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RESEARCH ARTICLE

Asymmetric impact of energy utilization and economic development on environmental degradation in Somalia

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Abstract

While there are enormous studies on climate change in stable countries, climate policy perspectives from conflict-prone regions including Somalia are limited. It is noteworthy that environmental degradation is an alarming issue that fuels the vulnerability of Somalia to climate change. To this end, this study investigates the asymmetric impact of energy and economic growth on environmental degradation in Somalia—by employing nonlinear autoregressive distributed lag model (NARDL) and causal techniques from 1985 to 2017. We find asymmetric long-term cointegration among the variables, whereas energy consumption and economic growth asymmetrically affect environmental degradation. Besides, the causal inferences reveal unidirectional causality from environmental pollution to positive change in energy consumption. Additionally, a bidirectional causality is observed between population growth and negative change in economic growth. A unidirectional causality is confirmed: from positive shock in economic growth to population growth—from a negative change in economic growth to negative shock in energy consumption—from positive change in economic growth to positive shock in energy consumption—and from a negative change in energy consumption to population growth. This calls for the implementation of clean energy investment and modern environmental strategies including good farming methods and improved grazing land policies. The adoption of these policies will improve both environmental quality and sustained economic development.

Keywords Energy · Economic growth · Environmental degradation · NARDL · Somalia

Introduction

Energy is a vital source for socio-economic activities by sustaining livelihoods and well-being while fostering sustainable development (Owusu and Asumadu 2016). However, the role of energy—typically fossil fuels—in promoting environmental pollution has raised several global concerns (Sarkodie and Strezov 2018). Thus, achieving sustainable economic growth by preserving environmental quality remains topical and timely since the last century. Sustainable development goals (SDGs) of the United Nations (2015–2030 period) have emphasized the importance of achieving economic growth by adopting SDG 8 (decent work and economic growth), but the goal offers a potential tradeoff between sustained economic development and environmental quality. To mitigate greenhouse gas (GHG) emissions and enhance environmental quality while achieving sustained economic growth, the United Nations adopted SDG 7—of ensuring accessible, sustainable, reliable, affordable, and modern energy for all. However, modern energy reduces the double burden of climate change by improving environmental quality, reducing poverty rates, hunger, creating employment opportunities, and promoting economic development (Bhattacharya et al. 2016; Owusu and Asumadu 2016; Luqman et al. 2019).

But unfortunately, global fossil fuel consumption outpaces alternative energy sources including clean and renewable energy—contributing 79.67% of total global energy consumption (World Bank, 2015). Fossil fuel energy consumption enhances economic growth at the cost of environmental quality. On the other hand, economic growth

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significantly contributes to energy consumption. Accordingly, several studies on the energy-growth-environment nexus have verified the energy-led growth hypothesis—attributing sustained economic growth to energy consumption (Kouton 2019; Akadiri et al. 2019). Cherni and Essaber Jouini (2017) and Asumadu-Sarkodie and Owusu (2016) confirmed the feedback hypothesis, which posits a mutual causal effect between energy consumption and economic growth. Besides, numerous studies validate the conservative hypothesis, which underscores intensive energy utilization driven by economic development (Bekun et al. 2019; Ahmed et al. 2015). Likewise, it is also true that economic growth driven by the combustion of energy and industrialization escalate environmental pollution by releasing CO_2, methane, nitrous oxide emissions and reducing forest areas (Farhani and Shahbaz 2014; Sarkodie and Strezov 2019; Rafindadi & Usman, 2019; Sharma and Kautish 2020).

Somalia has been severely affected by over two decades of civil conflicts and political instabilities. While the country's economic production is an agrarian-based economy with limited economic diversification, half of the country's population is under the poverty line (World Bank 2018). Despite Somalia is regarded as one of the least energy-consuming nations in the world, 82% of the country's total energy consumption consists of traditional biomass including firewood and charcoal (Federal Government of Somalia 2015). Charcoal is used locally and exported through trade to Gulf cooperation Council countries. Around 80–90% of Somalia's population utilizes biomass fuels such as firewood and charcoals for cooking. Commiphora and acacia are two of the most deforested trees converted into charcoal. Moreover, Somalia consumes 4 million tons of charcoal per year as energy (Federal Government of Somalia 2015; African Development Bank, 2015). However, this erodes the few remaining forests due to lack of government protection, leading to loss of biodiversity, hence, affecting environmental quality which ultimately increases temperature and induces climate change. It is argued that climate change consequences are already present in Somalia because of recurrent droughts and flash floods. Moreover, Somalia is counted as one of the most vulnerable countries exposed to climatic variabilities (Wheeler 2011). As a result, increasing temperatures, droughts, and flash floods have been noted in Somalia's national development plan as major climatic risks (Federal Government of Somalia 2013).

Furthermore, environmental degradation in Somalia is evidenced by the increasing rate of deforestation—which is measured as one of the main sources of environmental degradation. According to Fig. 1, the deforestation rate has been rising marginally from 1961 to 2001, but in 2002, the rate of deforestation skyrocketed from 1.66% in 2001 to 1.91% in 2002. The highest rate of deforestation is recorded in 2005 (2.15%). But in subsequent years, the rate of forest clearing declined, despite it is higher than the rates recorded in the last century. Thus, this is attributed to the country's dependence on biomass fossil fuel energy consumption, poor agricultural practices, and overgrazing land. Moreover, charcoal trade export is another factor that results in widespread deforestation. Consequently, removing forest trees enhances soil erosions, desertification, and exposure to natural hazards including extreme floods and droughts—which ultimately inhibits environmental quality. Moreover, environmental degradation—as a result of deforestation—releases carbon dioxide, leading to a rise in temperature and climate change (Magazzino et al. 2021). It also poses a threat to agriculture production, livelihood systems, and food security (Warsame et al. 2021a).

