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Institutional quality, economic growth, and environmental sustainability: a long-run analysis of the ecological footprint in Somalia

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Abstract
This study investigates the complex linkage between economic growth, institutional quality, urbanization, trade openness, and Somalia's ecological footprint from 1990 to 2020. To ensure reliable results, we initially conducted an assessment of the order of integration of our variables through the use of the augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) stationarity tests, which indicated a mixed order of integration. Following this, we employed the autoregressive distributed lag (ARDL) technique, in combination with the fully modified ordinary least squares (FMOLS) and canonical cointegrating regression (CCR) methods, to investigate the long-term relationships and causal connections between these variables, further supported by the application of the Granger causality test. Our findings indicate that a 1% increase in GDP per capita increases the ecological footprint by 3.79%, while a 1% increase in GDP per capita squared decreases it by 0.05%. This supports the environmental Kuznets curve hypothesis, which means that at higher stages of economic development, the damage to the environment decreases. However, improvements in institutional quality have had minimal and statistically insignificant effects on the ecological footprint. While urbanization showed a considerable impact in the long run, its short-term effects were minimal. Interestingly, trade openness emerged as a positive factor, contributing to a reduction in the ecological footprint over time. To build a sustainable future, Somalia should balance economic growth with environmental protection by prioritizing green technologies, enhancing governance for enforcing environmental regulations, integrating sustainability into urban planning, and promoting trade in clean technologies to reduce its ecological footprint.

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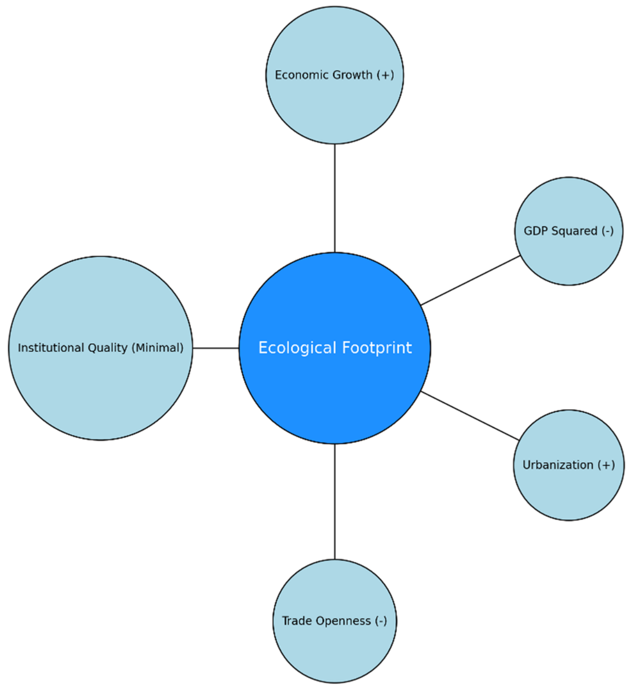
Graphical abstract



Article highlights

- The study analyzes linkages among economic growth, institutional quality, urbanization, trade, and Somalia's ecological footprint.
- Growth initially harms, and then benefits the environment (Kuznets curve)
- Institutional quality shows minimal environmental impact.
- Urbanization increases, while trade reduces the footprint over time.
- The study suggests green tech, better governance, sustainable planning, and clean tech trade for growth

Keywords Ecological footprint · Urbanization · Economic growth · Institutional quality · Trade openness · ARDL

Abbreviations

SDGs	Sustainable development goals
UN	United Nations
GFN	Global Footprint Network
PP	Phillips-Perron
ADF	Augmented Dickey-Fuller
ARDL	Autoregressive distributed lag
FMOLS	Fully modified ordinary least squares
CCR	Canonical Cointegration regression
EKC	Environmental Kuznets Curve
ICRG	International Country Risk Guide
ECF	Ecological footprint

1 Introduction

Environmental degradation is one of the primary adversities faced by most people in modern times, and it significantly impairs public health. It involves the destruction and depletion of natural resources such as soil, water, and air due to overexploitation [1, 2]. Extensive research has connected environmental conditions to social well-being, which demonstrates that while environmental risks expose people to harmful substances, they also disrupt ecosystems that are essential for life [3]. In recent decades, urgent issues such as climate change and global warming have monopolized international attention across many countries [4]. The 2019 United Nations (UN) Report on the Sustainable Development Goals (SDGs) emphasized that environmental challenges are of critical importance, as degradation obstructs the attainment of sustainable development and social well-being [5]. In this regard, the enhancement of environmental quality has emerged as a global strategic priority, with a focus on fostering sustainability and improving overall quality of life. With growing awareness of these issues, efforts to mitigate environmental degradation have garnered increased support globally, positioning environmental quality as a cornerstone in global sustainability strategies [6].

During the present century, most countries have achieved impressive economic development and structural change, although often with high environmental costs. For example, while in 1961 humankind used more than 50% of Earth's biodiversity, by 2006, it had soared to 44 percent over the sustainable limit [7]. As many as 1.6 Earths, according to [8], would be needed if we are to keep up with the current consumption pattern. Economic development must, therefore, be offset against environmental protection—a very challenging job for any policymaker, which, however, needs an in-depth understanding of pollution drivers so that credible strategies may be formulated and implemented easily for improved environmental quality [4]. Recent studies in environmental economics have focused on examining various factors that contribute to environmental degradation, such as macroeconomic, social, political, and sectoral factors [9]. While much development in the world has posed many challenges, a lot is being done to protect the environment. Different studies confirm the fact that countries need to improve the continuously deteriorating environmental quality through specific strategies aimed at environmental degradation reduction and sustainability facilitation [10]. While all economies have to grow, the resources are relatively scarce; there is some form of tension between economic growth and sustainability [11].

The recent COP28 summit highlighted the urgent need for coordinated global efforts to address climate change, with an emphasis on sustainable development goals and reducing ecological footprints. This aligns with Somalia's environmental challenges, where economic growth must balance sustainability imperatives. According to the COP28, advancing green technologies and strengthening institutional frameworks are essential steps toward mitigating environmental degradation and achieving long-term ecological sustainability. In Somalia, there is an ecological deficit driven by rapid economic growth and a lack of institutional capacity to control the pervasive deforestation across the country [9]. Economic growth, urbanization, and trade openness have increased pressure on natural resources, leading to unsustainable exploitation, particularly of forest areas, which exacerbates environmental degradation. The absence of robust institutional mechanisms has hindered efforts to manage these resources sustainably, which contributes to a rising ecological footprint that surpasses the country's biocapacity. Figure 1 shows the evolution of Somalia's ecological footprint and biocapacity from 1961 to 2022. Over the past seven decades, Somalia's ecological footprint has gradually risen, overtaking its biocapacity in recent years and creating an ecological deficit. While biocapacity has remained mostly stable, the increase in ecological footprint—driven by economic growth and resource demands—has resulted in unsustainable resource consumption, which places significant environmental pressure on the country.

