

# Asymmetric Impact of Energy Utilization and Economic Development on Environmental Degradation in Somalia

Abdimalik Ali Warsame (✉ [abdimalikali1995@gmail.com](mailto:abdimalikali1995@gmail.com))

Garaad Institute for Social Research and Development Studies <https://orcid.org/0000-0001-6130-5607>

Samuel Asumadu Sarkodie

Nord University Business School (HHN).

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## Research Article

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2 **Asymmetric Impact of Energy Utilization and Economic Development on**  
3 **Environmental Degradation in Somalia**

4 **Abdimalik Ali Warsame\*<sup>1</sup>**

5 **Samuel Asumadu SARKODIE<sup>2</sup>**

6 <sup>1</sup>\*Garaad Institute for Social Research and Development Studies, Mogadishu, Somalia

7 <sup>1</sup>\* Faculty of Economics, SIMAD University, Mogadishu, Somalia

8 <sup>2</sup>Nord University Business School (HHN). Post Box 1490, 8049 Bodø, Norway

9 \*Email for correspondence: [abdimalikali1995@gmail.com](mailto:abdimalikali1995@gmail.com)

10 **Abstract**

11 While there are enormous studies on climate change in stable countries, climate policy perspectives  
12 from conflict-prone regions including Somalia are limited. This study investigates the asymmetric  
13 impact of energy and economic growth on environmental degradation in Somalia—by employing  
14 nonlinear autoregressive distributed lag model (NARDL) and causal techniques from 1985 to 2017.  
15 We find asymmetric long-term cointegration among the variables, whereas energy consumption and  
16 economic growth asymmetrically affect environmental degradation. Besides, the causal inferences  
17 reveal unidirectional causality from environmental pollution to positive change in energy  
18 consumption. Additionally, we find unidirectional causality from negative shock in economic growth  
19 to positive shock in economic growth. Moreover, a bidirectional causality is observed between  
20 population growth and negative change in economic growth. A unidirectional causality is confirmed  
21 from positive shock in economic growth to population growth—from negative change in economic  
22 growth to negative shock in energy consumption—from positive change in economic growth to  
23 positive shock in energy consumption—and negative change in energy consumption to population  
24 growth. This calls for the implementation of clean energy investment policies, good farming methods,  
25 and improved grazing land policies. The adoption of these policies will improve both environmental  
26 quality and sustained economic development.

27

28 **Keywords:** Energy, Economic growth, Environmental degradation, NARDL, Somalia

## 29 **1. Introduction**

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

44 But unfortunately, global fossil fuel consumption outpaces alternative energy sources including clean  
45 and renewable energy—contributing 79.67% of total global energy consumption (World Bank, 2015).  
46 Fossil fuel energy consumption enhances economic growth at the cost of environmental quality. On  
47 the other hand, economic growth significantly contributes to energy consumption. Accordingly,  
48 several studies on energy-growth-environment nexus have verified the energy-led growth  
49 hypothesis—attributing sustained economic growth to energy consumption (Kouton, 2019; Akadiri,  
50 Bekun, & Sarkodie, 2019). Cherni & Essaber Jouini, (2017) and Asumadu-Sarkodie & Owusu, (2016)  
51 confirmed the feedback hypothesis, which posits a mutual causal effect between energy consumption  
52 and economic growth. Besides, numerous studies validate the conservative hypothesis, which  
53 underscores intensive energy utilization driven by economic development (Bekun, Emir, & Sarkodie,  
54 2019; Ahmed, Shahbaz, Qasim, & Long, 2014). Likewise, it is also true that economic growth driven  
55 by the combustion of energy and industrialization escalate environmental pollution by releasing CO<sub>2</sub>,