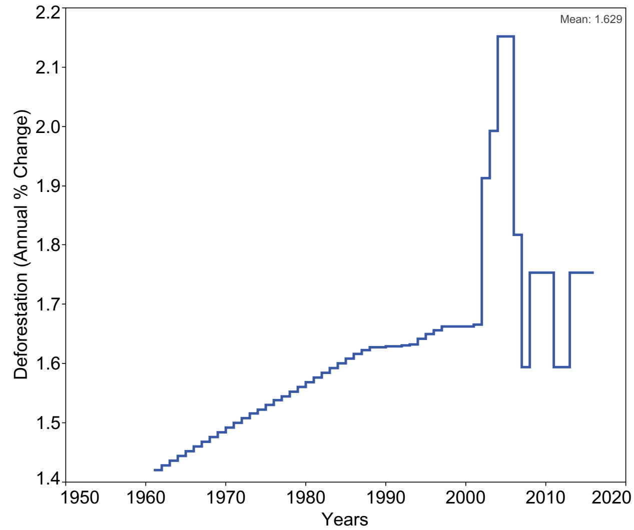

Fig. 1 Annual percent change in deforestation. Data source: World Bank

Because environmental quality is affected by energy and economic growth, existing literature employs several indicators for measuring environmental pollution including, inter alia, CO_2, methane, nitroxide emissions, ecological footprint, and deforestation. Carbon dioxide is the largest contributor of greenhouse gas (GHG) emissions, which is responsible for 72% of total GHG (Olivier and Peters 2019), justifying why most existing literature adopted CO_2 emissions as proxy for environmental pollution (Bölük and Mert 2014; Farhani and Shahbaz 2014; Shafiei and Salim 2014; Jamel and Abdelkader 2016; Ssali et al. 2019; Nathaniel and Iheonu 2019).

In a panel study of 16 European countries, it is reported that the impact of energy consumption on CO_2 emissions encompasses fossil fuel and renewable energy, and economic growth (Bölük and Mert 2014). Both sources of energy inhibit environmental quality, whereas economic growth reduces CO_2, and squared term of economic growth rises CO_2 emissions—confirming the invalidity of the EKC hypothesis. Similarly, the impact of renewable, non-renewable electricity consumption, and economic growth on CO_2 emissions is reported in 10 MENA countries (Farhani and Shahbaz 2014). Renewable, non-renewable electricity consumption, and economic growth are reported to enhance CO_2 emissions, while the squared term of economic growth mitigates CO_2 emissions—thus, validating the EKC hypothesis. Again, both fossil fuel energy utilization and economic growth are found to escalate environmental pollution in OECD countries (Shafiei and Salim 2014).

In a follow-up study, energy and economic growth are reported to have significant positive influence on CO_2 emissions in 8 Asian countries (Jamel and Abdelkader 2016). A recent study on the nexus between energy, CO_2 emissions, foreign direct investment, and economic growth found energy and growth increase CO_2 emissions in 6 Sub-Saharan African countries (Ssali et al. 2019). But the squared term of economic growth reduces CO_2 emissions, validating the EKC hypothesis. The impact of renewable and fossil energy on CO_2 emissions abatement was assessed in 19 African countries (Nathaniel and Iheonu 2019). Renewable energy was found to reduce CO_2 emissions, whereas fossil fuels undermine environmental quality by increasing CO_2 emissions. Energy and economic growth were reported to have positive and negative effects on CO_2 emissions in South Africa (Bekun et al. 2019). The study also observed a unidirectional causality from energy use to economic growth and environmental pollution. This finding is consistent with the studies of Mohiuddin et al. (2016) who revealed energy use unidirectionally causes economic growth and environmental pollution.

Despite the extensive studies on CO_2, energy consumption, and economic growth nexus, it is worth noting that developing and least developed countries contribute a tiny fraction of the global CO_2 emissions. For instance, the African continent contributes 2–3% of the global CO_2 emissions (United Nations 2006). Though industrialized-driven CO_2 emissions are not an issue in least-developed countries such as Somalia, however, other options contribute to environmental pollution including deforestation, ecological footprint, and others. Nevertheless, few studies have systematically employed environmental degradation indicators—other than CO_2 emissions such as deforestation, ecological footprint, methane, and nitrous dioxide emissions. Some notable studies include Baz et al. (2020), Och (2017), Esmaeili and Nasrnia (2014), Ahmed et al. (2015), Zambrano-Monserrate et al. (2018), Chiu (2012), and Waluyo and Terawaki (2016).

The asymmetric impact of energy and economic growth on ecological footprint revealed a positive and negative shock in energy consumption enhances environmental quality—whereas a positive shock in economic growth hampers environmental quality and a negative shock in economic growth tends to increase environmental quality (Baz et al. 2020). Moreover, Akadiri et al. (2019) examined the nexus between energy, economic growth, and ecological footprint in South Africa by utilizing an ARDL methodology. The study found energy consumption hampers environmental quality, whereas an increase in economic growth enhances environmental quality. Moreover, they reported environmental pollution granger causes economic growth, whereas energy causes economic growth and environmental pollution. The study reported bidirectional causation between a positive change in environmental quality and energy consumption. In contrast, economic growth undermines environmental quality in Mongolia, whereas the squared term of economic growth enhances environmental quality—validating the EKC hypothesis (Och 2017). Besides, the study found bidirectional causation between environmental pollution and economic growth.

Furthermore, economic growth has positive long-term effects on deforestation in Iran, whereas the squared term of income inhibits deforestation (Esmaeili and Nasrnia 2014). Hence, the result confirmed the existence of an EKC in Iran. Likewise, Ahmed et al. (2015) validated the EKC hypothesis by utilizing deforestation as environmental pollution indicator and found both energy consumption and economic growth undermine deforestation. Moreover, energy and economic growth are observed to cause environmental pollution, whereas bidirectional causality is found between energy and economic growth. Also, Zambrano-Monserrate et al. (2018) analyzed the EKC hypothesis in 5 European countries using deforestation as measurement for environmental pollution. The results validated the EKC hypothesis—where economic growth increases environmental pollution whereas the squared term of economic growth reduces environmental pollution in 4 of 5 countries investigated. Besides, a unidirectional causality is observed from economic growth to deforestation. The validity of the hypothesis is further confirmed by Chiu (2012) and Waluyo and Terawaki (2016), who employed deforestation as indicator for environmental degradation.