Human needs are endless, but these natural resources have their limits. In light of this, energy use is considered to be a prime factor in causing waste and environmental degradation [12, 13]. Indeed, the effects of economic globalization make this an even more complex issue because, although greater trade and investment can imply faster economic growth and tariff cuts, they can also mean higher emissions on account of energy-intensive forms of production. While it can, on the other hand, facilitate structural changes toward greener economies, which in turn could lower emissions as practices change [14, 15]. Traditionally, CO_2 emissions are considered the prime indicator of environmental deterioration. However, [16] argue that by trying to represent environmental deterioration, it is a very narrow indicator since CO_2 is only a component of the larger problem. [17] also arrives at a related argument of sole reliance on CO_2 and air pollution being unable to present the actual impacts of economic activities on all natural resources. It is too narrow; critical agents of environmental degradation such as agriculture, deforestation, and mining are excluded from consideration. Besides, the complex effects of urbanization present a major challenge to efforts aimed at reducing ecological footprints [9]. As the economic divide between rural and urban areas widens, settlement patterns shift rapidly, and urban economies experience significant growth in developing nations [18].

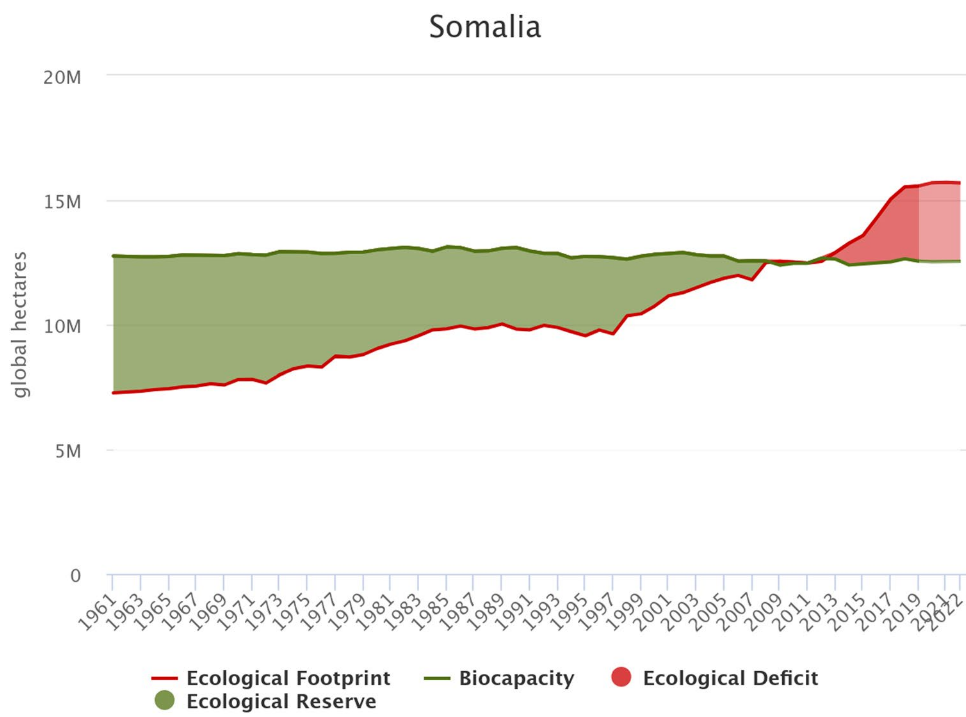


Fig. 1 The ecological footprint and the biocapacity of Somalia. Data source: (Global Footprint Network, 2022)

Regarding these lacunas, researchers such as [19] believe that more holistic-type indicators need to be considered. In this respect, the ecological footprint has begun to emerge as a measure of environmental degradation. It is defined as a measure of the capacity of biologically productive land and water resources to regenerate the resources consumed by society in addition to absorbing waste [20–22]. Rapid globalization and the expansion of production and consumption have implied, apparently, the use of natural resources unsustainably beyond their regeneration capacity. This decline has led to an increase in the ecological footprint, which is a result of ecological deficits and reduced biological capacity. Hence, the ecological footprint has turned into an important indicator for understanding environmental degradation within a perspective of production and consumption at levels that are unprecedentedly high. Many studies on Somalia, including those by [18, 23, 24], have focused primarily on CO2 emissions as a measure of environmental degradation. While this approach has provided some important insights, it tends to offer a limited perspective on the broader environmental issues facing the country.

Energy consumption, carbon emission, and environmental sustainability have become prime focuses of today's research. The majority of the literature concentrates on how different energy sources, including geothermal, natural gas, coal, and biomass, can aid in achieving carbon neutrality [25–28]. Although the role of clean energy and economic causes in ensuring sustainable development is quite evident, there is still much left to learn about how these elements interact. Despite this huge success in the area of environmental impact studies, there are still a number of important questions that remain to be answered, including the numerous causes of environmental degradation in less developed countries like Somalia. A significant portion of the literature overlooks the broader landscape, which includes increasing urbanization, trade patterns, and institutional influence, and focuses solely on CO2 emissions. Thus, the paper will bridge these gaps by assessing the effect of trade openness, urbanization, institutional quality, and economic growth on the ecological footprint in Somalia for the period 1990–2020. In this regard, the primary goal of this study is to explore the short- and long-term relationships between economic growth, trade openness, urbanization, and institutional quality, and their collective impact on Somalia's ecological footprint. This investigation also considers whether the Environmental Kuznets Curve hypothesis holds true in the context of Somalia, providing a comprehensive analysis of the dynamics between development and environmental sustainability. This work stands out because it takes an ecological footprint as a general measure of environmental degradation away from the dominant adoption of the CO2-based approach." To achieve the study objectives, we adopted various stationarity tests such as augmented Dickey-Fuller (ADF) and Phillips-Perron (PP). In addition, the study employs the autoregressive distributed lag (ARDL) model, fully modified ordinary least squares (FMOLS), canonical cointegrating regression (CCR) techniques, and the Granger causality test to examine the long-term relationships and causal interactions among the variables.

The rest of the study is structured as follows: The second section reviews the relevant literature, while the third section outlines the theoretical framework, data description, and model development. Section four presents the results and discussion, and the final section offers conclusions and recommendations.

2 Literature review

Studies that investigated the effect of economic growth, institutional quality, trade openness, and urbanization on the environment are ubiquitous. The findings from these studies have always yielded wide discrepancies due to variations in the data range, methodologies adopted, proxies for variables, and country or regional peculiarities [29].

2.1 Trade openness and ecological footprint

Many studies have examined the relationship between trade openness and the ecological footprint, with mixed findings. Research by [16, 30–32], and [33] consistently shows that as countries increase their trade openness, their ecological footprint tends to grow. This is likely due to intensified industrial activity, higher resource consumption, and the importation of polluting technologies, especially in fast-growing economies. This reflects the "scale effect" of trade, where economic growth leads to more environmental degradation, particularly in developing nations. As in the study by [34], economic globalization has long-run ecological degradation consequences, while environmental sustainability is enhanced by factors such as political stability, energy transitions, and economic complexity. On the other hand, [35] and [36] offer a more nuanced view, suggesting that trade openness can sometimes reduce the ecological footprint or produce different outcomes depending on the type of footprint. For instance, [35] found that while trade openness reduces per capita production footprints, it increases import-related footprints. Destek and Sinha [36] argue that in more developed countries, trade openness can promote cleaner technologies and better environmental practices, ultimately reducing the ecological footprint through what is known as the "technique effect."

