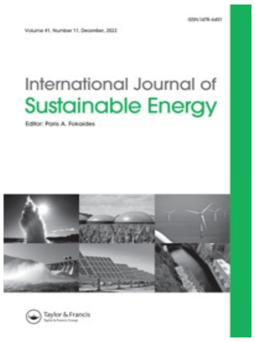

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Pathways to sustainable development in Somalia: evaluating the impact of agriculture, renewable energy, and urbanisation on ecological footprints and CO_2 emissions

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ABSTRACT
Environmental sustainability has become a critical concern globally, particularly for developing economies, where environmental deterioration severely impacts human and livestock livelihoods. As these economies grow and populations expand, the quality of the environment typically deteriorates, exacerbating already fragile living conditions. In pursuit of a sustainable future, this study investigates the impact of agricultural value-added, renewable energy consumption, economic growth, and urbanization on ecological footprints and CO_2 emissions in Somalia, using time series data from 1990 to 2020. By employing the ARDL bounds testing technique and dynamic ordinary least squares (DOLS), the results reveal that, in the long-run, agricultural value-added and renewable energy consumption significantly reduce both ecological footprints and CO_2 emissions. In the short-run, agricultural value-added temporarily increases both variables, while renewable energy's impact remains consistently beneficial. Economic growth exhibits a dual effect: it significantly increases the ecological footprint in the long-run but reduces CO_2 emissions in the short- and long-run, which suggests that sustainable practices can decouple economic expansion from environmental degradation. Urbanization increases both ecological footprints and CO_2 emissions in the short- and long-run. In light of these outcomes, the study proposes promoting agricultural sustainability, expanding renewable energy adoption, implementing sustainable urban planning, and encouraging green economic growth.

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KEYWORDS
Ecological footprints; CO2 emissions; agricultural value-added; renewable energy; urbanisation

1. Introduction

Balancing economic growth with environmental sustainability became the central challenge faced by societies worldwide. This tradeoff arises because economic growth, driven by rapid industrialisation, increased consumption, and higher production levels, accelerates the depletion of natural resources, even as it improves living standards and advances nations toward prosperity (Hanif 2017). Since the onset of the industrial revolution around 1750, greenhouse gas (GHG) emissions have risen dramatically, particularly carbon dioxide (CO_2), leading to significant environmental and climatic impacts (Abdi 2023; Ritchie, Rosado, and Roser 2023). According to Serajuddin et al. (2017), CO_2 emissions surged by 60%, rising from 22.4 billion metric tons in 1990 to 35.8 billion in 2013. Global energy-related CO_2 emissions grew by 1.1% in 2023, increasing by 410 million

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tons to reach a record high of 37.4 billion tons (IEA 2024). Agriculture remains a cornerstone of many economies, providing food security and livelihoods, yet it also poses significant environmental challenges, such as land degradation and water scarcity (FAO 2018). Thus, understanding the ecological footprint – the measure of human demand on earth's ecosystems – is essential for evaluating the environmental impacts of these activities and guiding sustainable development policies (Wackernagel and Rees 1998). In addition, renewable energy emerges as a crucial solution to reduce dependency on fossil fuels, mitigate climate change, and foster economic opportunities (IRENA 2019). Simultaneously, economic growth must be pursued in ways that do not compromise ecological integrity, which necessitates the adoption of green growth strategies that emphasise resource efficiency and low-carbon technologies (UNEP 2017).

Economic growth impacts environmental sustainability through increased CO_2 emissions and expanding ecological footprints, which are major concerns for sustainable development (Abdi et al. 2024). In rapidly industrialising countries, economic activities significantly contribute to rising CO_2 emissions (Wang et al. 2016). Similarly, Abdi (2023) highlights how economic development is often accompanied by increased energy consumption and higher GHG emissions, challenging environmental sustainability. Moreover, economic growth's impact on ecological footprints is profound. For instance, Gernaat et al. (2015) and Jahanger et al. (2022) both highlight that economic growth, while advancing socio-economic development, leads to greater resource use, waste generation, pollution, and resource depletion, thereby exacerbating ecological footprints. Recent studies exploring the nexus between economic growth and environmental sustainability often consider the Environmental Kuznets Curve (EKC) hypothesis (Aşıcı 2013; Djellouli et al. 2022; Kasman and Duman 2015). The EKC, proposed by Simon Kuznets (1955), describes the relationship between economic growth and environmental degradation. It suggests that in the initial stages of economic growth, environmental quality deteriorates as pollution increases. This relationship forms an inverted U-shape curve, where economic development initially leads to higher levels of pollution and resource depletion. However, the trend reverses at a certain income level; further economic growth leads to environmental improvements. This turnaround is attributed to higher incomes, fostering greater environmental awareness, and the adoption of cleaner technologies and sustainable practices.

Agricultural activities play a pivotal role in shaping environmental sustainability, standing as the second largest source of GHG emissions globally, accounting for 21% of total emissions (Balsalobre-Lorente et al. 2019). Intensive agricultural practices such as deforestation for farmland, soil cultivation, fertiliser application, and livestock digestion processes are significant contributors to GHG emissions (Ali Warsame and Hassan Abdi 2023; Smith et al. 2014). Moreover, the ecological footprint of agriculture is substantial due to its extensive land use, high water consumption, and considerable resource inputs, which result in habitat destruction, biodiversity loss, and soil degradation (Salari, Roumiani, and Kazemzadeh 2021). The conversion of forests and natural landscapes into agricultural land releases stored carbon and reduces the Earth's capacity to sequester CO_2, thereby exacerbating climate change (Steffen et al. 2015). However, sustainable agricultural practices offer a pathway to mitigate these impacts. Rockström et al. (2017) advocate for agroforestry, conservation agriculture, and precision farming, which can enhance carbon sequestration and improve environmental quality. On the other hand, the environmental implications associated with rapid urbanisation are crucial. In 2020, urban areas were responsible for approximately 70% of global CO_2 emissions, a figure expected to increase with ongoing urbanisation. By 2050, around 90% of urban population growth is projected to occur in Asia and Africa, significantly impacting environmental sustainability (IEA 2021). This is because shifts in energy consumption, increased transportation, and infrastructure development associated with population growth contribute to the depletion of natural resources and increased waste generation (Liu et al. 2022; Warsame et al. 2023).

Environmental degradation arises from various factors, including the heavy reliance of many nations, especially developing economies, on nonrenewable energy sources for economic growth (Djellouli et al. 2022; Hanif 2017). Transitioning to renewable energy can significantly improve air quality, mitigate climate change, and enhance overall quality of life by reducing CO_2 emissions and the ecological footprint. Renewable energy sources such as solar, wind, and hydroelectric power are crucial for reducing dependence on fossil fuels and lowering GHG emissions (Abdi 2023). This shift is particularly effective because it displaces coal and natural gas in electricity generation, which are major contributors to CO_2 emissions (Luderer et al. 2019). The International Renewable Energy Agency (IRENA) estimates that global implementation of renewable energy could cut CO_2 emissions by approximately 70% by 2050 (IRENA 2020). Despite having some of the world's most abundant renewable energy resources, Africa exploits only a small portion of this potential (Attiaoui et al. 2017). In addition to reducing CO_2 emissions, renewable energy mitigates the ecological footprint. Renewable energy projects generally have lower environmental impacts compared to fossil fuel-based generation, requiring less water and producing minimal air and water pollution (Fthenakis and Kim 2009). This leads to a smaller ecological footprint, preserving biodiversity and reducing habitat destruction associated with fossil fuel extraction and combustion (Adebayo et al. 2022; Tsoutsos, Frantzeskaki, and Gekas 2005).