Notwithstanding, the majority of the previous undertakings have focused on developed countries (Shafiei and Salim 2014; Sarkodie and Strezov 2018; Zakari et al. 2021) that are responsible for a larger portion of the global greenhouse gases. There is also growing literature in developing countries that contribute a significant percentage of global emissions (Esmaeili and Nasrnia 2014; Baz et al. 2020; Och 2017). There is scanty literature that ascertains the deforestation-energy-growth nexus in Africa, specifically in Somalia. The very few studies in SSA have not only excluded Somalia in their sample but also failed to use deforestation as a measurement for environmental pollution. Deforestation is an alarming issue in these countries since cutting trees and land clearing for the utilization of energy and agricultural cultivation, respectively, are popular (Ssali et al. 2019; Bello et al. 2021). Moreover, they have also ignored to consider the nonlinear effect of energy use and economic growth on environmental degradation (Akadiri et al. 2019; Nathaniel and Iheonu 2019), thus, timely to ascertain the impact of energy and economic growth on environmental degradation in conflict-prone countries including Somalia. This study contributes to the literature in several ways—first, to the best of our knowledge, this is the first study conducted in Somalia to address the impact of energy and economic development on environmental degradation. Second, extant literature fails to consider deforestation as indicator of environmental pollution in the least developing countries dependent on wood fuel. Third, the majority of previous studies investigated energy-growth-environment nexus symmetrically, even though the nexus could be nonlinear due to financial, socio-economic, and political changes that exert nonlinear effects on energy and economic growth. Thus, this study examines the asymmetric impact of energy and economic development on environmental degradation in Somalia by employing recent nonlinear ARDL econometric methodology—by utilizing deforestation as indicator for environmental pollution.

The remaining sections of the study are structured as follows: Sect. 2 presents data sources, descriptions, and methodology, Sect. 3 reports empirical results and discussion, and Sect. 4 concludes the study and suggests policy recommendations to concerned policymakers.

Data and methodology

Data source and description

Energy is crucial for socio-economic development; however, the dependence on fossil fuels escalates GHG emissions—which leads to climate change—affecting the global temperature. Thus, this study ascertains the impact of energy consumption and economic growth on environmental degradation in Somalia by using time series data spanning 1985–2017. The selection of data period is limited to data availability. The data is sourced from the World Bank, Organization of Islamic Cooperation Countries (OIC) database and our world in data. We employed several variables including environmental pollution, energy consumption, economic growth, and population growth. All variables were converted into natural logarithm to reduce heteroskedasticity. To date, various indicators have been introduced to measure environmental pollution. Previous literature employed CO_2 emissions as indicator for environmental pollution; however, we utilize deforestation as indicator for environmental degradation. Deforestation proxied as arable land (hectares) herein is the main contributor to environmental degradation in Somalia. Besides, energy consumption is measured in energy use (kg oil equivalent per capita), whereas real GDP per capita is used as proxy of income level. It is argued that climate change is related to the consequences of human activities. Therefore, to account for this, we include population growth as a control variable in the proposed model to account for the effect of human activities on environmental degradation. The trends of the sampled variables are presented in Fig. 2. Energy consumption and economic growth exhibit a downward trend. They have been declining all the periods except economic growth which is constant in some years from 1999 to 2006. But from 2007, it shows a marginal reduction. In addition, population growth in Somalia has been volatile from 1985 to 2017. In some years, the population has been increasing such as in 1986, 1987, and 1988. But after this period, it dramatically plummeted. It began to recover in 1994. It is notable that since the start of this century, the population growth rate shows a stable growth rate. Finally, deforestation—in the same vein as population growth—shows trending volatility.

Econometric methodology

We apply the NARDL framework methodology to estimate the short- and long-run effects of energy, economic growth, and environmental degradation nexus. One of the shortfalls of linear ARDL and other previous cointegration methods is that they ignore the asymmetric relationship between the investigated variables. Therefore, Shin et al. (2014) proposed the NARDL technique which considers the nonlinearity of the variables and, hence, represents the advanced version of the ARDL cointegration method. The main idea behind NARDL is to capture the effects of hidden and unpredicted events such as economic crises, political and social changes, which cannot be captured in linear models. Thus, this technique applies to the context of the environment-energy-growth nexus in Somalia, justifiable for several reasons. First, unlike other cointegration methods such as Johansen cointegration and Engle and Granger cointegration methods, NARDL is advantageous in estimating variables integrated at level I(0), first difference I(1), or a combination of both (Sarkodie and Adams 2020). Second, the NARDL framework is suitable for dealing with convergence issues, which is better than the conventional cointegration methods. Third, NARDL avoids the problem of multicollinearity by using an effective automatic lag selection criterion. Fourth, the NARDL is good at estimating a small observation which is more appropriate to our study since our sample size is small. The NARDL model utilized herein can be expressed as

$$z_t = z_0 + z_t^+ + z_t^- \tag{1}$$

where z_t^+ and z_t^- indicate the partial sum of positive and negative shocks occur in z_t:

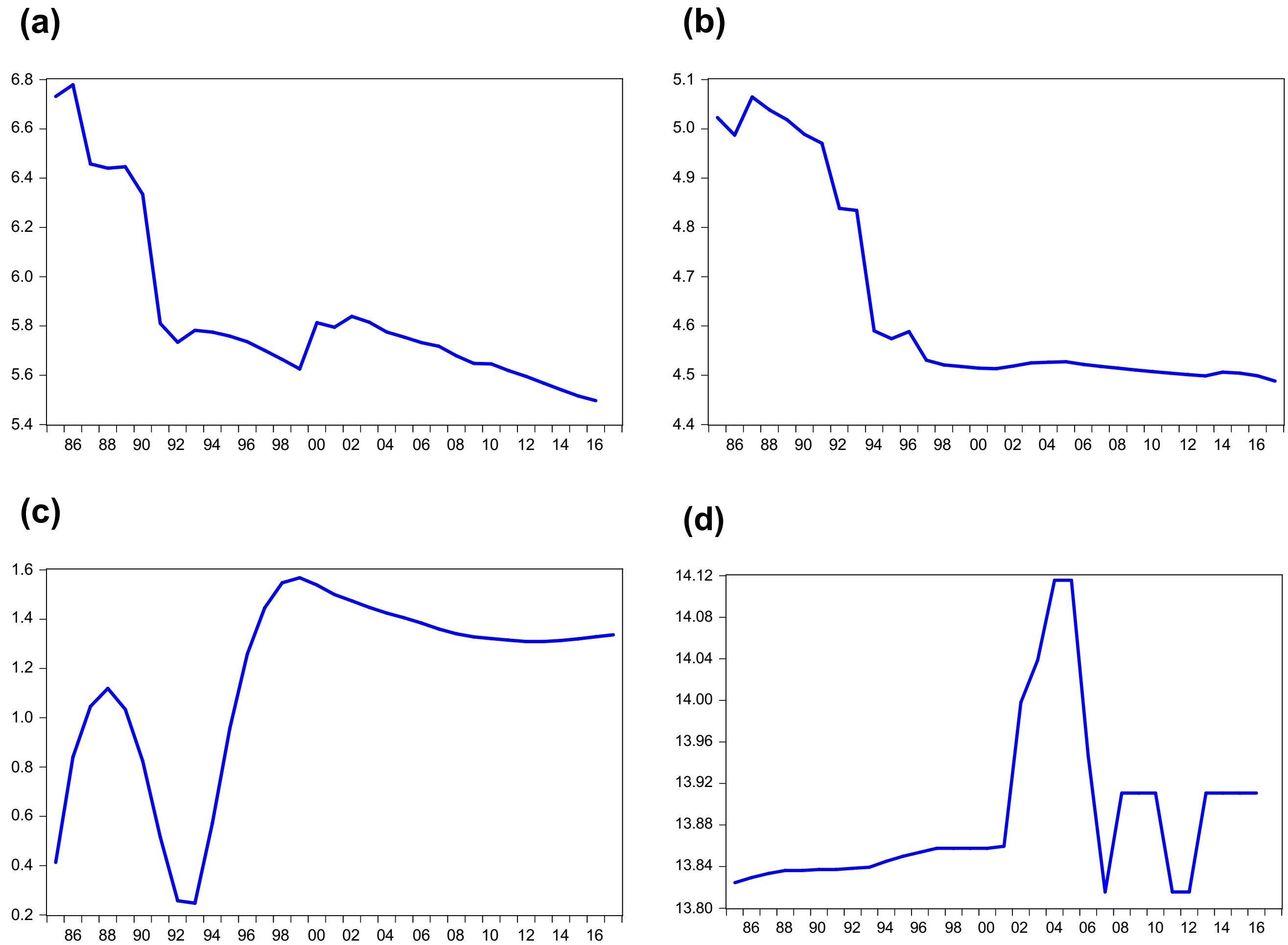

Fig. 2 Trends of the sampled variables. (**a**) Energy consumption, (**b**) economic growth, (**c**) population growth, and (**d**) deforestation

$$z_t^+ = \sum_{j=1}^{t} \Delta z_j^+ = \sum_{j=1}^{t} \max\left(\Delta x_j, 0\right) \tag{2}$$

$z_t^- = \sum_{j=1}^{t} \Delta z_j^- = \sum_{j=1}^{t} \min\left(\Delta x_j, 0\right)$. The long-run asymmetric cointegration of the variables can be specified as

$$y_t = \alpha_0 + \beta^+ z_t^+ + \beta^- z_t^- + \mu_t \tag{3}$$

where α_0 is the intercept, and $\beta^+$and β^- represent the long-run coefficient elasticities of the explanatory variables. β^+ is intended to capture the long-term positive shock of variable z on y, whereas β^- captures the long-term negative shock of z on y. According to Shin et al. (2014), utilizing Eq. (3) can specify the NARDL framework, which represents the asymmetric error correction term expressed as

$$\begin{aligned}\Delta y_t =& \alpha_0 + \Delta y_{t-1} + \delta^+ z_{t-1}^+ + \delta^- z_{t-1}^- + \sum_{j=1}^{p-1} \alpha_j \Delta y_{t-j} \\ &+ \sum_{j=0}^{q-1} \beta_j^+ \Delta z_{t-j}^+ + \sum_{j=0}^{q-1} \beta_j^- \Delta z_{t-j}^- + \mu_t\end{aligned} \tag{4}$$

where y is the regressed variable, x is the explanatory variable, p and q are the optimal lag length of the dependent and independent variables, respectively, δ^+ and δ^- are the asymmetric long-term coefficients, β_j^+ and β_j^- represent the short-term dynamic effect of coefficient elasticities, and μ_t is the error term.

We apply the Wald-F test to ascertain the validity of long-run asymmetric cointegration among the investigated variables. Moreover, the study utilizes Broock et al. (1996) nonlinearity of BDS test to examine nonlinearity of the series. The long-term null hypothesis is set as: $\delta^+ = \delta^-$ (no asymmetric cointegration) against the alternative $\delta^+ \neq \delta^-$ (there is asymmetric cointegration). If the Wald F-statistics is greater than the upper bound critical values, the null hypothesis of no asymmetric long-term cointegration is rejected, thus, validating the existence of asymmetric long-term cointegration among the variables. If the critical value is above the Wald F-statistics, we fail to refute the null hypothesis of no asymmetric long-term cointegration. Moreover, if the Wald F-statistics falls between the two critical values, the decision becomes inconclusive.