2.2 Economic growth and ecological footprint

The exploration of the relationship between economic growth and the environment has developed through several key ideas, one of the most prominent being the Environmental Kuznets Curve (EKC) hypothesis. This concept stems from [37] original theory, which described an inverted U-shaped relationship between economic growth and income inequality. It was later adapted to explain the link between economic growth and environmental degradation. Grossman and Krueger [38] were among the first to study this, discovering a similar inverted U-shaped pattern. The EKC hypothesis suggests that while economic growth initially leads to increased environmental damage, this trend reverses once a certain level of income is achieved, resulting in environmental improvement. Early studies supported this optimistic view [39, 40]. However, later research presented more mixed results, challenging the simplicity of the EKC hypothesis. Katz [39] noted that results can vary greatly depending on the econometric methods used. Lin et al. [41] pointed out that outcomes can also depend heavily on the specific country or region being analyzed. Others, like [42, 43], argued that the time period studied and the availability of data also play crucial roles. Additionally, [44] emphasized the importance of how the models are structured, including the choice of variables. Studies focusing on specific regions provide further context. Saboori and Sulaiman [45], for instance, looked at the relationship between economic growth, carbon emissions, and energy consumption in Malaysia from 1980 to 2009. They found no evidence of the EKC when energy consumption data was combined, but when they broke it down by source—such as oil, coal, gas, and electricity—the EKC hypothesis appeared to hold. On the other hand, researchers [46], who examined Tunisia between 1961 and 2004, found that the relationship between sulfur dioxide emissions and per capita GDP followed an inverted U-shape, consistent with the EKC hypothesis. A study by [47] on Italy's ecological footprint from 1985 to 2018 revealed that economic growth increases the footprint, while renewable energy, trade globalization, and human capital reduce it. All these factors promote sustainability in Italy. Zhang et al. [48] investigated the link between economic development, resource efficiency, and biomass energy in Malaysia. They found out that increased resource exploitation and emissions were linked to economic growth at the expense of environmental degradation. But they also spotted that improvement in resource efficiency and promotion of biomass energy can help cancel out these negative effects, hence underlining the intrinsic importance of sustainability in the whole economic development strategy. Furthermore, it was revealed by [26, 49], and [50] that economic growth impedes environmental sustainability.

2.3 Urbanization and ecological footprint

Urbanization plays a significant role in shaping environmental outcomes, particularly through its impact on ecological footprints and CO_2 emissions. Research across different regions and income levels shows how urban growth affects the environment in complex ways. For instance, Dogan et al. [51] found that urbanization leads to a larger ecological footprint in countries like Indonesia, Mexico, and Turkey, while in Nigeria, urban growth surprisingly reduced the ecological footprint. This contrast likely reflects differences in development paths and how countries manage their resources and urban expansion. In sub-Saharan Africa, a study conducted by [52] between 1990 and 2014 revealed that urbanization significantly contributes to environmental degradation. This is largely due to increased energy consumption and changing lifestyles in growing cities. Similarly, [53] found that in the European Union from 1992 to 2010, urbanization led to higher CO_2 emissions, driven by energy-intensive activities like transportation and construction. In the ASEAN region, [54] observed that a 1% increase in the urban population resulted in a 0.2% rise in CO_2 emissions, further highlighting the environmental pressures of urban growth. Studies [55–59] also stress how important it is to look at regional contexts, economic growth, and policy choices when trying to figure out how urbanization and environmental degradation are connected. A study in Brazil by [60] proved that urbanization doesn't affect environmental sustainability much. This result has brought attention to the very complicated relationship between urban growth and sustainability, suggesting that the effect might vary quite a lot under different local economic conditions.

2.4 Institutional quality and ecological footprint

In recent years, more attention has been given to the connection between institutional quality and environmental outcomes. Researchers have explored how different institutional factors influence environmental quality across a range of countries and regions. For example, [61] found that improved institutional quality helps lower CO_2 emissions in 40 sub-Saharan African countries. Similarly, [62] showed that democratic governance and political stability contribute to reducing CO_2 emissions in Sub-Saharan Africa. In South Africa, [63] found that stronger political institutions have a negative impact on CO_2 emissions. In other regions, [64] concluded that stronger institutions help reduce CO_2 emissions in 24 transition economies. Bhattacharya et al. [65] reported that more economic freedom leads to a decrease in CO_2 emissions across 85 countries. In India, [66] highlighted that better institutional quality helps tackle environmental problems by cutting down on traditional energy consumption. Salman et al. [67] pointed out that a strong legal framework in three Asian countries plays a key role in reducing CO_2 emissions, while [68] found that corruption increases CO_2 emissions in South Asian nations. However, not all studies show a clear-cut positive impact. Le and Ozturk [69] revealed that in emerging market economies, stronger institutions can lead to more CO_2 emissions due to increased economic activity. Similarly, Hassan et al. [70] found that in Pakistan, institutional quality is linked to higher CO_2 emissions, largely because of the boost it gives to economic growth.

A review of the literature on the factors that influence environmental sustainability reveals large knowledge gaps in understanding environmental degradation. Though many studies deal with the interaction of these factors, most of them use CO2 emissions and load capacity factors as surrogates for environmental deterioration. Much of this literature focuses on factors such as human capital, biomass, energy use, and efficiency in resources. However, such a narrow focus may compel the analysis to overlook other dimensions of environmental impact. Our study, therefore, takes an alternative approach by using ecological footprint as a measure of environmental impact and offers a broader insight into issues of sustainability. This becomes all the more relevant in view of the complexity and diversity of environmental issues in Somalia. Indeed, our research contributes to the understanding of environmental sustainability in this region by providing insight valuable for these intricate interlinkages through the use of an ecological footprint while taking into consideration the peculiarities of Somalia.

3 Data and methodology

3.1 Theoretical background

The Environmental Kuznets Curve (EKC) builds on Simon Kuznets' original idea about economic development and income inequality. In his 1955 paper, Kuznets suggested that as economies grow, income inequality first rises and then falls, creating an inverted U-shaped curve [71]. This idea was later applied to environmental issues. Grossman and Krueger took Kuznets' concept and applied it to environmental degradation in their 1995 study. They found that as economies grow, pollution levels typically increase at first but then start to decrease once a certain income level is reached. This decline happens because wealthier countries can invest in cleaner technologies, enforce stricter environmental regulations, and have a more informed public that demands better environmental protection [72]. In simple terms, the EKC theory suggests that environmental damage often worsens during the early stages of economic growth. However, as a country becomes more developed, it usually adopts better practices and technologies that help improve environmental quality.