Somalia, located in the Horn of Africa, faces numerous challenges that impede its sustainable development. The country's economy is heavily dependent on agriculture, which accounts for approximately 65% of GDP and employs over 70% of the workforce. This reliance on agriculture comes with significant environmental costs. The sector's heavy dependence on non-renewable energy sources such as fossil fuels, coal, and oil, alongside the extensive use of nitrogen-rich fertilisers, contributes to substantial emissions and ecological footprints (Ali Warsame and Hassan Abdi 2023). Overgrazing and deforestation for charcoal production further exacerbate the depletion of natural resources, leading to soil erosion, vegetation loss, and accelerated land degradation (Mohamed and Nageye 2021). Somalia's ecological footprint is critically high, with natural resources under immense pressure due to unsustainable agricultural practices, deforestation, and overgrazing. These activities result in soil erosion, biodiversity loss, and degradation of arable land. Moreover, biocapacity – the ecosystem's ability to generate natural resources and absorb waste – is gradually declining in Somalia. According to the Global Footprints Network, the country has experienced an ecological deficit exceeding 3 million global hectares since 2013. This growing deficit exacerbates resource scarcity and environmental degradation, which intensifies the detrimental effects faced by the community as a whole (Ali 2024). Climate change compounds these issues, intensifying water scarcity and increasing the frequency of extreme weather events, which pose significant threats to the livelihoods of both humans and livestock (Nurgazina et al. 2021).

Figure 1 illustrates a consistent decline in both ecological footprints and CO_2 emissions per capita in Somalia from 1990 to 2020. Initially, ecological footprints show a peak around 1991, followed by a steady decline, indicating improvements in sustainable resource use and environmental practices. Similarly, CO_2 emissions exhibit a sharp reduction until the early 2000s, continuing to decrease at a slower rate thereafter. By 2020, both ecological footprints and CO_2 emissions reach their lowest levels. Despite being one of the world's least energy-consuming countries, Somalia relies heavily on biomass energy, with charcoal and firewood constituting 82% of the country's energy sources (Warsame and Sarkodie 2022). The nation consumes approximately 4 million tons of charcoal annually, contributing to environmental degradation (Federal Government of Somalia 2015). Rapid urbanisation has further strained energy resources, with 47% of the population now residing in urban areas, up from 30% three decades ago (World Bank 2024). However, only 49% of the population has access to electricity, necessitating the continued use of fossil fuels, charcoal, and firewood to meet growing energy demands, which further degrades environmental quality. Somalia possesses significant renewable energy potential, which remains largely untapped. The country enjoys high solar energy potential, with solar radiation levels ranging from 5 to 7 kWh/m^2/day and over 310 sunny days per year, equating to approximately 3,000 h of sunshine annually. In addition to benefits from robust wind conditions, Somalia has the potential for small hydropower generation, estimated between 100 and 120 MW along the Shebelle and Juba rivers (Somalia Investment Promotion Office 2022).

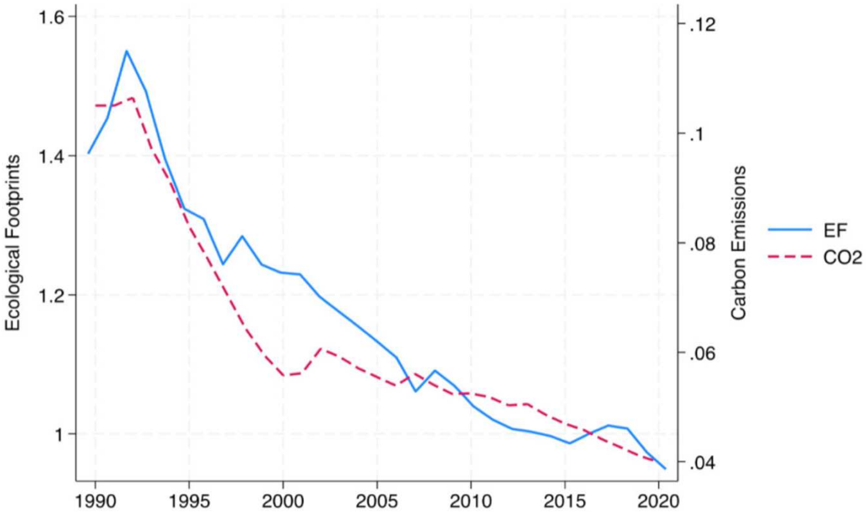

Figure 1. Ecological footprints and CO_2 emissions in Somalia.

Notwithstanding extensive research on the impact of economic growth on the environment (Galvan et al. 2022; Kasman and Duman 2015; Nurgazina et al. 2021; S. Wang et al. 2016), there is a noticeable gap in studies that simultaneously consider both ecological footprints and CO_2 emissions, particularly in the context of Somalia. The scanty previous studies from Somalia, such as Warsame et al. (2023) and Abdi et al. (2024), primarily used CO_2 emissions as the sole indicator of environmental pollution. This narrow focus leaves a critical void in our understanding of how economic activities comprehensively affect the environment, encompassing broader ecological impacts. Hence, this study aims to bridge this gap by examining the impacts of agricultural value-added, renewable energy consumption, economic growth, and urbanisation on ecological footprints and CO_2 emissions in Somalia using time-series data from 1990 to 2020. By focusing on various indicators of environmental degradation, this research provides a comprehensive analysis of the environmental impacts of economic activities. Employing robust econometric methodologies, such as the autoregressive distributed lag (ARDL) bounds testing technique and dynamic ordinary least squares (DOLS), this study seeks to offer reliable and actionable findings. Moreover, these insights are intended to guide the development of strategies that harmonise economic and environmental goals, ensuring a balanced approach to the country's sustainable future growth.

The remainder of this study is structured as follows: Section 2 provides a review of the existing literature. Section 3 outlines the methodology employed in the research. Section 4 presents the empirical results and offers a detailed discussion. Finally, the study concludes with policy implications in Section 5.