The final and general model of our investigated variables—lnDEFO, lnRGDPC, lnEC, and lnPG—in the NARDL framework can be expressed as Bekun et al. (2019), Sarkodie and Adams (2020), and Ahmed et al. (2015):

$$\begin{aligned}\Delta lnDEFO_t = {} & \alpha_0 + \Delta lnDEFO_{t-1} + \delta_1^+ lnEC_{t-1}^+ + \delta_1^- lnEC_{t-1}^- + \delta_2^+ lnRGDPC_{t-1}^+ \\ & + \delta_2^- \mathrm{lnR}GDPC_{t-1}^- + \delta_3 lnPG_{t-1} + \sum_{j=1}^{p-1} \beta_j \Delta lnDEFO_{t-j} \\ & + \sum_{j=0}^{q-1} \beta_{1j}^+ \Delta lnEC_{t-j}^+ + \sum_{j=0}^{q-1} \beta_{1j}^- \Delta lnEC_{t-j}^- + \sum_{j=0}^{q-1} \beta_{1j}^+ \Delta lnRGDPC_{t-j}^+ \\ & + \sum_{j=0}^{q-1} \beta_{1j}^- \Delta lnRGDPC_{t-j}^- + \sum_{j=1}^{q-1} \beta_j \Delta lnPG_{t-j} + \varepsilon_t \end{aligned} \quad (5)$$

where lnDEFO denotes log of deforestation proxied for environmental degradation, lnEC^- represents negative shock in energy consumption, lnEC^+ represents positive shock in energy consumption, $\mathrm{lnRGDPC}^-$ signifies a negative shock in real GDP per capita, $\mathrm{lnRGDPC}^+$ signifies a positive shock in real GDP per capita, p and q denote the optimal lag length of dependent and explanatory variables, respectively.

Empirical results and discussion

Descriptive statistics

The descriptive statistical analysis presents the characteristics of the data. Table 1 outlines the summary statistics of the variables including mean, median, and standard deviation. Deforestation and energy consumption have the highest average values of 13.8 and 5.8, respectively, while population growth has the lowest average value (1.15). In the same vein, deforestation, energy consumption, and real GDP have maximum values of 14.1, 6.7, and 5, respectively. But population growth has the lowest mean, median, maximum, and minimum values. On the contrary, population growth has the highest standard deviation (0.38) compared to all other variables—indicating the values of population growth are far from its average. Besides, Table 1 also presents the correlation among the interested variables. Energy consumption and real GDP per capita have a negative correlation with deforestation, whereas a positive correlation is found between deforestation and population growth. A positive relationship is observed between real GDP and energy consumption, whereas there exists a negative correlation between real GDP and population growth. In addition, population growth is negatively correlated with energy consumption and real GDP per capita, whereas a positive correlation is established between population and deforestation.

Table 1 Descriptive statistics

	lnDEFO	lnEC	lnRGDPC	lnPG
Mean	13.8871	5.853653	4.649785	1.158153
Median	13.8576	5.745077	4.523417	1.317473
Maximum	14.1156	6.778529	5.064555	1.567599
Minimum	13.8155	5.496287	4.498364	0.247130
Std. dev.	0.0795	0.349871	0.211245	0.383316
Correlation				
LDEFO	1			
LEC	−0.2753	1		
LRGDPC	−0.4203	0.8568	1	
LPG	0.4153	−0.4246	−0.6975	1

Testing the stationarity of time series data is a requirement of the NARDL technique and essential to controlling for spurious regression, hence, producing unbiased results. To test the unit root of our sampled variables and prevent model misspecification and biased inferences, we utilized Augmented Dickey-Fuller (ADF) and Philips-Perron (PP) tests. The results of the unit root test presented in Table 2 highlight that all variables contain unit root problems, viz. level I (0), except population growth which is stationary in ADF. In contrast, all variables are stationary at first difference I (1). The ADF and PP tests are inadequate to detect the presence of structural break dates; therefore, we used Zivot and Andrews (1992) unit root test to check for structural break date of the series to avoid mis specified model estimation and incorrect inferences. However, the structural break unit root test presented in Table 2 confirms all series are integrated at first difference I (1). Hence, we proceeded to estimate the nonlinear ARDL model.

Unit root tests

The study employed BDS test to check the nonlinearity of the series presented in Table 3. Broock et al. (1996) postulated this method to detect and test the predicted residuals of time series model which have been converted into identically scattered errors. The null hypothesis (H_0) is formulated as the data series are normally and identically distributed—which implies the data series are dependent (linear), whereas the alternative hypothesis (H_0) expresses a violation of normal and identical distribution—implying the data series are nonlinear. Thus, the z-statistics of all series indicate statistical significance—leading to the rejection of the null hypothesis and failure to reject the alternative hypothesis of the non-normal distribution of the series. Hence, this confirms the nonlinearity of the data series and further verifies the suitability of the NARDL model in this study (energy-growth-environment nexus).

The next step after passing through the unit root test is the selection of optimal lag-length. Thus, we employed the stepwise least square approach to select the optimal lag-length. Owing to our small sample size, we limited the highest lag

Table 2 Unit root tests

	ADF	PP	ZA Structural break unit root test	
Variable	T-statistics	T-statistics	T-statistics	Time break
lnDEFO	−2.9883	−2.1945	−5.3718(1)**	2002
lnRGDPC	−3.1825	−1.1392***	−8.7213(0)***	1994
lnEC	−2.2325	−2.1970	−4.6391(4)	2012
lnPG	−35.4002***	−2.2718	−9.2904***(4)	1996
ΔlnDEFO	−4.3080***	−5.9454***	−6.8032(1)***	2006
ΔlnRGDPC	−2.7325	−5.9296***	−17.9212(0)***	1996
ΔlnEC	−5.3904***	−5.3908***	−7.2244***(0)	1993
ΔlnPG	−1.6992***	−2.9030	−7.9586***(4)	1994

Notes: Δ denotes first difference. The T-statistics reported are the intercept and trend