3.2 Description of data

The study aims to understand how ecological footprint, real GDP per capita, institutional quality, trade openness, and urbanization are interconnected in Somalia. It uses data from 1990 to 2020 to build a time series model, drawing on sources such as the Organization of Islamic Cooperation (OIC-SESRIC), the Global Footprint Network (GFN), the World Bank, and the International Country Risk Guide (ICRG) dataset. The details of these sources are provided in Table 1. The ecological footprint (ECF) measures various types of land use, including cropland, grazing land, fishing grounds, forestland, and built-up areas. It serves as an indicator of environmental impact by evaluating resources such as water, forests, and air quality. The ecological footprint provides a broader and more detailed view of environmental degradation compared to the "CO_2 emissions" measure used in earlier studies [19], offering a more comprehensive assessment of environmental impact. The set of graphs in Fig. 2 presents trends in various economic indicators for Somalia over time, covering the period from 1990 to around 2020.

3.3 Model construction

Inspired by the methods of [19, 73–75], we made the following enhancements to our model:

$$ECFP_t = \alpha_0 + \beta_1 GDP_t + \beta_2 GDPS_t + \beta_3 X_t + \varepsilon_t \tag{1}$$

In this study, ECFP stands for ecological footprint, GDP represents GDP per capita, and GDPS refers to the square of GDP per capita. The variable X includes various factors that could affect the ecological footprint in Somalia. Both trade openness and urbanization play significant roles in shaping the ecological footprint. Research by [20, 51, 76] highlights that urbanization is a major driver of environmental impact. Additionally, trade openness influences the ecological footprint as well. Zahra et al. [77] discovered that changes in trade openness can lead to both increases and decreases in the ecological footprint, affecting it in different ways over the short and long term. Given these findings, Eq. (1) can be expanded to include these considerations.

$$ECFP_t = \alpha_0 + \beta_1 GDP_t + \beta_2 GDPS_t + \beta_3 IQ_t + \beta_4 UR_t + \beta_5 TO_t + \varepsilon_t \tag{2}$$

Table 1 Variables, proxy, measurement and source

Variables	Proxy	Measurement	Sources
Ecological footprint	ECFP	Total ecological footprint of consumption in global hectares (gha)	GFN
Economic growth	GDP	GDP per capita (constant 2015 US$)	WDI
Institutional quality	IQ	Government Effectiveness: Estimate	ICRG
Urbanization	UR	Urban population (% of total population)	WDI
Trade openness	TO	Percent	SESRIC

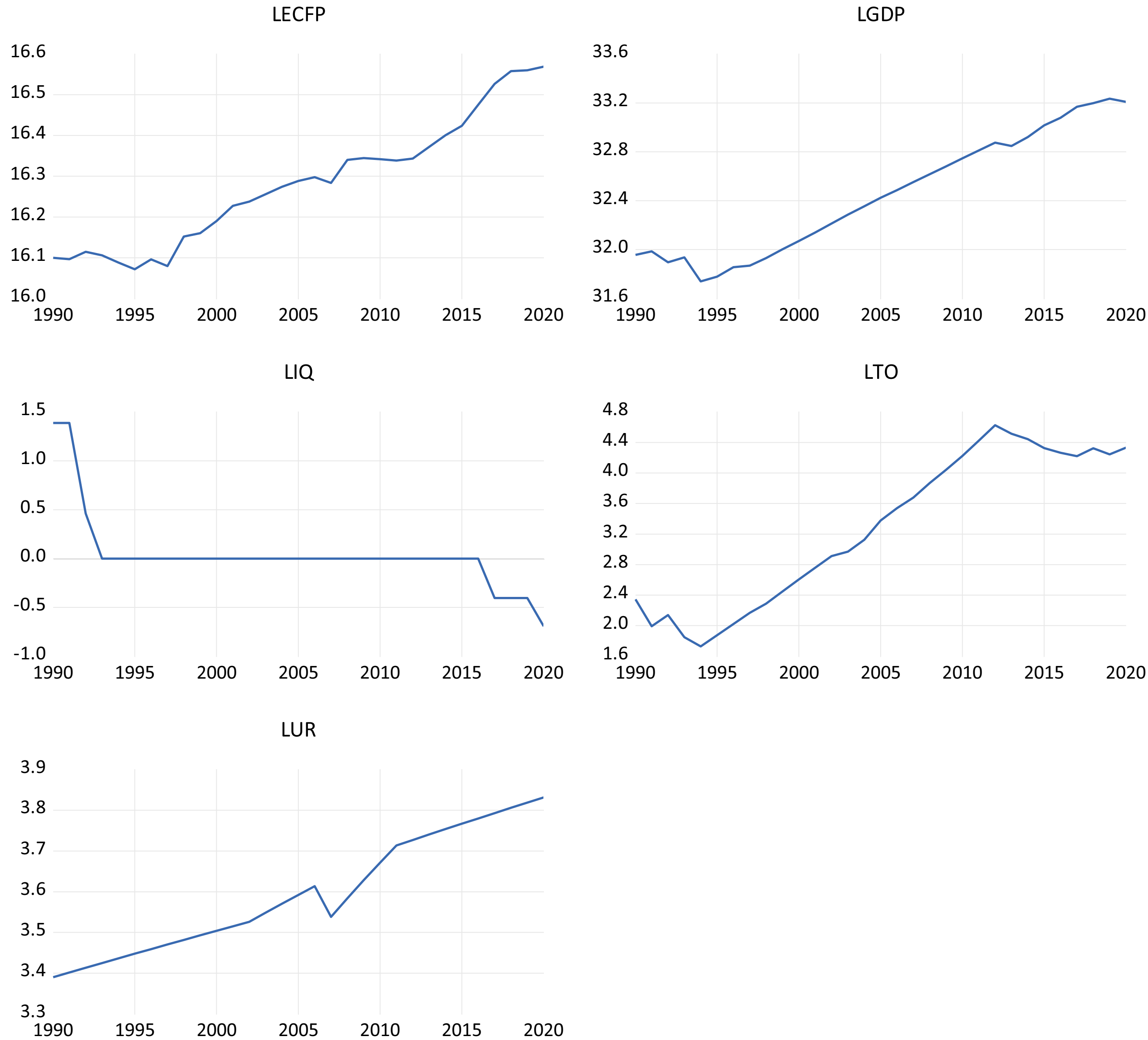


Fig. 2 Trend of sampled variables

In this study, TO represents trade openness, UR stands for urbanization, and IQ denotes institutional quality. To address heteroskedasticity and simplify percentage interpretation, the study transformed all variables using natural logarithms. Equation (2) can be updated to reflect this transformation.

$$LECFP_t = \alpha_0 + \beta_1 LGDP_t + \beta_2 LGDPS_t + \beta_3 LIQ_t + \beta_4 LUR_t + \beta_5 LTO_t + \varepsilon_t \tag{3}$$

Building on Eq. (3), we can outline the autoregressive distributed lag (ARDL) model like this:

Table 2 Descriptive statistics

	LECFP	LGDP	LGDPS	LIQ	LTO	LUR
Mean	16.28107	32.44768	1053.088	0.042664	3.279235	3.594804
Maximum	16.56884	33.23367	1104.477	1.386294	4.626051	3.831702
Minimum	16.07163	31.73947	1007.394	− 0.693147	1.728109	3.389732
Std. dev	0.155275	0.494247	32.11494	0.407105	0.997839	0.142646
Skewness	0.338664	0.166877	0.180067	2.136201	− 0.144240	0.256851
Kurtosis	2.090069	1.614907	1.621569	8.731452	1.442718	1.670990
Jarque–Bera	1.662050	2.621921	2.621784	66.00799	3.239949	2.622285
Probability	0.435603	0.269561	0.269580	0.000000	0.197904	0.269512
Observations	31	31	31	31	31	31

Table 3 Correlation matrix

	LECFP	LGDP	LGDPS	LIQ	LTO	LUR
LECFP	1					
LGDP	0.979553	1				
LGDPS	0.97988	0.999984	1			
LIQ	− 0.58443	− 0.49973	− 0.50071	1		
LTO	0.908052	0.957624	0.956376	− 0.4538	1	
LUR	0.963787	0.973072	0.973524	− 0.60669	0.93304	1

$$\begin{aligned}\Delta LECFP_t = {} & \alpha_0 +_{\varphi 1} LECFP_{t-1} +_{\varphi 2} LGDP_{t-1} +_{\varphi 3} LGDPS_{t-1} \\ & +_{\varphi 4} LIQ_{t-1} +_{\varphi 5} LUR_{t-1} +_{\varphi 6} LTO_{t-1} + \sum_{i=1}^{p} {}_{\gamma 1}\Delta LECFP_{t-i} \\ & + \sum_{i=1}^{q} {}_{\gamma 2}\Delta LGDP_{t-i} + \sum_{i=1}^{q} {}_{\gamma 3}\Delta LGDPS_{t-i} + \sum_{i=1}^{q} {}_{\gamma 4}\Delta LIQ_{t-i} \\ & + \sum_{i=1}^{q} {}_{\gamma 5}\Delta LUR_{t-i} + \sum_{i=1}^{q} {}_{\gamma 6}\Delta LTO_{t-i} + \phi ECT_{t-1} + \varepsilon_t\end{aligned} \tag{4}$$

In the ARDL model, α_0 is the intercept or constant term. The coefficients ${}_{\gamma 1}$ through γ6 reflect the short-term effects, while φ1 through φ6 capture the long-term relationships. The variables p and q represent the best lag lengths for the dependent and independent variables. The symbol Δ denotes short-term variables, and ϕ is the coefficient for the error correction term.

To check if there is a long-run relationship between the dependent and independent variables, the bounds test uses the F-statistic to evaluate two hypotheses: The null hypothesis (H_0) claims that the variables do not have a long-term connection, meaning their coefficients are equal and they move independently over time. While the alternative hypothesis (H_1) suggests that the variables do share a long-term relationship, with different coefficients indicating a consistent, interconnected movement over time. The test involves comparing the F-statistic to critical bounds. If the F-statistic is above the upper bound I(1), it confirms a long-run relationship. If it's below the lower bound I(0), no such relationship exists. If the F-statistic falls between the bounds, the result is inconclusive.

4 Results and discussion

4.1 Descriptive statistics

Tables 2 and 3 offer a detailed look at the descriptive statistics and correlations for the variables in the study. From Table 2, it's clear that the log of GDP squared (LGDPS) has the highest average value at 1053 and also the highest maximum value. On the flip side, the log of institutional quality (LIQ) has the lowest average of just 0.04 and the lowest minimum value.

Table 4 Unit root tests

Variable	PP		ADF	
	Level Intercept	Intercept and trend	Level Intercept	Intercept and trend
LECFP	1.0268	– 2.2118	0.9921	– 3.6309**
LGDP	0.5545*	– 3.3266*	0.7916	– 3.2314*
LGDPS	0.5889*	– 3.4295*	0.8317	– 3.2495*
LIQ	– 3.4835**	– 3.4824*	0.067073	– 7.228854***
LTO	– 0.5006	– 2.1869	– 1.25189	– 2.437953
LUR	0.5984	– 2.4554	0.086156	– 2.463982
Variable	PP		ADF	
	Intercept	Intercept and trend	Intercept	Intercept and trend
ΔLECFP	– 5.1126***	– 5.3431***	– 5.1129***	– 5.3431***
ΔLGDP	– 4.6867***	– 4.9667***	– 4.5531***	– 4.7969***
ΔLGDPS	– 4.653***	– 4.9504***	– 4.5189***	– 4.7789***
ΔLIQ	– 3.8808***	– 4.0373***	– 3.880772***	– 3.932048**
ΔLTO	– 4.6039***	– 4.5479***	– 4.611902***	– 4.551223***
ΔLUR	– 6.0776***	– 6.8003***	– 5.473765***	– 5.419515***

*, **, and *** represent the significance levels of 1%, 5%, and 10%, respectively

LGDPS also shows the most variation among the variables, while the log of urbanization (LUR) shows the least variation. Lastly, the Jarque–Bera test results indicate that, with the exception of the log of institutional quality, the rest of the data follow a normal distribution quite well. On the flip side, the pair-wise correlation results reveal how two variables move in relation to each other. According to Table 3, most variables are positively correlated with the ecological footprint, meaning that as these variables go up, so does the ecological footprint. The only exception is institutional quality, which has a negative correlation with the ecological footprint. This suggests that better institutional quality tends to be associated with a lower ecological footprint.

4.2 Stationarity test

In time series modeling, it's important to check for unit root issues before moving on to ARDL analysis to ensure the results are reliable. The augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were used to check for stationarity. The null hypothesis of these tests suggests that a unit root is present, while the alternative suggests it is not. According to the results in Table 4, the variables show different levels of stationarity: some are stationary at the level (I(0)), while others need to be compared once to become stationary (I(1)). It's important to use the right methodological approach for time series analysis to be useful, since a wrong model or technique would have led to biased or incorrect results [78]. It is thus important to establish the stationarity of the variables before going ahead. When the variables are integrated at I(1), then the application of the Johansen cointegration method and the Vector Error Correction Model VECM in the analysis is admissible [79, 80]. On the other hand, if the order of integration is inconsistent across all variables, it is advisable to follow the autoregressive distributed lag (ARDL) approach as suggested by [81, 82]. Selection of the model and integration order holds a lot of importance for time series research to come up with an accurate and meaningful result. Since none of the variables is stationary at a second-difference level I(2), the next step involves carrying out a bounds test for cointegration.

Table 5 F-bound cointegration test

Model	F-statistic	Significance	Bounds test	Critical values
			K (5)	
			I (0)	I (1)
LECFP = F(LGDP, LGDPS, LIQ, LTO, LUR)	4.605	10%	2.578	3.858

4.3 F-bound tests

In this study, the general-to-specific approach from [80] is used within the ARDL framework to figure out the best way to combine the variables and choose the length of the lags for the models. This method proceeds through the deletion of variables with the highest p-values one by one until no more correlation is left in the error term and the model parameters stabilize. This helps to effectively handle any issues of serial correlation and to render the model robust. Although the small size of the dataset meant that the analysis first considered two lags, it finally opted for a single lag in its final specification. Table 5 shows the results of the bounds test, which looks at whether there's a long-term relationship between the ecological footprint and factors like gross domestic product, institutional quality, trade openness, and urbanization. The Wald F-statistic is 4.605, which is higher than the upper bound critical value of 3.858 at the 10% significance level. This means we can reject the idea that there is no long-term relationship between these variables. In other words, the results suggest that there is a meaningful long-term connection between the ecological footprint and the variables being studied.