2. Literature review

The relationship between economic growth and environmental degradation has been widely examined across different regions and contexts. Studies have consistently highlighted the significant impact of economic activities on environmental indicators such as CO_2 emissions and ecological footprints. For instance, Galvan et al. (2022) demonstrated that while GDP growth in higher-income countries within Latin America substantially increases CO_2 emissions, this effect is weaker in middle-income nations. Similarly, Kasman and Duman (2015) found a long-run cointegrated relationship between energy consumption, economic growth, trade openness, urbanisation, and environmental quality among prospective EU members. In the European Union, Hysa et al. (2020) emphasised the positive correlation between the environment and economic growth, particularly through the circular economy, highlighting the critical role of innovation and sustainability in driving economic progress. However, Sun et al. (2024) explored the environmental impacts of technological advancements, economic growth, natural resource utilisation, renewable energy adoption, and urbanisation in 17 APEC countries over the period from 1990 to 2019. Their findings indicate that economic growth deteriorates environmental quality, whereas the use of renewable energy enhances environmental sustainability. This is echoed by Ahmed et al. (2023), who noted an increasing ecological deficit in Asia from 2000 to 2017, thereby advocating for rapid implementation of environmentally friendly policies to balance economic development and sustainability.

The Environmental Kuznets Curve (EKC) hypothesis has also been a focal point of research. Ertugrul et al. (2016) and Apergis and Ozturk (2015) both supported the EKC hypothesis, showing that environmental degradation increases with economic growth up to a certain point, after which it begins to decline. This indicates that further economic growth can lead to environmental improvements beyond a specific income threshold. Similarly, Bello, Solarin, and Yen (2018) found an inverted U-shaped relationship between environmental degradation and GDP in Malaysia, suggesting that initial economic growth may exacerbate environmental issues, but further growth beyond a certain point can facilitate environmental improvements. Moreover, Pata and Yurtkuran (2023) found evidence supporting the EKC hypothesis exclusively in Switzerland and Denmark, among five highly globalised European Union countries. Adebayo et al. (2024) explored the dynamic relationships between economic growth, agriculture, energy utilisation, urbanisation, and environmental degradation in Pakistan. They reveal a significant bidirectional causality between economic expansion and environmental deterioration. Nathaniel, Nwulu, and Bekun (2021) added to this discourse by demonstrating that while economic growth and natural resource exploitation increase ecological footprints, the adoption of renewable energy can mitigate these effects. By the same token, Kartal et al. (2023) discovered that investments in renewable energy technologies have positive environmental effects, whereas economic growth and financial development negatively impact environmental quality.

The empirical studies recognised the significant role of renewable energy in mitigating environmental degradation across various regions. Ibrahim and Ajide (2021) investigated the effects of trade openness, nonrenewable energy, and renewable energy on environmental quality in the G7 countries from 1990 to 2019. Their findings revealed that while trade openness and nonrenewable energy use increased environmental degradation, renewable energy consumption effectively reduced them. Similarly, Sbia, Shahbaz, and Hamdi (2014) examined the connection between economic growth, foreign direct investment (FDI), clean energy, and carbon emissions in the United Arab Emirates from 1975 to 2011. They discovered that clean energy positively influenced energy consumption and economic growth, while trade openness and FDI reduced energy demand. In the N-11 countries, Sinha, Shahbaz, and Balsalobre (2017) demonstrated that nonrenewable energy exacerbates environmental degradation, whereas renewable energy mitigates it. Nepal et al. (2021) emphasised the importance of energy-efficient practices through FDI to reduce carbon emissions and enhance energy security. By using disaggregated renewable electricity sources, Al-Mulali, Ozturk, and Lean (2015) found that while GDP growth, urbanisation, and financial development undermined environmental quality, renewable electricity from nuclear power, hydroelectricity, and waste had a long-run positive impact in 23 European nations. Besides, Smolović et al. (2020) analysed the link between economic growth and renewable energy use in EU member states, showing a positive long-term impact of renewable energy on economic growth, though the effect was negative in the short term for new member states. In South America, Ali et al. (2022) demonstrated that although economic growth initially increased pollution, the use of renewable energy reduced it significantly.

Furthermore, Zhao et al. (2022) focused on China's renewable energy regulations and green economic growth, emphasising the role of environmental laws in fostering renewable energy development and sustainable economic progress. Sharma, Sinha, and Kautish (2021) highlighted that increased renewable energy use significantly reduced the ecological footprint despite rising emissions due to population density increases. Several studies conducted across Africa have indicated the critical role of renewable energy in mitigating environmental degradation and fostering economic growth. Djellouli et al. (2022) examined the relationship between environmental degradation, renewable and nonrenewable energy, economic growth, and FDI in 20 African countries from 2000 to 2015, finding that all variables except renewable energy were significantly and positively correlated with CO_2 emissions. Using various environmental indicators, Kartal and Pata (2023) and Abdi et al. (2024) found that while renewable energy consumption decreases CO_2 emissions and ecological footprints, globalisation increases them. However, Samour and Pata (2022) found a significant negative impact of the US interest rate on renewable energy adoption through income. Pata et al. (2024) also identified that renewable energy not only offers environmental benefits but also exhibits a bidirectional causal relationship with economic growth. Using panel data from 37 African countries, Qudrat-Ullah and Nevo (2021) concluded that renewable energy development boosts economic growth in both the short- and long-term. Mohamud and Mohamud (2023) investigated the relationship between renewable energy use, economic growth, and environmental degradation in Somalia from 1990 to 2020. They found a negative correlation between renewable energy consumption and environmental degradation.

The literature has presented varying impacts of agriculture on environmental quality across different regions and economic contexts. Usman et al. (2022) analysed the effects of agricultural value-added, economic growth, tourism, non-renewable energy, and renewable energy on CO_2 emissions in South Asian countries from 1995 to 2017. They found that increased tourism, economic growth, non-renewable energy use, and agricultural value-added significantly contributed to environmental degradation. Additionally, Najafi Alamdarlo (2016) found an inverted U-shaped relationship between per capita income and both water consumption and CO_2 emissions. Spatial estimation revealed that agricultural sector emissions had a direct relationship with these variables in neighbouring areas. In Azerbaijan, Gurbuz, Nesirov, and Ozkan (2021) found a unidirectional causality from agricultural value-added and energy consumption to carbon emissions. In the five most populous Asian countries, Li et al. (2023) indicated that agricultural value addition and globalisation increased the ecological footprint, whereas renewable energy use mitigated it. Conversely, Wang et al. (2020) found that while globalisation, financial development, and natural resources increased carbon emissions, agricultural value-added decreased them. Using panel cointegration techniques and Granger causality tests in five North African countries, Ben Jebli and Ben Youssef (2015) indicated bidirectional causality between CO_2 emissions and agriculture in the short-run, while long-run results showed that increased agricultural value-added reduced environmental degradation. In low and lower-middle-income countries, Ali et al. (2019) and Anwar et al. (2019) explored the correlation between agricultural value-added and environmental quality, concluding that there is a positive but insignificant association.