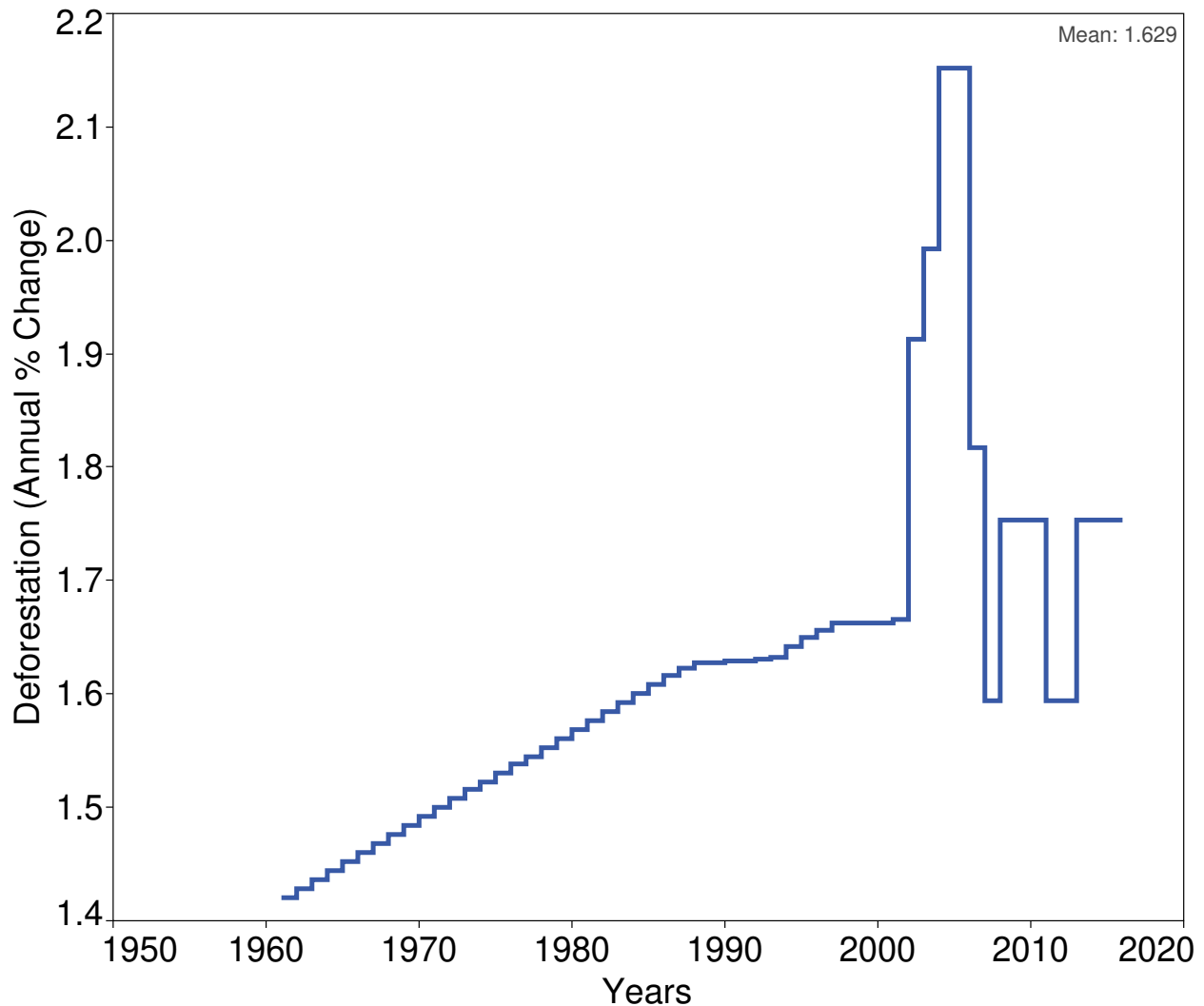
56 methane, nitrous oxide emissions and reducing forest areas (Farhani & Shahbaz, 2014; Sarkodie &  
57 Strezov, 2019; Rafindadi & Usman, 2019; Sharma & Kautish, 2020).

