alterations in climate and the ecosystem. Some research (Lanhui and Ibrahim, 2024) have acknowledged similar immediate adverse impacts of CO_2. The immediate favorable effect of foreign direct investment on carbon dioxide emissions, along with the possibility of attracting foreign direct investment (FDI) in Somalia's environmental sector, has the potential to promote sustainable economic growth in the long term. However, reaching this goal requires a methodical and coordinated approach to efficiently utilize foreign resources and knowledge in order to attain positive results in sustainable development. This verdict aligns with the findings of Khan et al. (2023), who concluded that an increase in foreign direct investment directly results in improvements in productivity. These advantages can have a major impact on the relationship between Foreign Direct Investment (FDI) and carbon dioxide (CO_2) emissions in Somalia. The enhanced efficiency brought about by Foreign Direct Investment

(FDI) can facilitate the optimal usage of resources and the adoption of environmentally friendly technology, therefore mitigating CO_2 emissions. Nevertheless, in the absence of sufficient environmental policies, the rise in economic activities could potentially lead to an escalation in emissions. In contrast, carbon emissions are negatively affected in the short term by changes in real GDP, energy consumption, and population expansion.

An upsurge in real GDP frequently results in an escalation in energy consumption as a consequence of the expansion of economic activities in the immediate term. This process can lead to a substantial rise in CO_2 emissions when the main sources of energy are derived from fossil fuels. Moreover, the increase in population might worsen this pattern by amplifying the need for energy, transportation, and industrial operations, all of which contribute to the surge in carbon emissions, as seen Minh et al. (2023). The results obtained from the co-integration estimations (FMOLS, DOLS, and CCR) strongly validate the long-term correlations established in the ARDL model.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study examines the effects of trade openness on carbon emissions in Somalia from 1980 to 2021, considering that Somalia's economy mainly depends on exporting items including cattle, charcoal, and raw agricultural products, which contribute significantly to carbon emissions. The study employed various econometric methodologies, such as Autoregressive Distributed Lag (ARDL), full modified Ordinary Least Squares (FMOLS), dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR), to investigate the immediate and long-term correlation between trade openness and carbon dioxide emissions in Somalia. The ARDL model captures the dynamic adjustments and cointegration between variables, allowing for the investigation of both short-term and long-term effects. Employing the FMOLS technique is crucial for obtaining robust long-term estimates as it effectively addresses endogeneity and serial correlation concerns. The inclusion of leads and delays of the differenced explanatory variables in DOLS helps to improve the accuracy of the long-run coefficients and address any potential issues with endogeneity. Ultimately, the CCR approach is utilized to ensure the coherence and effectiveness of the cointegration estimations, so facilitating a comprehensive understanding of the relationship between trade openness and carbon emissions. The study employs a range of tests, including unit root tests, correlation analysis, descriptive statistics, cointegration tests using F-statistics, short-run error correction modeling, and diagnostic tests, to assess the effects of trade openness, energy consumption, real gross domestic products, foreign direct investment, and population growth on carbon dioxide emissions in Somalia, both in the short and long term.

The ADF unit root test results show that energy consumption, LRGDP, LFDI, and trade openness are not stable at the level, but carbon dioxide emissions and population growth are stationary. This indicates that carbon emissions and population increase are interconnected at a fundamental level (I (0)). However, the primary distinction is defined by the lack of a unit root, as all variables exhibit stationarity. The complexity of the variables is highlighted by the amalgamation of integrated orders (1) and (0). The cointegration test conducted in Somalia reveals a persistent relationship between the degree of trade openness and the level of carbon emissions over an extended period of time. It is important to highlight that the data demonstrate that a rise in carbon emissions significantly impedes trade openness. The results of all models, including ARDL, FMOLS, DOLS, and CCR, confirm the existence of long-term correlations between carbon emissions and other independent variables. In the short run, there is a negative correlation between trade openness, energy consumption, real GDP, and population growth in Somalia. This indicates that these factors have harmful effects on carbon emissions. The model's reliability is validated by diagnostic tests, which indicate the absence of serial correlation, heteroscedasticity, and normality concerns. This study examines the relationships between the degree of trade openness and the amount of carbon emissions in Somalia. The increased stability of the model enhances confidence in the accuracy of the findings, providing significant insights to policymakers and stakeholders dealing with the issues of international trade and environmental quality in Somalia.

5.2. Practical Implication of the Study

Understanding the relationship between trade openness and carbon emissions is crucial for developing effective environmental policy. The results can assist policymakers in developing policies that promote sustainable trading practices. For example, implementing stricter environmental standards on exported goods, especially those such as cattle and charcoal that have significant carbon footprints, can mitigate negative environmental impacts.

The research suggests that expanding the economy into industries with reduced carbon emissions can contribute to long-lasting sustainable development. Allocating funds towards renewable energy, ecotourism, and other industries with low carbon emissions has the potential to create innovative economic opportunities while reducing environmental damage. Conversely, the results of the study can provide direction for trade agreements and international joint efforts. By aligning its trade policies with international environmental standards, Somalia can improve its ability to compete in global markets and attract foreign investments in green technologies. Collaborating with international partners can provide technical and financial support for implementing sustainable practices in Somalia.

5.3. Study Limitations and Recommendations for Future Research

The study included data spanning from 1980 to 2021, which may have been limited in terms of accessibility. Future study could benefit from longer time series or more comprehensive data sources. The research focused on analyzing the impact of trade openness, energy consumption, RGDP (Real Gross Domestic Product), FDI (Foreign Direct Investment), population growth, and carbon emissions on the studied phenomenon. However, it did not consider other potential elements that could also

influence the phenomenon, such as technical innovation, global economic shifts, climate change, and policy changes. Enhanced understanding could be attained by expanding the range of variables. A more extensive longitudinal research could provide a deeper understanding of the linkages as they develop over time, considering potential fluctuations in economic, environmental, and social factors. Further investigation that employs advanced causal inference approaches may lead to more significant findings. The study's findings are specific to the setting of Somalia and may not be universally relevant to other locations or countries. Comparative studies and cross-country analysis have the potential to shed light on broader patterns. Although the ARDL model is extensively utilized, it is not without its drawbacks. Future study could explore alternative models or employ more advanced econometric approaches to enhance the analysis's robustness. It is crucial to explore different mitigation measures in order to reduce the carbon footprint of trade, as suggested by the research. Future study should explore the possibilities of sustainable trade practices, improvements in energy efficiency, and the use of renewable energy as means to decrease CO_2

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