Urbanisation emerges as a critical factor influencing environmental quality, with its long-term effects varying significantly across different contexts and regions. Munir and Ameer (2018) investigated the short- and long-term impacts of trade openness, urbanisation, economic growth, and technological advancements on environmental degradation in developing Asian countries. Their research revealed that while urbanisation eventually improves environmental quality, both trade openness and technological progress help mitigate environmental degradation. In a similar vein, Sahoo and Sethi (2021) reported that in developing nations, economic growth, reliance on non-renewable energy, and urbanisation lead to an increased ecological footprint. On the other hand, renewable energy positively impacts environmental quality, whereas globalisation has a detrimental effect. However, Abdi (2023) argues that urbanisation exacerbates environmental pollution over the long term. Likewise, Warsame et al. (2023) demonstrated that in Somalia, external conflict, globalisation, and urbanisation contribute to long-term CO_2 emissions, though they do not have the same impact in the short term. Using GHG emissions as an environmental indicator, Hussein, Warsame, and Abdi (2024) found that urbanisation increases emissions in the short run but has no significant long-term impact. In addition, Pata, Kartal, and Zafar (2023) indicate that CO_2 emissions increase because of geopolitical risks and economic policy uncertainty. Wang et al. (2023) and Hassan et al. (2019) concluded that natural resources significantly shape the country's ecological footprints.

The current body of literature on environmental sustainability exhibits several key gaps. Generally, there has been an insufficient focus on integrating ecological footprints as a comprehensive indicator of environmental impact, with much of the research disproportionately emphasising CO_2 emissions. Additionally, while the relationships between economic growth, urbanisation, and environmental degradation have been extensively studied in various contexts, there remains a lack of consensus on the long-term impacts of urbanisation, particularly when considering diverse environmental indicators across different regions. Specifically in Somalia, the literature is limited and fragmented, often neglecting the interactions between agriculture, renewable energy, and urbanisation in contributing to environmental outcomes. The role of agriculture, in particular, has been underexplored despite its significant impact on both CO_2 emissions and broader ecological footprints. From a methodological perspective, there is a noticeable gap in the use of integrated approaches that simultaneously assess the impact of multiple sectors, such as agriculture, energy, and urbanisation, on ecological footprints and CO_2 emissions. Most studies have employed single-indicator analyses or limited-scope models, failing to capture the broader environmental implications of combined economic activities. This study aims to bridge these gaps by utilising robust econometric methodologies, such as the ARDL bounds testing technique and DOLS, to provide a comprehensive understanding of sustainable development pathways in Somalia.

3. Materials and methods

3.1. Variables and data

Somalia faces severe environmental challenges, including land degradation and natural resource depletion, driven by both natural and human-induced factors. These environmental issues significantly impact the livelihoods of the Somali population, which predominantly relies on rain-fed agriculture (Abdi et al. 2024). However, agriculture significantly impacts the environment through practices that lead to land degradation, deforestation, and water resource depletion, exacerbating soil erosion and reducing arable land quality (Ali Warsame and Hassan Abdi 2023). Hence, this study aims to investigate the effects of economic growth, renewable energy consumption, agricultural value-added, and urbanisation on environmental sustainability in Somalia. To achieve the objectives of the study, we utilise time series data from 1990 to 2020, sourced from reputable databases such as the Global Footprint Network, World Development Indicators (WDI), and the Organisation of Islamic Cooperation database – SESRIC. The model incorporates variables including ecological footprints, CO_2 emissions, renewable energy consumption, agricultural value-added, economic growth, and urban population growth. Ecological footprints and CO_2 emissions serve as the dependent variables, acting as proxies for environmental quality, while the remaining variables are independent variables. To ensure consistency and reduce variance, all variables are transformed into their natural logarithms. This transformation helps in achieving a more stable and interpretable relationship between the variables. Table 1 provides a summary of the data descriptions and sources used in the study.

3.2. Econometric modelling

To achieve the objectives of this study and examine the cointegrating properties of the scrutinised variables, we utilise the ARDL model developed by Pesaran, Shin, and Smith (2001). For several reasons, the ARDL model is preferred over traditional cointegration methods. Firstly, the ARDL model effectively tackles the complications of co-integration among the variables by offering flexibility in handling variables with mixed orders of integration, i.e. I(0), I(1), or a combination of both,

Table 1. Variables, data sources, description, and symbols.

Variable	Symbol	Description	Source
Ecological footprints	EF	Ecological footprint (gha)	Global Footprints Network
Carbon emissions	CO_2	CO_2 emissions (metric tons per capita)	WDI
Renewable energy	REC	Renewable energy consumption (% of total final energy consumption)	WDI
Economic growth	EG	GDP per capita (constant 2015 $US)	SESRIC
Agricultural value-added	AVA	Agriculture, value-added, constant 2015 prices	SESRIC
Urbanisation	URB	Urban population (% of total population)	WDI

provided none are I(2). Traditional models, which require all variables to be integrated in the same order, are less accommodating and may lead to inaccurate forecasts and unreliable analyses when this condition is not met. The model also evaluates the long-term cointegration among the variables using the F-bounds test, which determines whether the variables maintain a significant relationship over time. Secondly, the ARDL approach is robust to small sample sizes. Given that our dataset spans from 1990 to 2020 with annual observations, the relatively small number of data points necessitates a method that can deliver unbiased and consistent estimates despite the limited sample size. Additionally, the ARDL model allows for flexibility in the lag specification, enabling the selection of appropriate lags based on information criteria such as the Akaike Information Criterion (AIC). Moreover, the ARDL method simultaneously estimates both short-run and long-run relationships, offering a comprehensive analysis of the impacts of the independent variables on environmental sustainability.

To investigate the role of the interested variables in environmental quality, we utilised two dependent variables: ecological footprints and CO2 emissions. Consequently, in modelling the impact of renewable energy, economic growth, agriculture, and urbanisation on environmental sustainability, we followed the model specifications outlined by Hassan et al. (2019), Gurbuz, Nesirov, and Ozkan (2021), Charfeddine (2017), Cetin, Ecevit, and Yucel (2018), and Djellouli et al. (2022), who incorporated similar variables in their analyses. Therefore, the model specifications for both dependent variables are presented in Equation (1) and Equation (2).

$$InEF_t = \alpha_0 + \alpha_1 InAVA_t + \alpha_2 InREC_t + \alpha_3 InEG_t + \alpha_4 InURB_t + \mu_t \tag{1}$$

$$InCO_{2t} = \beta_0 + \beta_1 InAVA_t + \beta_2 InREC_t + \beta_3 InEG_t + \beta_4 InURB_t + \varepsilon_t \tag{2}$$

where lnEF, $\ln CO_2$, lnAVA, lnREC, lnEG, and lnURB represent the natural logarithms of ecological footprints, carbon dioxide emissions, agricultural value-added, renewable energy consumption, economic growth, and urbanisation, respectively. The terms α_0 and β_0 are the intercepts, while μ_t and ε_t denote the error terms, which are normally distributed with a zero mean and constant variance. Additionally, α_1 through α_4 and β_1 through β_4 are the long-run coefficients to be estimated, reflecting the influence of the independent variables on ecological footprints and CO_2 emissions, respectively. Primarily, the objective of this study is to investigate the long-run connection among agriculture, renewable energy, economic growth, urbanisation, and ecological footprints. To achieve this, we estimate the conditional ARDL model corresponding to Equation (1) of Model I, which is articulated as follows:

$$\begin{aligned} \Delta lnEF_t = {} & \alpha_0 + \alpha_1 lnEF_{t-1} + \alpha_2 lnAVA_{t-1} + \alpha_3 lnREC_{t-1} + \alpha_4 lnEG_{t-1} + \alpha_5 lnURB_{t-1} + \\ & \sum_{i=1}^{p} 1\delta_1 \Delta lnEF_{t-i} + \sum_{i=1}^{q} 2\delta_2 \Delta lnAVA_{t-i} + \sum_{i=1}^{q} 3\delta_3 \Delta lnREC_{t-i} + \sum_{i=1}^{q} 4\delta_4 \Delta lnEG_{t-i} + \\ & \sum_{i=1}^{q} 5\delta_5 \Delta lnURB_{t-i} + \mu_t \end{aligned} \tag{3}$$

where α_1 to α_5 represent the long-run coefficients, δ_1 to δ_5 denote the short-run coefficients, p and q indicate the optimal lag lengths of the variables, Δ represents the first difference operator, capturing the short-run parameters, and i stands for the lags. The conditional ARDL model symbolyzing Eq. (2) of Model II is articulated as follows:

$$\begin{aligned}\Delta lnCO_{2_t} = {} & \beta_0 + \beta_1 lnCO_{2_{t-1}} + \beta_2 lnAVA_{t-1} + \beta_3 lnREC_{t-1} + \beta_4 lnEG_{t-1} + \beta_5 lnURB_{t-1} + \\ & \sum_{i=1}^{p} \gamma_1 \Delta lnCO_{2_{t-1}} + \sum_{i=1}^{q} \gamma_2 \Delta lnAVA_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta lnREC_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta lnEG_{t-i} + \\ & \sum_{i=1}^{q} \gamma_5 \Delta lnURB_{t-i} + \varepsilon_t \end{aligned} \tag{4}$$

where β_1 to β_5 denote the long-run coefficients, and γ_1 to γ_5 illustrate the short-run coefficients. To initially determine the long-run cointegration among the fundamental variables, we apply the ordinary least squares (OLS) regression approach to analyse Equation (3) and (4). To assess the long-run association between the variables, this study applies the Wald F-statistic to test the null hypothesis of no cointegration for Model I (H_0:$\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$) against the alternative hypothesis indicating the existence of cointegration (H_a:$\alpha_1 \neq \alpha_2 \neq \alpha_3 = \alpha_4 \neq \alpha_5 \neq 0$). Moreover, the null hypothesis of no cointegration relationship for Model II (H_0:$\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$) against the alternative hypothesis (H_a:$\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq 0$). The Wald-test values determine whether to reject or accept the null hypothesis by comparing the computed F-statistic with the critical values of the lower bound I(0) and the upper bound I(1). The decision rule is straightforward: if the F-statistic lies above the upper bound, the null hypothesis of no cointegration is rejected, indicating a long-run relationship between the variables. Conversely, if the F-statistic is below the lower bound, we fail to reject the null hypothesis, suggesting no cointegration. If the F-statistic falls between the bounds, the result is inconclusive. After performing cointegration tests using Equations (3) and (4), the next step involves employing error correction models (ECM) to study the short-run relationships between the independent variables and the dependent variables. The error correction term (ECT) coefficients are indicated by ψ and ϕ. Thus, Equations (3) and (4) are redefined within an error correction framework as follows:

$$\begin{aligned}\Delta lnEF_t = {} & \alpha_0 + \sum_{i=1}^{p} \delta_1 \Delta lnEF_{t-i} + \sum_{i=1}^{q} \delta_2 \Delta lnAVA_{t-i} + \sum_{i=1}^{q} \delta_3 \Delta lnREC_{t-i} \\ & + \sum_{i=1}^{q} \delta_4 \Delta lnEG_{t-i} + \sum_{i=1}^{q} \delta_5 \Delta lnURB_{t-i} + +\psi ECT_{t-1} + \mu_t \end{aligned} \tag{5}$$

$$\begin{aligned}\Delta lnCO_{2_t} = {} & \beta_0 + \sum_{i=1}^{p} \gamma_1 \Delta lnCO_{2_{t-1}} + \sum_{i=1}^{q} \gamma_2 \Delta lnAVA_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta lnREC_{t-i} \\ & + \sum_{i=1}^{q} \gamma_4 \Delta lnEG_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta lnURB_{t-i} + \phi ECT_{t-1} + \varepsilon_t \end{aligned} \tag{6}$$

4. Findings and discussion

The descriptive summary of the series is presented in Table 2. The reported descriptive statistics summarise and present the main features of the datasets, including the central tendencies and variability. The mean values for the sample are as follows: ecological footprints (0.062), CO_2 emissions (−1.223), agricultural value-added (9.248), renewable energy consumption (1.967), economic growth (2.507), and urbanisation (1.561). The agricultural value-added, economic growth, and

Table 2. Descriptive analysis and pair-wise correlation.

	lnEF	lnCO$_2$	lnAVA	lnREC	lnEG	lnURB
Mean	0.062	−1.223	9.248	1.967	2.507	1.561
Maximum	0.190	−0.973	9.679	1.980	2.756	1.664
Minimum	−0.023	−1.399	8.935	1.936	2.341	1.472
Std. Dev.	0.061	0.123	0.245	0.011	0.134	0.062
Skewness	0.465	0.796	0.441	−1.282	0.683	0.257
Kurtosis	2.060	2.614	1.940	4.021	2.271	1.671
Jarque-Bera	2.262	3.469	2.457	9.840	3.095	2.622
Probability	0.323	0.177	0.293	0.007	0.213	0.270
Observations	31	31	31	31	31	31

urbanisation indicate the highest observed maximum values, while CO$_2$ emissions (−1.399) and ecological footprints (−0.023) present the lowest observed minimum values. Standard deviation reflects the variability of the data points around the mean, with agricultural value-added having the highest standard deviation of 0.245, indicating moderate dispersion, and renewable energy usage showing the least variability at 0.011. The skewness values provide insights into the data distribution's asymmetry, where most of the variables show positive skewness values, suggesting a right-skewed distribution. Only renewable energy consumption (−1.282) has negative skewness, which indicates a left-skewed distribution. In addition, kurtosis values measure the tailedness of the data distribution. For instance, renewable energy consumption has a kurtosis of 4.021, indicating a leptokurtic distribution with heavier tails, whereas urbanisation, with a kurtosis of 1.671, is platykurtic, suggesting lighter tails. The Jarque-Bera test statistics and their associated probabilities assess the normality of the data distribution. While only renewable energy consumption has shown a lower probability value, which implies a deviation from normality, all variables demonstrate higher values, which suggests that the data distribution is closer to normal.

Based on the correlation analysis, summarised in Table 3, we measured the degree to which the movement of two variables is associated. The signs of the correlation coefficients vary, indicating both positive and negative associations among the variables. For instance, ecological footprints and CO2 emissions have strong negative correlations with agricultural value-added, renewable energy consumption, economic growth, and urbanisation. This pattern indicates that higher values of these variables are associated with a lower ecological footprint and CO2 emissions. It is essential to note that while many correlations are strong, they are all meaningful and indicate significant relationships among the variables in the context of the study.