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

75 Furthermore, environmental degradation in Somalia is evidenced by the increasing rate of  
76 deforestation—which is measured as one of the main sources of environmental degradation.  
77 According to Figure 1, the deforestation rate has been rising marginally from 1961 to 2001, but in  
78 2002, the rate of deforestation skyrocketed from 1.66% in 2001 to 1.91% in 2002. The highest rate of  
79 deforestation is recorded in 2005 (2.15%). But in subsequent years, the rate of forest clearing declined,  
80 despite it is higher than the rates recorded in the last century. Thus, this is attributed to the country's  
81 dependence on biomass fossil fuel energy consumption, poor agricultural practices, and overgrazing  
82 land. Moreover, charcoal trade export is another factor that results in widespread deforestation.  
83 Consequently, removing forest trees enhances soil erosions, desertification, and exposure to natural  
84 hazards including extreme floods and droughts—which ultimately inhibits environmental quality.  
85 Moreover, environmental degradation—as a result of deforestation—releases carbon dioxide, leading

86 to a rise in temperature and climate change (Magazzino, et al., 2021). It also poses a threat to agriculture  
87 production, livelihood systems, and food security (Warsame, Sheik-Ali, Ali, & Sarkodie, 2021).

88



89

90

Figure 1. Annual % Change in Deforestation. Data Source: World Bank

91

92 Because environmental quality is affected by energy and economic growth, existing literature employs  
93 several indicators for measuring environmental pollution including, inter alia, CO<sub>2</sub>, methane, nitroxide  
94 emissions, ecological footprint, and deforestation. Carbon dioxide is the largest contributor of  
95 greenhouse gas (GHG) emissions, which is responsible for 72% of total GHG (Olivier & Peters,  
96 2019), justifying why most existing literature adopted CO<sub>2</sub> emissions as proxy for environmental

97 pollution (Bölük & Mert, 2014; Farhani & Shahbaz, 2014; Shafiei & Salim, 2014; Jamel & Abdelkader,  
98 2016; Ssali, Du, Mensah, & Hongo, 2019; Nathaniel & Iheonu, 2019).

99 In a panel study of 16 European countries, it is reported that the impact of energy consumption on  
100 CO<sub>2</sub> emissions encompasses fossil fuel and renewable energy, and economic growth (Bölük & Mert,  
101 2014). Both sources of energy inhibit environmental quality, whereas economic growth reduces CO<sub>2</sub>,  
102 and squared term of economic growth rises CO<sub>2</sub> emissions—confirming the invalidity of EKC  
103 hypothesis. Similarly, the impact of renewable, non-renewable electricity consumption and economic  
104 growth on CO<sub>2</sub> emissions is reported in 10 MENA countries (Farhani & Shahbaz, 2014). Renewable,  
105 non-renewable electricity consumption, and economic growth are reported to enhance CO<sub>2</sub> emissions,  
106 while the squared term of economic growth mitigates CO<sub>2</sub> emissions—thus, validating the EKC  
107 hypothesis. Again, both fossil fuel energy utilization and economic growth are found to escalate  
108 environmental pollution in OECD countries (Shafiei & Salim, 2014).

109 In a follow-up study, energy and economic growth are reported to have significant positive influence  
110 on CO<sub>2</sub> emissions in 8 Asian countries (Jamel & Abdelkader, 2016). A recent study on the nexus  
111 between energy, CO<sub>2</sub> emissions, foreign direct investment, and economic growth found energy and  
112 growth increase CO<sub>2</sub> emissions in 6 Sub-Saharan African countries (Ssali, Du, Mensah, & Hongo,  
113 2019). But the squared term of economic growth reduces CO<sub>2</sub> emissions, validating the EKC  
114 hypothesis. The impact of renewable and fossil energy on CO<sub>2</sub> emissions abatement was assessed in  
115 19 African countries (Nathaniel & Iheonu, 2019). Renewable energy was found to reduce CO<sub>2</sub>  
116 emissions whereas fossil fuels undermine environmental quality by increasing CO<sub>2</sub> emissions. Energy  
117 and economic growth were reported to have positive and negative effects on CO<sub>2</sub> emissions in South  
118 Africa (Bekun, Emir, & Sarkodie, 2019). The study also observed a unidirectional causality from energy  
119 use to economic growth and environmental pollution. This finding is consistent with the studies of  
120 Mohiuddin et al., (2016) who revealed energy use unidirectionally causes economic growth and  
121 environmental pollution.