ADF Augmented Dickey-Fuller test, *PP* Philips Perron test, *ZA* Zivot-Andrews

Table 3 Nonlinearity of BDS test

	lnDEFO		lnEC		lnRGDPC		lnPG	
Dimension	BDS	z-Stat	BDS	z-Stat	BDS	z-Stat	BDS	z-Stat
2	0.1244	6.0705	0.2035	10.2346	0.20199	12.3083	0.1501	8.8449
3	0.2112	6.2734	0.34651	10.6671	0.34253	12.9243	0.2415	8.7217
4	0.2605	6.2782	0.4441	11.1575	0.43907	13.6811	0.2953	8.7172
5	0.2808	6.2704	0.5085	11.9049	0.50293	14.7769	0.3280	9.0334
6	0.2756	6.1575	0.5498	12.9516	0.5445	16.2931	0.3447	9.5668

Table 4 F-bound cointegration tests

Model	F-statistic	Significance	Bounds test critical values	
lnDEF = *f*(lnEC⁺, lnEC⁻,RGDPC⁺, RGDPC⁻, lnPG)				K (3)
			I (0)	I (1)
	7.5108	1%	5.333	6.975
		5%	3.653	4.965
		10%	2.985	4.133

Notes: The critical values are based on Narayan (2005). K=number of explanatory variables

number to 2, then, determined the existence of long-run asymmetric cointegration among the variables, and its result is presented in Table 4. We used Wald F-test by comparing it with the critical values; however, the Wald F-statistic (7.5) is above the critical value of 6.9 at 1% significance level, hence, confirming long-run asymmetric cointegration between environmental degradation and the regressors.

After determining the existence of long-run cointegration among the variables, we estimated the long-run asymmetric elasticities and short-run asymmetric dynamic effect with error correction term (ECT) of the explanatory variable reported in Table 5. The positive shock of energy consumption and economic growth induces positive effects on environmental degradation in the long-run, whereas negative shock of energy consumption and economic growth have no long-run significant effect on environmental degradation in Somalia. Interpretively, 1% shock increase in energy consumption and economic growth increases environmental degradation in the long run by ~2.44% and 7.58%, respectively. However, both energy consumption and economic growth have adverse effects on environmental quality. Moreover, population growth is observed to have an insignificant effect on environmental pollution in the long run. Our findings of positive effect of economic growth and energy consumption on environmental degradation are corroborated by studies in Iran (Esmaeili and Nasrnia 2014), Pakistan (Ahmed et al. 2015), 6 SSA countries (Ssali et al. 2019). Furthermore, Zakari et al. (2021) found that energy consumption pollutes the environment in a sample of African countries. In contrast, it contradicts several previous studies that concluded that energy consumption and economic growth do not exert any effect on environmental pollution. For instance, Asumadu-Sarkodie and Owusu (2016) found that economic growth and energy consumption do not have any significant effect on carbon dioxide emissions in Ghana. Moreover, Bölük and Mert (2014) reported that economic

Table 5 Long-run and short-run coefficient elasticities

Variable	Coefficient
Long-run coefficient elasticities	
$lnEC^+$	2.4454***
	(6.4495)
$lnEC^{--}$	0.0308
	(0.7335)
$lnRGDPC^+$	7.5898***
	(6.2740)
$lnGDPC^{--}$	−0.0087
	(−0.1253)
lnPG	−0.0374
	(−1.7002)
Short-run coefficient elasticities	
Variable	Coefficient
Constant	6.7495***
	(5.8705)
$\Delta lnDEFO_{t-1}$	0.4065***
	(2.9884)
$\Delta lnEC^+_{t-1}$	−1.7991**
	(−2.4913)
$\Delta lnEC^{--}_{t-2}$	0.4680***
	(3.0539)
$\Delta lnRGDPC^+_{t-1}$	2.7198
	(0.8174)
$\Delta lnRGDPC^+_{t-2}$	0.7251
	(1.2174)
$\Delta lnRGDPC^{--}$	0.7546***
	(3.0251)
$\Delta lnRGDPC^{--}_{t-1}$	−0.2632
	(−0.9601)
$\Delta lnRGDPC^{--}_{t-2}$	−0.4251*
	(−1.7854)
$\Delta lnPG$	0.6651**
	(2.1439)
$\Delta lnPG_{t-1}$	−1.0735*
	(−2.0479)
$\Delta lnPG_{t-2}$	0.3226
	(1.2043)
$ECT1_{t-1}$	−0.9380***
	(−5.8774)

Note: Δ implies differencing whereas T-statistic are reported in parenthesis

*** and ** indicate significance at 1% and 5% levels, respectively

growth reduces greenhouse gases in panel European countries. These heterogeneous results could be attributed to different methodologies adopted and the nature of the data used.

The positive effects of energy consumption and economic growth on environmental degradation are not unusual. Energy consumption is the main driver of environmental pollution—higher percentage of Somalia's final energy consumption consists of biomass, viz. charcoal, and firewood. Consequently, an increase in energy use depletes forest areas and leads to soil erosions, releasing atmospheric CO_2 emissions—which undermines environmental quality. Moreover, poverty level and dominant rural population comprising 65% of total population engage in agropastoral and pastoral activities—driving deforestation rate to meet livelihood pressures. The majority of livelihoods depend on fuelwood and charcoal production, which depletes forest reserve and resources—leading to loss of biodiversity. Thus, lack of biomass alternatives due to conflicts and limited investments in clean energy exacerbates environmental quality.

On the other hand, despite the positive change, energy consumption is regarded a determinant of environmental degradation; positive change in economic growth is considered the highest significant driver of environmental pollution, accounting for 7.5%. Some of the remarkable explanations for this effect can be attributed to the sources of Somalia's economic growth. Somalia is an agrarian-based economy comprising crop and livestock production. This sector creates 65% of employment opportunities, 93% of the country's export, and represents 65% of the country's GDP (World Bank; FAO 2018; Warsame et al. 2021a, 2021b), while crop production and livestock rearing contribute to a higher percentage of the world's deforestation. Thus, environmental quality is affected by poor cultivation practices, loss of vegetation land, overgrazing land, conflicts over natural resources, and lack of technical agricultural extension services. Somalia's economic dependence on the agricultural sector implies that an increase in economic growth poses long-term environmental costs.