Time series data often exhibit trends and may contain unit root problems, which can result in spurious regression if not properly addressed. To ensure the stationarity of the variables, we performed several unit root tests: the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test. The null hypothesis for both tests indicates the presence of a unit root, while the alternative hypothesis suggests its absence. The results of these tests are presented in Table 4. Our analysis reveals that all variables are stationary at a combination of levels I(0) and first differences I(1). Specifically, agricultural value-added and renewable energy consumption are stationary at level I (0), while the remaining variables become stationary after differencing I(1). Given this mixed

Table 3. Pairwise-correlation analysis.

	lnEF	lnCO$_2$	lnAVA	lnREC	lnEG	lnURB
lnEF	1.000					
lnCO$_2$	0.949	1.000				
lnAVA	−0.885	−0.825	1.000			
lnREC	−0.900	−0.974	0.741	1.000		
lnEG	−0.773	−0.704	0.976	0.618	1.000	
lnURB	−0.939	−0.896	0.961	0.851	0.907	1.000

Table 4. Unit root test results.

Variables	ADF		PP	
	Level			
	Intercept	Intercept and trend	Intercept	Intercept and trend
lnEF	−1.107	−2.257	−0.297	−2.257
lnCO$_2$	−2.055	−3.805**	−1.643	−1.531
lnAVA	0.254	−3.642**	0.894	−4.137**
lnREC	−5.950***	−3.370*	−5.950***	−5.001***
lnEG	−0.009	−3.077	0.408	−2.166
lnURB	0.086	−2.464	0.598	−2.455
	Δ			
	Intercept	Intercept and trend	Intercept	Intercept and trend
ΔlnEF	−4.882***	−4.831***	−5.374***	−7.962***
ΔlnCO$_2$	−3.310**	−3.539*	−3.299**	−3.539*
ΔlnAVA	−2.845*	−2.435	−3.309**	−3.542*
ΔlnREC	−3.526**	−3.439*	−3.526**	−3.439*
ΔlnEG	−4.008***	−4.386***	−4.052***	−4.403***
ΔlnURB	−5.474***	−5.420***	−6.078***	−6.800***

Note: ***, **, and * symbolise significance level at 1%, 5%, and 10%. Δ represents first difference level.

order of integration, the ARDL method is the most appropriate model for our data, as it is well-suited to handle variables integrated at different orders.

The study employed the Krolzig and Hendry (2001) general-to-specific approach within the ARDL framework to identify the most efficient lag length for our models. This method efficiently tackles serial correlation and model stability concerns by progressively removing variables with the highest *P*-values, ensuring that the error term becomes uncorrelated and the parameters reach stability. Since the sample size of the study was small, we adopted 3 lags at maximum. Next, the presence of long-run cointegration between the dependent variables and the predictors was explored using the Wald F-statistics test. The test operates under the null hypothesis of no cointegration, while the alternative hypothesis asserts the presence of cointegration. Table 5 presents the test results, showing that the independent variables – agricultural value-added, renewable energy consumption, economic growth, and urban population – exhibit long-run cointegration with the dependent variables – ecological footprints and CO$_2$ emissions. Specifically, the Wald F-statistic for ecological footprints (12.930) and CO$_2$ emissions (6.832) surpasses the upper bound critical value of 5.476 at the 1% significance level. This leads to the rejection of the null hypothesis of no long-run cointegration, thereby confirming a long-run equilibrium relationship between the ecological footprints, CO$_2$ emissions, and the examined regressors.

Following the determination of the variables' integration order and the establishment of a cointegration relationship, the long-run and short-run results of both Models I and II are presented in Table 6. For Model I, the analysis reveals that all independent variables significantly impact the ecological footprint in the long-run, except for the urban population rate. In the long run, agricultural value-added has a significant negative impact on both the ecological footprint and CO$_2$ emissions in Somalia. Specifically, a 1% increase in agricultural value-added leads to a 0.23% reduction in the ecological footprint, a result that is significant at the 1% level. Although agricultural value-added also contributes to a reduction in CO$_2$ levels by 0.06%, this effect is statistically insignificant. These outcomes are consistent with the results of Gurbuz, Nesirov, and Ozkan (2021) and Wang et al. (2020), supporting the notion that improvements in agricultural productivity can lead to better environmental outcomes. Conversely, Usman et al. (2022) found that agricultural value-added undermines environmental quality. In contrast, Ali et al. (2019) identified a positive but insignificant linkage between agricultural value-added and environmental impacts. In the context of Somalia, enhancing agricultural productivity and efficiency can significantly reduce the overall environmental impact. This reduction is likely achieved through the adoption of more sustainable

Table 5. Bounds testing outcomes.

Model	*F*-statistic	Bounds test critical values, *k* = 4: I(0)	I(1)	Decision
lnEF=*f*(lnAVA, lnREC, lnEG, lnURB)	12.930	4.320*** 3.033** 2.518*	5.785*** 4.188** 3.513*	Cointegration
$lnCO_2$=*f*(lnAVA, lnREC, lnEG, lnURB)	6.832	4.320*** 3.033** 2.518*	5.785*** 4.188** 3.513*	Cointegration

Note: ***, **, and * symbolise significance level at 1%, 5%, and 10%.

Table 6. Long-run and short-run outcomes.

	Model I: lnEF			Model II: $lnCO_2$		
Variable	Coefficient	Std. Error	*t*-Statistic	Coefficient	Std. Error	t-Statistic
Long-run estimates						
Constant	2.820***	0.650	4.340	12.566***	2.536	4.954
lnAVA	−0.227***	0.038	−5.891	−0.060	0.060	−1.007
lnREC	−0.737*	0.373	−1.973	−6.751***	1.257	−5.369
lnEG	0.243***	0.062	3.892	−0.160*	0.080	−2.005
lnURB	0.083	0.096	0.867	0.737***	0.151	4.889
Short-run estimates						
Constant	−0.024***	0.005	−4.554	−0.069*	0.035	−1.977
$\Delta lnEF_{t-1}$	−0.604***	0.183	−3.291			
$\Delta lnEF_{t-2}$	−0.213	0.153	−1.395			
$\Delta lnEF_{t-3}$	−0.533***	0.152	−3.507			
$\Delta lnCO_{2t-1}$				0.393	0.248	1.585
$\Delta lnCO_{2t-2}$				−0.158	0.173	−0.909
$\Delta lnAVA$	0.527**	0.193	2.722			
$\Delta lnAVA_{t-1}$	0.060	0.066	0.921	0.063	0.075	0.849
$\Delta lnAVA_{t-2}$				0.081	0.250	0.323
$\Delta lnAVA_{t-3}$				−0.176**	0.075	−2.357
$\Delta lnREC$				−10.226***	1.584	−6.457
$\Delta lnREC_{t-1}$	−0.468	1.139	−0.411	2.713	2.970	0.914
$\Delta lnREC_{t-2}$	−1.493	1.105	−1.351	−2.821	1.857	−1.519
$\Delta lnREC_{t-3}$	2.613**	1.019	2.564			
$\Delta lnEG$	−0.444**	0.195	−2.281	−0.271***	0.071	−3.831
$\Delta lnEG_{t-2}$				−0.150	0.220	−0.682
$\Delta lnEG_{t-3}$	0.155**	0.055	2.826			
$\Delta lnURB$	0.270*	0.136	1.989	0.033	0.180	0.184
ECT_{t-1}	−0.159**	0.062	−2.582	−0.104**	0.048	−2.149

Note: ***, **, and * symbolize significance level at 1%, 5%, and 10%.

farming practices and improved resource management. By implementing these strategies, Somalia can mitigate environmental degradation and promote ecological sustainability, contributing to the country's long-term sustainable development.