122 Despite the extensive studies on CO<sub>2</sub> energy consumption, and economic growth nexus, it is worth  
123 noting that developing and least developed countries contribute a tiny fraction of the global CO<sub>2</sub>  
124 emissions. For instance, the African continent contributes 2-3% of the global CO<sub>2</sub> emissions (United  
125 Nations, 2006). Though industrialized-driven CO<sub>2</sub> emissions is not an issue in least-developed  
126 countries such as Somalia, however, other options contribute to environmental pollution including

127 deforestation, ecological footprint, and others. Nevertheless, few studies have systematically employed  
128 environmental degradation indicators—other than CO<sub>2</sub> emissions such as deforestation, ecological  
129 footprint, methane, and nitrous dioxide emissions. Some notable studies include Ref. (Baz et al., 2020;  
130 Och, 2017; Esmacili & Nasrnia, 2014; Ahmed, Shahbaz, Qasim, & Long, 2014; Zambrano-  
131 Monserrate, Carvajal-Lara, Urgilés-Sanchez, & Ruano, 2018; Chiu, 2012; Waluyo & Terawaki, 2016).

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

145 Furthermore, economic growth has positive long-term effects on deforestation in Iran, whereas the  
146 squared term of income inhibits deforestation (Esmacili & Nasrnia, 2014). Hence, the result confirmed  
147 the existence of an EKC in Iran. Likewise, Ahmed, Shahbaz, Qasim, & Long, (2014) validated the  
148 EKC hypothesis by utilizing deforestation as environmental pollution indicator, and found both  
149 energy consumption and economic growth undermine deforestation. Moreover, energy and economic  
150 growth are observed to cause environmental pollution whereas bidirectional causality is found  
151 between energy and economic growth. Also, Zambrano-Monserrate, Carvajal-Lara, Urgilés-Sanchez,  
152 & Ruano, (2018) analyzed the EKC hypothesis in 5 European countries using deforestation as  
153 measurement for environmental pollution. The results validated the EKC hypothesis—where  
154 economic growth increases environmental pollution whereas squared term of economic growth  
155 reduces environmental pollution in 4 of 5 countries investigated. Besides, a unidirectional causality is  
156 observed from economic growth to deforestation. The validity of the hypothesis is further confirmed

157 by Ref. (Chiu, 2012; Waluyo & Terawaki, 2016), who employed deforestation as indicator for  
158 environmental degradation.

159 Notwithstanding, there is scanty literature that ascertains deforestation-energy-growth nexus in Africa,  
160 specifically in Somalia. Thus, it is timely to ascertain the impact of energy and economic growth on  
161 environmental degradation in conflict-prone countries including Somalia. This study contributes to  
162 the literature in several ways—first, to the best of our knowledge, this is the first study conducted in  
163 Somalia to address the impact of energy and economic development on environmental degradation.  
164 Second, extant literature fails to consider deforestation as indicator for environmental pollution in  
165 least developed countries dependent on wood fuel. Third, majority of previous studies investigated  
166 energy-growth-environment nexus symmetrically, even though the nexus could be nonlinear due to  
167 financial, socioeconomic and political changes that exert nonlinear effect on energy and economic  
168 growth. Thus, this study examines the asymmetric impact of energy and economic development on  
169 environmental degradation in Somalia. We employ recent nonlinear ARDL econometric methodology  
170 by utilizing deforestation as indicator for environmental pollution.

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

174

## 175 **2. Data and Methodology**

### 176 **2.1. Data source and Description**

177 Energy is crucial for socio-economic development, however, the dependence on fossil fuels escalates  
178 GHG emissions—which leads to climate change—affecting global temperature. Thus, this study  
179 ascertains the impact of energy consumption and economic growth on environmental degradation in  
180 Somalia by using time series data spanning 1985-2017. The selection of data period is limited to data  
181 availability. The data is sourced from World Bank, Organization of Islamic Countries (OIC) database  
182 and our world in data. We employed several variables including environmental pollution, energy  
183 consumption, economic growth and population growth. All variables were converted into natural  
184 logarithm to reduce heteroskedasticity. To date, various indicators have been introduced to measure  
185 environmental pollution. Previous literature employed CO<sub>2</sub> emissions as indicator for environmental