Additionally, one striking point is that neither the negative change in energy consumption nor economic growth enhances environmental quality, implying that energy efficiency and decarbonized economic development are expected to rise environmental quality. However, such sustainable options are lacking in Somalia, due to limited environmental regulations. Somalia's political instability and lack of good governance for over two decades have consequently affected environmental protection; thus, the adoption of NARDL captured the nonlinear effects. Somalia's forest areas are traded globally by producing and exporting illegal charcoal compared to countries with institutional quality, where such illegal trading is prohibited.

The short-run dynamics and ECT are reported in Table 5. Historical pollution (deforestation) has a positive effect on current environmental pollution by 0.40%. A positive shock in energy consumption has a favorable effect on environmental quality by reducing environmental degradation by 1.79% in the short run. Contrary, 1% increase in negative shock of energy consumption spurs environmental pollution by 0.46%

Table 6 Diagnostic tests

LM test	0.0857
	(0.8489)
Heteros kedasticity test	0.4892
	(0.8013)
Normality test	3.7737
	(0.1516)
Reset test	0.0119
	(0.9146)
Adjusted R^2	0.6071

in the short run. Moreover, a positive shock in economic growth has no significant effect on environmental pollution in the short run. But 1% increase in negative shock of economic growth escalates environmental degradation by 0.75% in the short run. Despite population growth is insignificant in the long run, the short run finds unfavorable effects on environmental quality. One percent increase in population growth reduces environmental quality by 0.66% in the short run. More importantly, Table 5 displays the ECT which denotes the speed of adjustment. The ECT is significant at 1% level and accompanies a negative coefficient; thus, this confirms the existence of long-run cointegration among the variables. Any short-run disequilibrium that occurs in environmental degradation is adjusted by the explanatory variables in the long run by 93% annually.

For sound, reliable, and accurate empirical results, we conducted several diagnostic tests as shown in Table 6. We applied the LM test, heteroskedasticity test, reset test, and normality test. More importantly, we tested the estimated model's parameter stability. The diagnostic tests show no serial correlation, model misspecification

Table 7 Results of Granger causality tests

Null hypothesis:	F-statistic	prob.
LRGDPC^{-} ⇨ LDEFO	1.0626	0.3613
LDEFO ⇨ LRGDPC^{-}	0.1215	0.8862
LRGDPC^{+} ⇨ LDEFO	0.6526	0.5297
LDEFO ⇨ LRGDPC^{+}	1.4164	0.2621
lnPG ⇨ LDEFO	1.2487	0.3042
lnDEFO ⇨ lnPG	0.9381	0.4047
lnEC^{+} ⇨ lnDEFO	0.0725	0.9303
lnDEFO ⇨ lnEC^{+}	4.2353	0.0266**
lnEC^{--} ⇨ lnDEFO	0.2471	0.7830
lnDEFO ⇨ lnEC^{--}	0.0323	0.9683
lnRGDPC^{+} ⇨ lnRGDPC^{--}	1.1055	0.3467
lnRGDPC^{--} ⇨ lnRGDPC^{+}	5.0725	0.0142**
lnPG ⇨ lnRGDPC^{--}	14.9304	5.E−05***
lnRGDPC^{--} ⇨ lnPG	25.9674	8.E−07***
LEC^{+} ⇨ LRGDPC^{--}	0.6667	0.5223
LRGDPC^{--} ⇨ lnEC^{+}	1.1224	0.3414
lnEC^{--} ⇨ lnRGDPC^{--}	10.5826	0.0005***
lnRGDPC^{--} ⇨ LEC^{--}	0.26341	0.7705
lnPG ⇨ lnRGDPC^{+}	1.9635	0.1614
lnRGDPC^{+} ⇨ lnPG	6.51176	0.0053***
lnEC^{+} ⇨ lnRGDPC^{+}	1.0492	0.3651
lnRGDPC^{+} ⇨ lnEC^{+}	4.8494	0.0166**
LEC^{--} ⇨ LRGDPC^{+}	0.8418	0.4428
LRGDPC^{+} ⇨ LEC^{--}	1.4990	0.2428
lnEC^{+} ⇨ lnPG	2.5406	0.0990*
lnPG ⇨ LEC^{+}	0.2798	0.7583
lnEC^{--} ⇨ LPG	48.6573	2.E−09***
lnPG ⇨ LEC^{--}	0.5739	0.5706
lnEC^{--} ⇨ lnEC^{+}	0.5267	0.5970
lnEC^{+} ⇨ lnEC	1.9318	0.1659

$^{--}$Notes: ⇨ indicates the null hypothesis that variable "*x*" does not granger cause variable "*y*"