In the long run, renewable energy consumption significantly reduces both the ecological footprint and CO_2 emissions in Somalia. Specifically, a 1% increase in renewable energy consumption leads to a 0.74% decrease in the ecological footprint at the 10% significance level and a substantial 6.75% reduction in CO_2 emissions at the 1% significance level. Our findings are supported by Abdi (2023) and Mohamud and Mohamud (2023), who also reported the negative effect of clean energy on CO_2 emissions. Similarly, Sharma, Sinha, and Kautish (2021) found a negative correlation between renewable energy and the ecological footprint in South and Southeast Asia. The combustion of fossil fuels releases significant emissions, including hazardous pollutants such as sulfur dioxide and nitrogen oxide, contributing substantially to air pollution and climate change. In contrast, renewable energy plays a pivotal role in promoting ecological sustainability and mitigating adverse environmental impacts. Transitioning to renewable energy sources reduces environmental degradation and presents the effectiveness of renewable energy policies in combating climate change and lowering GHG emissions. This could potentially provide a sustainable pathway for Somalia's development.

Moreover, economic growth has a complex impact on the Somalia's environmental sustainability in the long-run. Economic growth enhances environmental quality by reducing CO_2 emissions but also deteriorates it by increasing ecological footprints. A 1% increase in GDP leads to a 0.24% rise in the ecological footprint at the 1% significance level, indicating that economic expansion heightens environmental impact due to increased production and consumption activities. This finding aligns with Ahmad et al. (2020) and Hassan et al. (2019), who found that economic growth expands ecological footprints, contributing to environmental degradation. However, economic growth contributes to a 0.16% reduction in CO_2 emissions, suggesting that when aligned with sustainable practices and technologies, economic growth can decouple from environmental degradation. This result supports the Environmental Kuznets Curve (EKC) hypothesis, which posits that as income improves, technological advancements and shifts towards cleaner energy are introduced, thereby reducing CO_2 emissions. This finding is consistent with studies by Acheampong (2018) in Caribbean-Latin America. Conversely, our results are contrary to the findings of Aye and Edoja (2017) and Mikayilov, Galeotti, and Hasanov (2018), who indicated the absence of the EKC hypothesis in their studies. While economic growth in Somalia contributes to increasing ecological footprints, indicating heightened environmental pressures, it simultaneously aids in reducing CO_2 emissions when coupled with sustainable practices.

In the long-run, urbanisation contributes to both ecological footprints and CO_2 emissions in Somalia. Despite being statistically insignificant, a 1% increase in the urban population results in a 0.08% rise in the ecological footprint. Moreover, a 1% increase in long-run urbanisation levels leads to a substantial 0.74% increase in CO_2 emissions. In contrast to Abdi and Hashi (2024), who indicated that urbanisation has a negative and insignificant effect on environmental degradation in Somalia, our findings align with Warsame et al. (2023). Similarly, Ahmad et al. (2021) reported that urbanisation enhances ecological footprints in the G-7 countries. This indicates that as urban areas in Somalia expand and the urban population grows, both the ecological footprint and CO_2 emissions rise significantly. This increase can be attributed to higher energy consumption, increased transportation, industrial activities, and other urban infrastructure developments that contribute to higher carbon emissions. To meet this rising demand, countries often rely heavily on fossil fuels, further exacerbating environmental degradation. Furthermore, rapid urbanisation leads to higher levels of industrialisation, which in turn increases the number of emissions released into the atmosphere.

The short-run results of the study reveal that the previous year's ecological footprints led to a decrease in the current value of ecological footprints. In contrast to the long-run results, the short-run analysis shows a positive impact of agricultural value-added on both ecological footprints and CO_2 emissions. Consistent with the long-run findings, the short-run impact of renewable energy consumption and the level of urbanisation remain similar. A 1% change in urbanisation significantly raises the ecological footprint by 0.27% and CO_2 emissions insignificantly by 0.03%. Conversely, changes in renewable energy consumption significantly reduce CO_2 emissions by 10.23% in the short-run. In addition, economic growth continues to exhibit a negative and significant impact on both models in the short-run. Specifically, a 1% change in GDP reduces the ecological footprint by 0.44% and CO_2 emissions by 0.27%. Additionally, Table 6 presents the ECT as statistically significant, with a negative coefficient of -0.159. This indicates that any short-run disequilibrium in the dependent variables is adjusted by 15.9% and 10.4% in the long-run, driven by the independent variables.

To validate the estimated models, we conducted a series of diagnostic checks, including tests for serial correlation, heteroscedasticity, normality, and functional form for both models. As presented in Table 7, the empirical results confirm that both models are free from these issues, ensuring the robustness of our findings. Furthermore, we performed stability tests using the Cumulative Sum

Table 7. Diagnostic test findings.

Test (Type)	Model I: lnEF Statistic	Model II: $lnCO_2$ Statistic
Adjusted R^2	0.619	0.813
Serial correlation (Breusch-Godfrey LM test)	1.711 [0.1908]	8.939 [0.0626]
Heteroscedasticity (Breusch–Godfrey test)	21.340 [0.1263]	13.811 [0.3873]
Normality test (Jarque-Bera)	0.427 [0.8073]	0.681 [0.7113]
Functional form (Ramsey RESET test)	1.133 [0.2836]	0.850 [0.4117]

Note: the t-statistic values are in […]

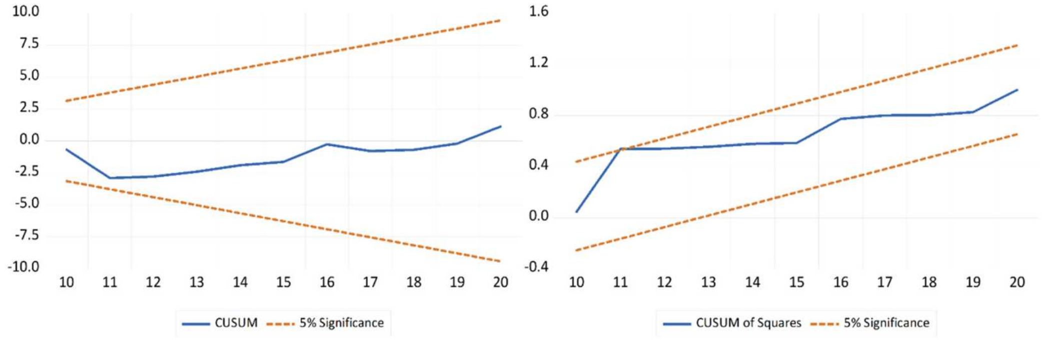

Figure 2. Stability tests of Model I.