186 pollution, however, we utilize deforestation as indicator for environmental degradation. Deforestation  
 187 is proxied as arable land (hectares). In Somalia, deforestation is the main contributor of environmental  
 188 degradation. Besides, energy consumption is measured in energy use (kg oil equivalent per capita).  
 189 Real GDP per capita is used as a proxy of economic growth/income. It is argued that climate change  
 190 is related to the consequences of human activities. Therefore, to account for this, we include  
 191 population growth as a control variable in our model to account for the effect of human activities on  
 192 environmental degradation.

## 193 2.2. Econometric Methodology

194 We apply NARDL framework methodology to estimate the short- and long-run effects of energy,  
 195 economic growth and environmental degradation nexus. One of the shortfalls of linear ARDL and  
 196 other previous cointegration methods is that they ignore the asymmetric relationship between the  
 197 investigated variables. Therefore, Shin et al., (2014) proposed NARDL technique which considers the  
 198 nonlinearity of the variables. Hence, it is advanced method of the ARDL cointegration method. The  
 199 main idea behind NARDL is to capture the effects of hidden and unpredicted events such as economic  
 200 crises, political and social changes, which cannot be captured in linear models. Thus, this technique is  
 201 applicable to the context of environment-energy-growth nexus in Somalia. Unlike other cointegration  
 202 methods such as Johansen cointegration and Engle & Granger cointegration methods, NARDL is  
 203 advantageous in estimating variables integrated at level I (0), first difference I (1) or combination of  
 204 both (Sarkodie and Adams, 2020). Moreover, NARDL framework is suitable in dealing with  
 205 convergence issues, which is better than the conventional cointegration methods. Another advantage  
 206 of NARDL is that it avoids the problem of multicollinearity by using an effective automatic lag  
 207 selection criterion. The NARDL model utilized herein can be expressed as:

$$208 \quad z_t = z_0 + z_t^+ + z_t^- \quad (1)$$

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

$$210 \quad z_t^+ = \sum_{j=1}^t \Delta z_j^+ = \sum_{j=1}^t \max(\Delta x_j, 0) \quad (2)$$

$$211 \quad z_t^- = \sum_{j=1}^t \Delta z_j^- = \sum_{j=1}^t \min(\Delta x_j, 0)$$

212 The long-run asymmetric cointegration of the variables can be specified as:

$$213 \quad y_t = \alpha_0 + \beta^+ z_t^+ + \beta^- z_t^- + \mu_t \quad (3)$$

214 Where  $\alpha_0$  is the intercept,  $\beta^+$  and  $\beta^-$  represent the long-run coefficient elasticities of the explanatory  
 215 variables.  $\beta^+$  is intended to capture the long-term positive shock of variable  $z$  on  $y$ , whereas  $\beta^-$   
 216 captures the long-term negative shock of  $z$  on  $y$ . According to Shin et al., (2014), utilizing equation  
 217 (3) can specify the NARDL framework, which represents the asymmetric error correction term  
 218 expressed as:

$$219 \quad \Delta y_t = \alpha_0 + \Delta y_{t-1} + \delta^+ z_{t-1}^+ + \delta^- z_{t-1}^- + \sum_{j=1}^{p-1} \alpha_j \Delta y_{t-j} + \sum_{j=0}^{q-1} \beta_j^+ \Delta z_{t-j}^+ + \sum_{j=0}^{q-1} \beta_j^- \Delta z_{t-j}^- + \mu_t$$

220 (4)

221 Where  $y$  is the regressed variable,  $x$  is the explanatory variable,  $p$  and  $q$  is the optimal lag length of the  
 222 dependent and independent variables, respectively,  $\delta^+$  and  $\delta^-$  is the asymmetric long-term  
 223 coefficients,  $\beta_j^+$  and  $\beta_j^-$  represent the short-term dynamic effect of coefficient elasticities and  $\mu_t$  is  
 224 the error term.