***,**,* represent statistical significance at 1, 5, 10% levels

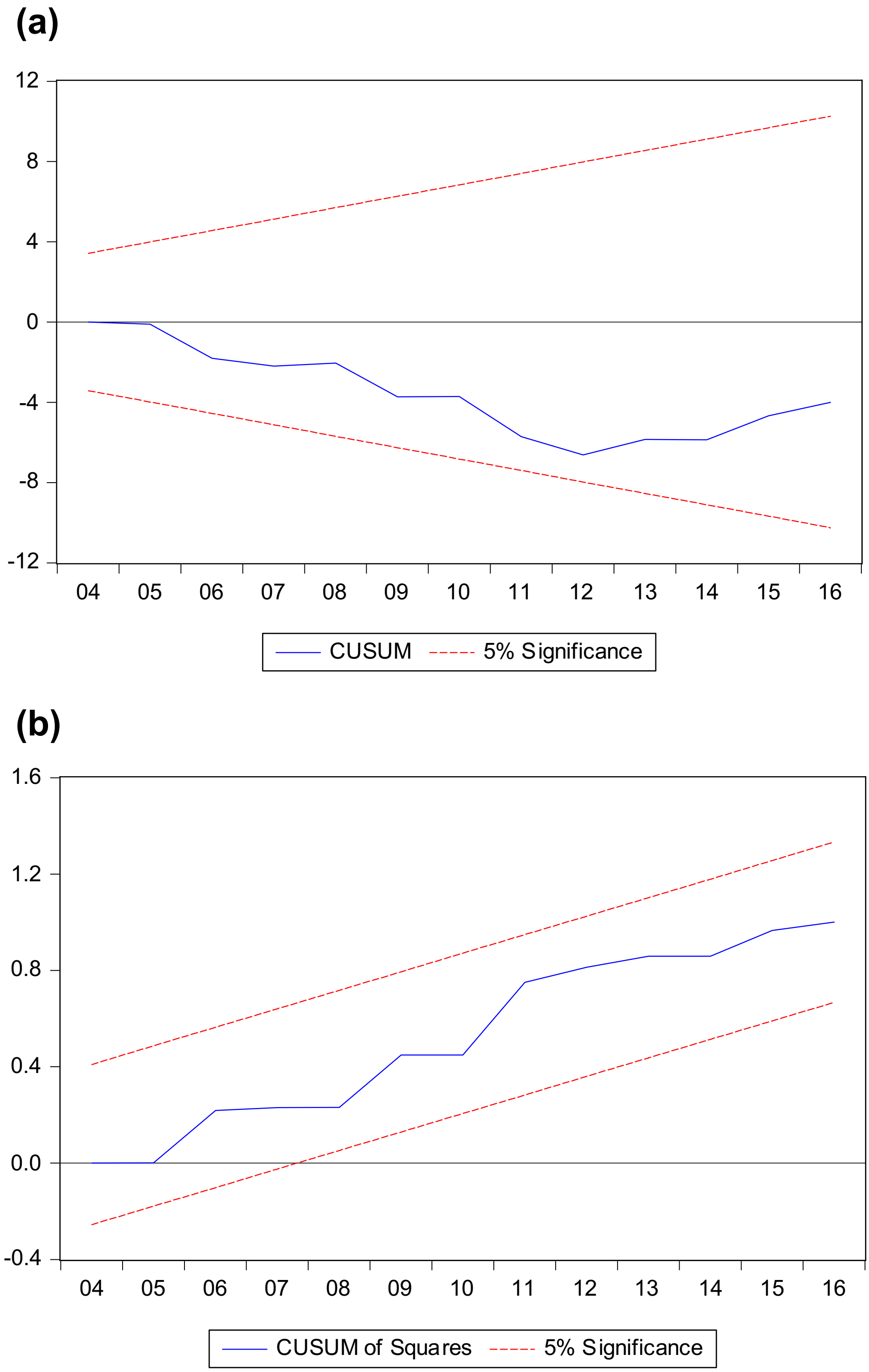

Fig. 3 Model stability. (**a**) CUSUM test. (**b**) CUSUM square test

(reset test), heteroskedasticity, and violation of normality detected—implying the findings are robust for policy formulation. The value of adjusted *R*-squared (0.60) denotes that energy, economic growth, and population growth explain 60% of variations in environmental degradation. Moreover, CUSUM and CUSUM square tests presented in Fig. 2 confirm the estimated parameters are stable over time.

Results of Granger causality

To determine the direction of causation among the investigated variables, we utilized Granger causality test. The results presented in Table 7 reveal unidirectional causation from environmental pollution to positive change in energy consumption, whereas negative change in economic growth causes positive shock in economic growth. Moreover, bidirectional causality is established between population growth and negative change in economic growth. Additionally, negative change in economic growth is also caused by negative shock in energy consumption which verifies the conservative hypothesis. A unidirectional causality is observed from positive shock in economic growth to population growth. On the other hand, positive change in economic growth unidirectionally granger causes positive shock in energy consumption. Finally, another unidirectional is established from a negative change in energy consumption to population growth (Fig. 3).

Conclusion and policy implications

Sustainable development goals 7 and 8 outline the importance of affordable and clean energy, decent work, and economic growth. However, nonrenewable energy and economic growth seem to undermine environmental quality. This study assessed the asymmetric impact of energy consumption and economic growth on environmental degradation in Somalia using the novel NARDL model for the econometric assessment. This study revealed that positive shocks of energy consumption and economic growth degrade environmental quality in the long run, whereas negative shock of energy consumption and economic growth is statistically insignificant in the long term. Also, population growth has no significant influence on environmental degradation in the long term. In the short term, positive change in energy consumption enhances environmental quality in the short run, whereas negative shock in energy consumption and economic growth undermines environmental quality, but positive change in economic growth is statistically insignificant in the short term. Moreover, population growth significantly inhibits environmental quality in the short term.

Besides, Granger causality is used to check the directional causation among the investigated variables. A unidirectional causality is established from environmental pollution to positive change in energy consumption, and from negative shock in economic growth to positive shock in economic growth. Moreover, bidirectional causality is found between population growth and negative change in economic growth. A unidirectional causality is found from positive shock in economic growth to population growth—from negative change in economic growth to negative shock in energy consumption. On the other hand, positive change in economic growth unidirectionally granger causes positive shock in energy consumption. Finally, another unidirectional is found from a negative change in energy consumption to population growth.

This study suggests several policy implications based on the empirical findings. First, reducing biomass energy consumption would contribute to environmental quality since using charcoal and firewood as energy would erode trees and affect the ecosystem which will ultimately lead to more emissions and rising temperature. Hence, policymakers should implement policies that encourage investments in renewable and clean energy production such as solar, wind, hydroelectric power, and others. This will not only improve environmental quality but will also enhance economic development. Second, raising awareness towards adverse effects of forest depletions would help decline deforestation, which ultimately inhibits environmental pollution. Third, Somalia's economic growth is mainly based on agriculture production. Corroborated by our findings, economic growth enhances environmental degradation; hence, implementing good agricultural and sustainable cultivation methods, modern technologies, and improved grazing land policies for livestock will lead to sustainable economic growth while enhancing environmental quality by reducing inefficient farming expansion and overgrazing.

The limitation of the study could provide an avenue for future empirical works. The limitation of the study could be that energy use is measured for aggregated values since different sources of energy have various effects. We suggest future studies could examine the role of disaggregate energy consumption in environmental degradation function.

Author contribution AAW: conceptualization, methodology, data collection and analyzing, writing; original draft. SAS: reviewing and editing.

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

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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