4.4 Long-run and short-run results

After confirming the long-term relationships between the variables, the study used the ARDL method to calculate the long-term coefficients. Table 6 shows that most of the explanatory variables have a significant effect on the ecological footprint at both the 1% and 5% significance levels, except for institutional quality. Precisely, the relationship between GDP per capita and ecological footprint presents both positive and negative effects. When GDP per capita rises, ecological footprint increases but further increases in GDP per capita reduces ecological footprint confirming the existence of a valid EKC in Somalia. Our findings for Somalia do indeed suggest that the initial phases of economic growth are associated with increased environmental stress propelled by resource-based growth, but further economic development and improvements in institutional quality may eventually alter behavior in an environmentally friendly direction. This result is in line with research by [37, 44, 45], [82], and [83] that showed an inverted U-shaped relationship between environmental degradation and economic growth. According to these studies, economic growth causes more environmental damage at first but then improves after a certain point because of improved technology and stricter environmental regulations. However, [84] find that GDP can exert a negative impact on ecological quality, which means that sometimes economic growth instead of environmental improvement can exacerbate environmental degradation. This again manifests the complicated relationship between ecological outcomes and economic development. While the environmental Kuznets curve may hold in some cases, one should not overlook the potential harming of the environment by growth in GDP, seeking a balance between growth and sustainability.

On the other hand, institutional quality has a very small and statistically insignificant effect on the ecological footprint. The ecological footprint only increases by 0.003% for every 1% increase in institutional quality. This positive but

Table 6 Long run coefficients

Variables	Coefficients
LGDP	3.791496*
	(1.236318)
LGDPS	– 0.055711*
	(0.018853)
LIQ	0.003637
	(0.017961)
LUR	0.272475**
	(0.105241)
LTO	– 0.051737*
	(0.014043)
C	– 57.67782**
	(20.20829)

*, **, and *** represent the significance levels of 1%, 5%, and 10%, respectively. Standard error is demonstrated in ()

negligible connection between Somalia's ecological footprint and institutional quality most likely reflects the political instability and poor governance that still afflict the nation. Even as institutions improve, they may still lack the strength to enforce environmental protections or promote sustainable practices effectively. In Somalia's case, better institutions might help drive economic activities that increase resource use, but without enough focus on environmental safeguards, the impact on the ecological footprint remains minimal. In essence, although governance advancements are significant, actual environmental benefits have not yet been realized. Our research deviates from the larger body of literature by showing a negligible impact of institutional quality on the ecological footprint. Higher institutional quality, for example, has been linked to lower CO2 emissions, especially in Sub-Saharan African nations, according to [58] and [59]. Furthermore, it was determined by [60] and [61] that environmental improvements are a result of stronger political institutions. However, our findings are more in line with those of [66], who proposed that more robust institutions may occasionally make environmental degradation worse, especially in developing nations where institutional growth can speed up economic activity and energy use.

Urbanization, however, has a more noticeable impact; a 1% rise in urbanization is associated with a 0.27% increase in the ecological footprint. The positive effect of urbanization on the ecological footprint in our study is in line with research by [51], who found that urban growth tends to increase the ecological footprint in countries like Indonesia and Turkey, and with [53], who observed similar effects in the European Union. These studies emphasize that urbanization drives energy-intensive activities and lifestyle changes that increase environmental stress. However, this result contrasts with the findings in Nigeria by [51], where urbanization unexpectedly reduced the ecological footprint. This suggests that the impact of urbanization on the environment may be context-specific, influenced by a country's stage of development, urban planning, and energy policies. This indicates that while institutional quality has a minor effect, urbanization tends to increase the ecological footprint over time.

Additionally, trade openness significantly impacts environmental sustainability: a 1% increase in trade openness results in a decrease of 0.05% in the ecological footprint. This finding is in contrast to the results in most studies, for example, [16, 30, 31, 33], and [83], where it was determined that increased trade openness often leads to an increase in ecological footprint. Through such studies, it was argued that trade can cause industrialization and the use of resources,

Table 7 Short run elasticities

Variable	Coefficient
Constant	1.568763*
	(0.767178)
Δ LGDP	12.4996**
	(5.711526)
$\Delta LGDP_{t-1}$	0.267339***
	(0.087172)
$\Delta LGDP_{t-2}$	– 9.698902
	(6.061116)
ΔLGDPS	– 0.189812**
	(0.088313)
$\Delta LGDPS_{t-2}$	0.153495
	(0.094872)
ΔLIQ_{t-1}	0.01153
	(0.025812)
ΔLUR	0.320687
	(0.187976)
ΔLTO	– 0.06644
	(0.040907)
ΔLTO_{t-1}	– 0.129072**
	(0.047405)
ECT_{t-1}	– 0.178889*
	(0.087864)

*, **, and *** represent the significance levels of 1%, 5%, and 10%, respectively. Standard error is demonstrated in ()

which, in fast-growing economies, lead to environmental degradation. However, our results support the "technique effect" suggested by [35] and [36], whereby trade openness in more developed nations may encourage the adoption of cleaner technologies and better practices, which are environmentally friendly, in order to reduce ecological footprints. Incidentally, this has also been evidenced by [83] and [84]. It reflects the complicated role of trade, where its environmental impact significantly fluctuates with the economic structure and level of development of a country. In light of this, Somalia could strive to establish trade regulations that facilitate the adoption of environmentally sustainable technologies and procedures. Another effective tactic related to this would be giving priority to trade agreements that promote sustainable products, investments in renewable energies, and exports of eco-friendly products. Further coordination of Somalia's trade activities with its sustainability objectives will ensue by the creation of regulatory frameworks that encourage sustainable business practices.

Table 7 shows the results of the short-run impact of different economic and institutional factors on Somalia's LECFP. These will always help understand a variable that is informative in the short run with respect to environmental outcomes. The constant term has a coefficient of 1.568 and is significant at 10% hence, there is just one level of environmental impact even when the other factors remain constant. This is an indication that strong social or economic structures deeper in the system drive the ecological footprint, regardless of changes in the short run of the key variables. Changes in GDP stand strongly correlated with the ecological footprint, represented by a coefficient of 12.4996 at 5% significance. This means that if the GDP increases by 1%, the ecological footprint accordingly increases by 12.5% in the short run. This finding supports the notion that economic growth often increases environmental strain, as higher production and consumption lead to greater resource use and, consequently, more environmental degradation. Moreover, the positive and significant impact of the previous period's GDP (ΔLGDPt-1), with a coefficient of 0.267, reinforces the idea that past economic growth continues to exert pressure on the environment in the current period. Interestingly, the square of GDP (ΔLGDPS) has a negative and significant coefficient of -0.1898 at the 5% level. This therefore means that with the faster growth of GDP, negative impacts on the environment begin to weaken. This may reflect that economies tend to get greener or technologically advanced with their growth, which reduces the ecological footprint even when the economic activities are at higher levels.