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

234 The final and general model of our investigated variables -  $\ln DEFO$ ,  $\ln RGDP$ ,  $\ln EC$  and  $\ln PG$  - in  
 235 the NARDL framework can be expressed as (Bekun et al., 2019; Sarkodie and Adams, 2020; and  
 236 Ahmed, Shahbaz, Qasim, & Long, 2014):

$$237 \quad \Delta \ln DEFO_t = \alpha_0 + \Delta \ln DEFO_{t-1} + \delta_1^+ \ln EC_{t-1}^+ + \delta_1^- \ln EC_{t-1}^- + \delta_2^+ \ln RGDP_{t-1}^+ + \delta_2^- \ln RGDP_{t-1}^-$$

$$238 \quad + \delta_3 \ln PG_{t-1} + \sum_{j=1}^{p-1} \beta_j \Delta \ln DEFO_{t-j} + \sum_{j=0}^{q-1} \beta_{1j}^+ \Delta \ln EC_{t-j}^+ + \sum_{j=0}^{q-1} \beta_{1j}^- \Delta \ln EC_{t-j}^-$$

$$239 \quad + \sum_{j=0}^{q-1} \beta_{2j}^+ \Delta \ln RGDP_{t-j}^+ + \sum_{j=0}^{q-1} \beta_{2j}^- \Delta \ln RGDP_{t-j}^- + \sum_{j=1}^{q-1} \beta_j \Delta \ln PG_{t-j} + \varepsilon_t$$

240 Where lnDEFO denotes log of deforestation proxied for environmental degradation, lnEC represents  
 241 energy consumption, lnRGDPC signifies real GDP per capita, p & q denote the optimal lag length of  
 242 dependent and explanatory variables.

243

### 244 3. Empirical Results and Discussion

#### 245 3.1. Descriptive Statistics

246 Descriptive statistics presents the characteristics of the data. Table 1 outlines the summary statistics  
 247 of the variables including mean, median, standard deviation and among others. Deforestation and  
 248 energy consumption have the highest average values of 13.8 and 5.8, respectively. Whilst population  
 249 growth has the lowest average value (1.15). In the same vein, deforestation, energy consumption and  
 250 real GDP have maximum values of 14.1, 6.7 and 5, respectively. But population growth has the lowest  
 251 mean, median, maximum and minimum values. On the contrary, population growth has the highest  
 252 standard deviation (0.38) compared to all other variables—indicating the values of population growth  
 253 are far from its average. Besides, Table 1 also presents the correlation among the interested variables.  
 254 Energy consumption and real GDP per capita have negative correlation with deforestation whereas  
 255 positive correlation is found between deforestation and population growth. A positive relationship is  
 256 observed between real GDP and energy consumption whereas there exists negative correlation  
 257 between real GDP and population growth. In addition, population growth is negatively correlated  
 258 with energy consumption and real GDP per capita, whereas a positive correlation is established  
 259 between population and deforestation.

260 Table 1: Descriptive Statistics

261		lnDEFO	lnEC	lnRGDPC	lnPG
262	Mean	13.8871	5.853653	4.649785	1.158153
263	Median	13.8576	5.745077	4.523417	1.317473
264	Maximum	14.1156	6.778529	5.064555	1.567599
265	Minimum	13.8155	5.496287	4.498364	0.247130
266	Std. Dev.	0.0795	0.349871	0.211245	0.383316
267	Correlation				
268	LDEFO	1			

269	LEC	-0.2753	1		
270	LRGDPC	-0.4203	0.8568	1	-0.6975
271	LPG	0.4153	-0.4246	-0.6975	1

273 Testing the stationarity of time series data is a requirement of the NARDL technique and essential to  
274 control for spurious regression, hence, producing unbiased results. To test the unit root of our  
275 interested variables and prevent model misspecification and biased inferences, we utilized Augmented  
276 Dickey Fuller (ADF) and Philips-Perron (PP) tests. The results of the unit root test presented in Table  
277 2 highlight that all variables contain unit root problems, viz. level I (0), except population growth  
278 which is stationary in ADF. In contrast, all variables are stationary at first difference I (1). The ADF  
279 and PP tests are inadequate to detect the presence of structural break dates, therefore, we used Zivot  
280 & Andrews, (1992) unit root test to check for structural break date of the series to avoid misspecified  
281 model estimation and incorrect inferences. However, the structural break unit root test presented in  
282 Table 2 confirm that all series are integrated at first difference I (1). Hence, we proceeded to estimate  
283 the nonlinear ARDL model.