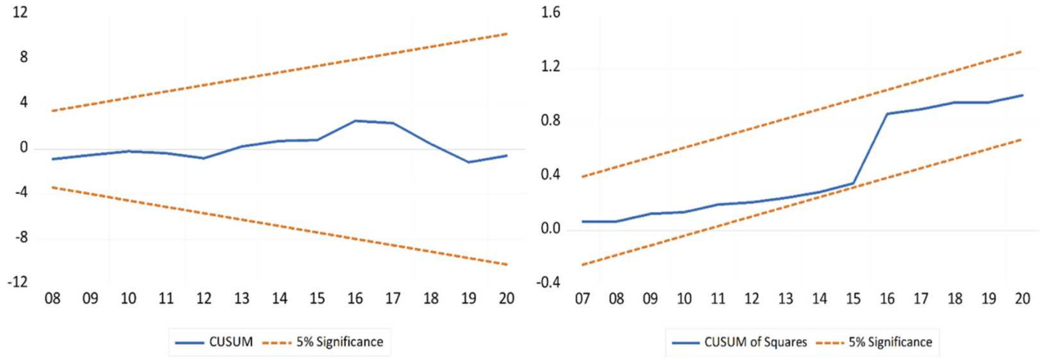

Figure 3. Stability tests of Model II.

(CUSUM) and Cumulative Sum of Squares (CUSUMSQ) methods. As illustrated in Figures 2 and 3, the results indicate that the plots for both tests fall within the critical boundaries at the 5% significance level, confirming the stability of the models. Additionally, the adjusted R^2 values for Model I and Model II are 0.62 and 0.81, respectively. This implies that the independent variables – agricultural value-added, economic growth, urbanisation, and renewable energy consumption – explain 62% and 81% of the variations in the dependent variables, ecological footprints, and carbon dioxide emissions, respectively.

The robustness of the ARDL findings is strongly corroborated by the results from the DOLS estimator of the two models, which exhibit consistent trends and reinforce the reliability of the initial results. As presented in Table 8, the DOLS estimations reveal that agricultural value-added has a

Table 8. Long-run elasticities of the DOLS estimator.

	Model I: lnEF			Model II: $\ln CO_2$		
Variable	Coefficient	Std. Error	*t*-Statistic	Coefficient	Std. Error	*t*-Statistic
Constant	4.042***	1.022	3.954	18.252***	1.573	11.606
lnAVA	−0.460***	0.084	−5.503	−0.602***	0.128	−4.684
lnREC	−0.365	0.623	−0.585	−8.262***	0.959	−8.615
lnEG	0.673***	0.118	5.709	0.635***	0.181	3.504
lnURB	−0.448**	0.217	−2.068	0.477	0.333	1.43
R^2	0.972			0.987		
Adjusted R^2	0.967			0.985		

Note: ***, **, and * symbolise significance level at 1%, 5%, and 10%. Std. Error indicates the standard error of the parameters.

significant negative impact on both the ecological footprint and CO_2 emissions, highlighting the critical role of increasing agricultural productivity and efficiency in mitigating environmental impacts. Similarly, renewable energy consumption demonstrates a substantial negative effect on both ecological footprint and CO_2 emissions, underscoring its importance in reducing environmental degradation and combating climate change. Conversely, economic growth exhibits a significant positive impact on both the ecological footprint and CO_2 emissions, suggesting that economic expansion is associated with increased environmental pressure and higher GHG emissions. Urbanisation presents a nuanced impact: it significantly reduces the ecological footprint but has an insignificant effect on CO_2 emissions in both models. The high R^2 and adjusted R^2 values across the DOLS models confirm that a substantial proportion of the variance in both ecological footprint and CO_2 emissions is explained by the independent variables.

5. Conclusion and policy recommendations

Environmental sustainability has become a prominent concern in recent years, particularly for developing economies. As these economies grow and populations expand, environmental quality typically deteriorates, further exacerbating the already fragile living conditions of people in these regions. In pursuit of a sustainable future, this study investigated the impact of economic growth, urbanisation, agricultural value-added, and renewable energy consumption on ecological footprints and carbon dioxide emissions in Somalia, using time series data from 1990 to 2020. The study employed the ARDL method to test for co-integration among the variables using the F-bounds testing technique. Additionally, the robustness of the study was assessed using DOLS to ensure the reliability of our results. The findings of this study reveal that, in the long run, agricultural value-added and renewable energy consumption significantly reduce both ecological footprints and CO_2 emissions in Somalia. These results highlight the importance of enhancing agricultural productivity and increasing the use of renewable energy sources as key strategies for environmental sustainability. In the short-run, however, agricultural value-added temporarily increases both ecological footprints and CO_2 emissions, although the impact of renewable energy consumption remains consistent with the long-run findings. Remarkably, economic growth exhibits a dual effect: while it significantly increases the ecological footprint in the long-run, indicating heightened environmental pressures from expanded economic activities, it concurrently reduces CO_2 emissions both in the long- and short-run. This suggests that when economic growth is coupled with sustainable practices and technologies, it can help decouple economic expansion from environmental degradation. Moreover, urbanisation presents a more complex picture, as it increases both ecological footprints and CO_2 emissions in both the short- and long-run. This demonstrates the environmental challenges associated with urban population growth and the need for sustainable urban planning to mitigate these impacts.

Based on the findings of this study, we provide several policy insights aimed at promoting environmental sustainability in Somalia. Firstly, promoting agricultural sustainability is crucial, as agricultural value-added significantly reduces environmental degradation in the long-run.

Policymakers should focus on enhancing agricultural productivity through sustainable farming practices, investing in agricultural research and development, and providing farmers with access to sustainable technologies. Secondly, expanding renewable energy adoption is essential, given its substantial impact on reducing environmental deterioration. Policymakers should prioritise the expansion of renewable energy infrastructure, such as solar and wind energy, by providing incentives for private investment in renewable energy projects and ensuring regulatory support. Thirdly, implementing sustainable urban planning is necessary to mitigate the environmental impacts of urbanisation, which undermines environmental quality. Policymakers should develop and enforce urban planning regulations that promote green spaces, efficient public transportation, and sustainable building practices. Lastly, encouraging green economic growth is vital, as economic growth has the potential to reduce CO_2 emissions when coupled with sustainable practices. Policymakers should incentivize businesses to adopt clean technologies and sustainable practices through tax breaks, subsidies for green technology, and green business certification programmes. By considering these key areas, Somali policymakers can effectively address environmental sustainability challenges and promote a sustainable future for the country.

One of the major limitations of this study is the exclusion of social and institutional factors, such as corruption, regulatory policies, and institutional strength. These components are essential in determining how policies pertaining to agriculture, renewable energy, and urbanisation are implemented and how successful they are in impacting environmental outcomes. Additionally, this study is geographically limited to Somalia and uses a fixed time frame extending from 1990 to 2020. Future studies should consider broadening the scope by incorporating cross-country analysis and extending the time period.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The datasets used and/or analysed during the current study are available from the author on reasonable request.

Ethical approval

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.

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