The small positive coefficient of 0.0115 for institutional quality (ΔLIQt-1) is not statistically significant. This suggests that changes in institutional quality, whether positive or negative, have little immediate impact on the ecological footprint. Similarly, urbanization (ΔLUR) has a positive but negligible effect (coefficient of 0.3207), indicating that, despite the fact that urbanization is usually linked to increased resource use and industrialization, short-term changes in urbanization do not significantly change environmental outcomes. Trade openness (ΔLTO) has a negative coefficient of − 0.0664, although it is not statistically significant. This suggests that increased trade openness does not have an immediate and significant effect on reducing Somalia's ecological footprint. However, the lagged value of trade openness (ΔLTOt-1), with a negative and significant coefficient of − 0.1291, reveals that over time, greater openness to trade contributes to reducing the ecological footprint. This could be due to the adoption of cleaner technologies through trade, adherence to stricter environmental standards in trade agreements, or a shift toward more environmentally friendly imports and exports. The error correction term (ECTt-1) is significant at the 10% level, with a negative coefficient of − 0.1789. This suggests that about 17.88% of any short-term deviation from the long-run equilibrium is corrected each period, indicating that the system tends to gradually return to its long-term balance when short-run disturbances occur. This highlights a strong adjustment process, ensuring that the variables eventually revert to a stable, long-term relationship.

In conclusion, the analysis shows that economic growth significantly increases Somalia's ecological footprint in the short run, reflecting the environmental cost of growth. However, as economies grow further, there is evidence that this negative impact lessens, suggesting a possible transition toward more sustainable practices. Institutional quality and urbanization do not seem to have a notable short-term impact on the ecological footprint, while trade openness shows a delayed, beneficial effect on environmental sustainability. The significant error correction term underscores the system's

Table 8 Diagnostic tests

Type	Statistic
LM test	1.1103 (0.3099)
Heteroskedasticity test	0.399 (0.9422)
Normality test (if applicable)	1.6584 (0.4364)
RESET test	0.0336 (0.8572)
Adjusted R^2	0.6427

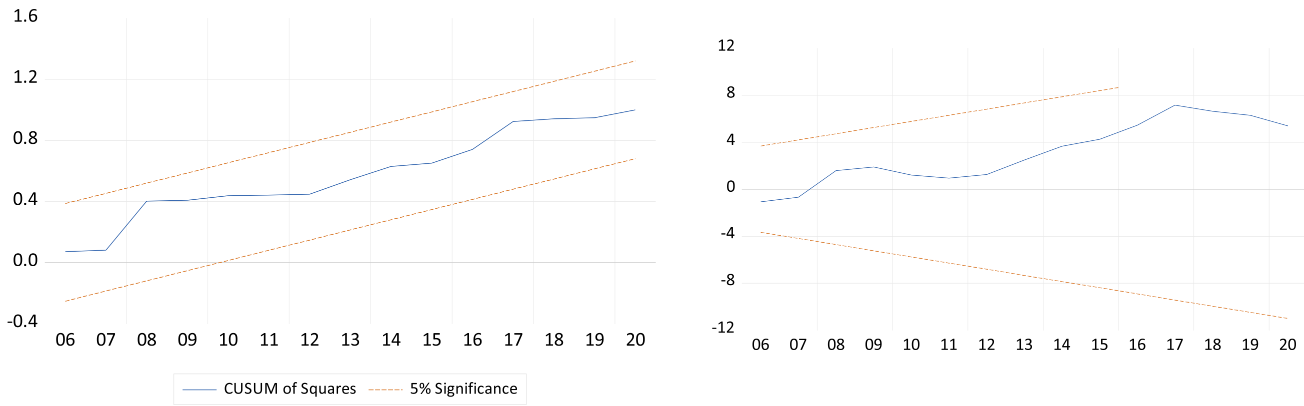


Fig. 3 CUSUM test and CUSUM square test

Table 9 Robust analysis

Variables	FMOLS Coefficients	CCR Coefficients
LGDP	6.712282**	7.1247**
	(2.489146)	(2.813817)
LGDPS	− 0.096393**	− 0.102276**
	(0.03817)	(0.042985)
LIQ	− 0.050309*	− 0.04205*
	(0.015099)	(0.013437)
LTO	− 0.104985*	− 0.116091*
	(0.022485)	(0.028811)
LUR	0.172105	0.161673
	(0.170235)	(0.176438)
C	− 100.2802**	− 107.3909**
	(40.86997)	(46.35147)

*, **, and *** represent the significance levels of 1%, 5%, and 10%, respectively. Standard error is demonstrated in ()

ability to return to long-term equilibrium after short-term shocks, indicating stability in the relationship between the variables and the ecological footprint. These findings emphasize the need for policies that balance economic growth with environmental protection and suggest that trade policies and long-term institutional reforms could be key to managing Somalia's ecological footprint effectively.

4.5 Diagnostic tests

As presented in Table 8, the statistical analysis provides strong support for the model's accuracy and appropriateness. The Lagrange Multiplier (LM) test, with a statistic of 1.1103 and a p-value of 0.3099, shows that there are no significant issues with model specification. The heteroskedasticity test reveals a statistic value of 0.399 and a p-value of 0.9422, further reinforcing the consistent variance of the residuals across observations, thus validating the homoscedasticity assumption. Also, for normality, the test was 1.6584 with a p-value of 0.4364; therefore, it showed that residuals were rather normally distributed. Also, the RESET gave a statistic of 0.0336 with a p-value of 0.8572, which means that the model is correctly specified with respect to functional form and choice of variables. The adjusted R2 of 0.6427 suggests that the model explains about 64.27% of the variability in the dependent variable. Such explanatory power would indicate that the model fits well. Overall, these results suggest that the model is robust and free of violations of the necessary assumptions. It is also both parsimonious and provides a relatively good fit for the variation in the dependent variable. Furthermore, the CUSUM and CUSUM of Squares tests were applied in the study to determine whether my model was stable over time.

The CUSUM test finds any systematic changes in the model parameters, while another important test—the CUSUM of Squares test—detects changes in the variance of the error terms. Both tests are important pre-requisites for the consistency of model parameters, which is essential for effective predictions. The results presented in Fig. 3 confirm that the model parameters remained stable during the period. These checks enhance the reliability of my findings; hence, they act as strong evidence that the results can be trusted for further analysis or decision-making.

4.6 Robust analysis

To further solidify the situation, we have decided to use Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegration Regression (CCR) to analyze the non-stationary time series data, as indicated in Table 9. This is because both approaches provide more detailed insights and enhance the results from the autoregressive distributed lag (ARDL) approach. FMOLS is especially good at handling problems such as serial correlation and endogeneity, which is enabling us to obtain consistent long-run estimates of the relationship among our variables. Likewise, CCR helps to purge potential omitted variable biases and thus identifies the underlying dynamics at work. These additional methodologies thus make the findings more robust and give a broader overview of how institutional quality, economic growth, and environmental sustainability in Somalia relate. Consistencies in results across these diverse approaches only reinforce our conclusions, but it also flags the high importance of this research in informing policy and practice.