### 285 3.2. Unit Root Tests

286 Table 2. Unit Root Tests

		<u>ZA</u>			
	<b>ADF</b>	<b>PP</b>	<b>Structural Break Unit Root Test</b>		
<b>Variable</b>	T-statistics	T-statistics	T-statistics	Time Break	
289 lnDEFO	-2.9883	-2.1945	-5.3718(1)**	2002	
291 lnRGDPC	-3.1825	-1.1392***	-8.7213(0)***	1994	
292 lnEC	-2.2325	-2.1970	-4.6391(4)	2012	
293 lnPG	-35.4002***	-2.2718	-9.2904***(4)	1996	
294 ΔlnDEFO	-4.3080***	-5.9454***	-6.8032(1)***	2006	
295 ΔlnRGDPC	-2.7325	-5.9296***	-17.9212(0)***	1996	
296 ΔlnEC	-5.3904***	-5.3908***	-7.2244***(0)	1993	
297 ΔlnPG	-1.6992***	-2.9030	-7.9586***(4)	1994	

298 Notes: Δ denotes first difference. ADF and PP stand for Augmented Dickey-Fuller and Philips Perron tests respectively.  
299 The T-statistics reported are the intercept and trend. ZA stands for Zivot-Andrews.

300

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

311 Table 3: Nonlinearity of BDS test

	lnDEFO		lnEC		lnRGDPC		lnPG	
313 Dimension	BDS	z-Stat	BDS	z-Stat	BDS	z-Stat	BDS	z-Stat
314 2	0.1244	6.0705	0.2035	10.2346	0.20199	12.3083	0.1501	8.8449
315 3	0.2112	6.2734	0.34651	10.6671	0.34253	12.9243	0.2415	8.7217
316 4	0.2605	6.2782	0.4441	11.1575	0.43907	13.6811	0.2953	8.7172
317 5	0.2808	6.2704	0.5085	11.9049	0.50293	14.7769	0.3280	9.0334
318 6	0.2756	6.1575	0.5498	12.9516	0.5445	16.2931	0.3447	9.5668

320 The next step after passing through the unit root test is the selection of optimal lag-length. Thus, we  
 321 employed Stepwise Least Square approach to select the optimal lag-length. Owing to our small sample  
 322 size, we limited the highest lag number to 2, then, determined the existence of long-run asymmetric  
 323 cointegration among the variables, and its result is presented in Table 4. We used Wald F-test by  
 324 comparing it with the critical values, however, the Wald F-statistic (7.5) is above the critical value of  
 325 6.9 at 1% significance level. Hence, confirming long-run asymmetric cointegration between  
 326 environmental degradation and the regressors.

327 Table 4: F-Bounds Cointegration Tests

328 Model	F-statistic	Significance	<u>Bounds test critical values</u>
-----------	-------------	--------------	------------------------------------

329	$\ln\text{DEF} = f(\ln\text{EC}^+, \ln\text{EC}^-, \text{RGDPC}^+,$		K (3)	
330	$\text{RGDPC}^-, \ln\text{PG})$			
331			I (0)	I (1)
332	7.5108	1%	5.333	6.975
333		5%	3.653	4.965
334		10%	2.985	4.133

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

336 After determining the existence of long-run cointegration among the variables, we estimated the long-  
337 run asymmetric elasticities and short-run asymmetric dynamic effect with error correction term (ECT)  
338 of the explanatory variable reported in Table 5. The positive shock of energy consumption and  
339 economic growth induces positive effects on environmental degradation in the long-run, whereas  
340 negative shock of energy consumption and economic growth have no long-run significant effect on  
341 environmental degradation in Somalia. Interpretively, 1% shock increase in energy consumption and  
342 economic growth increases environmental degradation in the long-run by ~2.44% and 7.58%,  
343 respectively. However, both energy consumption and economic growth have adverse effect on  
344 environmental quality. Moreover, population growth is observed to have insignificant effect on  
345 environmental pollution in the long-run. Our findings of positive effect of economic growth and  
346 energy consumption on environmental degradation is corroborated studies in Iran (Esmacili &  
347 Nasrnia, 2014), Pakistan (Ahmed, Shahbaz, Qasim, & Long, 2015), 6 SSA countries (Ssali, Du,  
348 Mensah, & Hongo, 2019).