The estimates depict that LGDP has positive coefficients estimated at 6.71 and 7.12 for FMOLS and CCR, respectively, implying that economic growth positively contributes significantly to the dependent variable. On the other hand, LGDPS, or GDP squared, shows negative coefficients estimated at – 0.10 in both methods and is significant at 1%. This suggests that as the magnitude of GDP squared increases, the effect diminishes due to resource constraints. LIQ and LTO both have negative coefficients that are significant at 10%, giving an indication of complex effects and trade-offs. The estimates for LUR are positive, though they fail to achieve the threshold of significance. Consequently, their potential growth effects are missed. Generally, sensitivity analysis testifies that results are in agreement with major outcomes from the model ARDL, except for various differences between institutional quality and urbanization.

4.7 Causality tests

Table 10 presents the Granger causality tests that determine the interaction of variables over time. These results indicate that changes in LECFP cannot be significantly predicted by LGDP (log of GDP) and LGDPS (log of GDP per capita), and vice versa. However, the influence is unidirectional, as LECFP appears to influence both urbanization (LUR) and institutional quality (LIQ. This hints at the fact that better environmental conditions might have positive effects on governance and urban development, a case where environmental sustainability leads to social development. On the other hand, no causal link can be established between LTO and LECFP, which means current trade activities do not influence ecological outputs in Somalia.

In other words, while LECFP can affect institutional quality and urbanization, there is no evidence that these variables might predict any change in LECFP. Besides, trade openness does not show any significant predictive power in relation to environmental performance. All this underlines the requirement of designing policies that take into account environmental considerations within trade and development strategies so as to foster sustainable outcomes.

Table 10 Granger outcomes

Null hypothesis: no granger causality	F-statistic	Direction
LGDP ≠ LECFP	1.52381	No causality
LECF ≠ LGDP	1.15407	
LGDPS ≠ LECFP	1.55817	No causality
LECFP ≠ LGDPS	1.18304	
LIQ ≠ LECFP	0.7294	Unidirectional
LECFP ≠ LIQ	6.59294***	
LTO ≠ LECFP	0.39913	No causality
LECFP ≠ LTO	0.25902	
LUR ≠ LECFP	6.04779***	Unidirectional
LECFP ≠ LUR	0.77845	

5 Conclusion and recommendation

Environmental degradation is a significant concern that heightens Somalia's vulnerability to climate change [24]. This study delved into the complex interplay between economic growth, institutional quality, urbanization, and trade openness and their impact on Somalia's ecological footprint from 1990 to 2020. Then, we used the ARDL method along with the FMOLS and CCR methods to look into the long-term relationships and causes between these variables. The Granger causality test helped us do this. Our model performed well in diagnostic tests, showing no significant issues such as autocorrelation, heteroskedasticity, or non-normality. Furthermore, we confirmed the stability of the model parameters over time through CUSUM and CUSUM square tests.

Our findings reveal that economic growth significantly contributes to an increased ecological footprint, both in the short and long term. This aligns with the Environmental Kuznets Curve hypothesis, suggesting that while growth initially harms the environment, it may lead to improved sustainability over time. However, the positive influence of institutional quality on the ecological footprint was minimal and statistically insignificant, indicating that improvements in governance have yet to make a real difference in environmental outcomes. Urbanization had a noticeable effect in the long run, but its impact in the short term was negligible. Interestingly, trade openness appeared to play a beneficial role in reducing the ecological footprint in the long run, likely due to cleaner technologies and better environmental practices emerging from increased trade.

Harmonizing economic growth with environmental conservation, while tackling peculiar challenges, is very instrumental in promoting sustainable development in Somalia. The governments should shift their investment into renewable energy sources like solar and wind, which would not only reduce reliance on imported fossil fuels but also tap into the abundant natural resources within the country. Increased access to cleaner energy could drive economic advancement in urban and rural areas while minimizing environmental consequences. Equally important are those institutional reforms that will improve governance and, subsequently, enhance the enforcement of environmental regulations. That is, enhancing the capacity of government institutions to engage local communities in decision-making contributes to the successful execution and close monitoring of sustainability initiatives.

Urbanization and trade policies also present opportunities for sustainable growth. Sustainable urban planning, incorporating eco-friendly building materials, efficient waste management systems, and green spaces, can mitigate the environmental impact of urban expansion while enhancing resilience against climate risks. Somalia's strategic position as a trade hub offers the potential to promote environmentally sustainable trade practices, such as exporting organic agricultural products and adopting climate-smart agriculture. Collaborating with international partners to introduce clean technologies and sustainable practices can further enhance Somalia's capacity to meet global environmental standards. Together, these measures can ensure Somalia achieves economic progress that aligns with global sustainability goals while addressing its specific needs. For example, through the use of very strict environmental legislation, Costa Rica has managed to incorporate sustainable tourism into its economy, hence fostering economic growth without necessarily compromising its natural resource base [85]. According to Onwe et al., Kenya's investment in renewable energy sources like wind and geothermal has ensured that the country attains economic growth with lowered levels of emissions. Organic farming has also provided an avenue through which the Philippines can diversify its income at the local level and increase farmers' incomes while at the same time contributing toward sustainability [86]. Ultimately, a long-term vision that harmonizes economic development with environmental sustainability will be key to ensuring that Somalia's growth aligns with global environmental goals. Through collaboration and commitment, we can work toward a brighter and greener future for the country.

5.1 Limitations and future studies

Future research could address the limitations of this study. Another line of inquiry might be how the different sectors, like agriculture and energy, are causing environmental degradation in Somalia. Adding more environmental indicators, such as CO_2 emissions and deforestation rates, would help provide a broader context to the ecological challenges Somalia faces. Comparative studies with other Sub-Saharan African countries could provide strategies that might be applicable in the Somali context. Analyzing changes over shorter time intervals could help capture shifting trends and provide more dynamic insights. In addition, the qualitative data from interviews with policymakers would make the findings more practically relevant and actionable. Future research on environmental sustainability in Somalia will thus factor in these limitations to increase its depth and applicability.

Author contributions The study was developed with significant contributions from the authors. Abdisalan Aden Mohamed: conception, design, and implementing the study; drafting the initial manuscript, data collection, data analysis, preparing revisions of the manuscript, and editorial support. Abdikafi Hassan Abdi made significant contributions to the development process by reviewing the draft manuscript, providing support in data collection, and assisting with the methodological framework. Bashir Mohamed Osman was in charge of writing the literature review section, while Salad Shire Mohamud concentrated on developing the introduction.

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Data availability The datasets used and/or analysed in the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate This study follows all ethical practices during writing. We declare that this manuscript is original, has not been published before, and is not currently being considered for publication elsewhere.

Consent for publication Not applicable.

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