349 The positive effects of energy consumption and economic growth on environmental degradation is  
350 not unusual. Energy consumption is the main driver of environmental pollution—higher percentage  
351 of Somalia’s final energy consumption consists of biomass, viz. charcoal and firewood. Consequently,  
352 an increase in energy use depletes forest areas, and leads to soil erosions, releasing atmospheric CO<sub>2</sub>  
353 emissions—which undermines environmental quality. Moreover, poverty level and dominant rural  
354 population comprising 65% of total population engage in agropastoral and pastoral activities—driving  
355 deforestation rate to meet livelihood pressures. Majority of livelihoods depend on fuelwood and  
356 charcoal production, which depletes forest reserve and resources—leading to loss of biodiversity.  
357 Thus, lack of biomass alternatives due to conflicts and limited investments in clean energy exacerbates  
358 environmental quality.

359 On the other hand, despite the positive change, energy consumption is regarded determinant of  
360 environmental degradation, positive change in economic growth is considered the highest significant  
361 driver of environmental pollution, with coefficient of 7.5%. Some of the remarkable explanations for  
362 this effect can be attributed to sources of Somalia's economic growth. Somalia is an agrarian based  
363 economy comprising crop and livestock production. This sector creates 65% of employment  
364 opportunities, 93% of the country's export and represents 65% of the country's GDP (World Bank;  
365 FAO, 2018). While crop production and livestock rearing contribute to higher percentage of the  
366 world's deforestation. Thus, environmental quality is affecting by poor cultivation practices, loss of  
367 vegetation land, overgrazing land, conflicts over natural resources and lack of technical agricultural  
368 extension services. Somalia's economic dependence on agriculture sector implies that an increase in  
369 economic growth poses long-term environmental cost.

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

378 The short-run dynamics and ECT are reported in Table 5. Historical pollution (deforestation) has a  
379 positive effect on current environmental pollution by 0.40%. A positive shock in energy consumption  
380 has a favorable effect on environmental quality by reducing environmental degradation by 1.79% in  
381 the short-run. Contrary, 1% increase in negative shock of energy consumption spur environmental  
382 pollution by 0.46% in the short-run. Moreover, a positive shock in economic growth has no significant  
383 effect on environmental pollution in the short-run. But 1% increase in negative shock of economic  
384 growth escalates environmental degradation by 0.75% in the short-run. Despite population growth is  
385 insignificant in the long-run, the short-run finds unfavorable effect on environmental quality. 1%  
386 increase in population growth reduces environmental quality by 0.66% in the short-run. More  
387 importantly, Table 5 displays the ECT which denotes the speed of adjustment. The ECT is significant  
388 at 1% level and accompanies a negative coefficient, thus, this confirms the existence of long-run

389 cointegration among the variables. Any short-run disequilibrium that occurs in environmental  
 390 degradation is adjusted by the explanatory variables in the long-run by 93% annually.

391 Table 5. Long-Run and Short-run Coefficient Elasticities

392	<b>Variable</b>	<b>Coefficient</b>
393	Long-Run Coefficient Elasticities	
394	$\ln EC^+$	2.4454***
395		(6.4495)
396	$\ln EC^-$	0.0308
397		(0.7335)
398	$\ln RGDP^+$	7.5898***
399		(6.2740)
400	$\ln GDPC^-$	-0.0087
401		(-0.1253)
402	$\ln PG$	-0.0374
403		(-1.7002)
404	Short-Run Coefficient Elasticities	
405	Variable	Coefficient
406	Constant	6.7495***
407		(5.8705)
408	$\Delta(\ln DEFO(-1))$	0.4065***
409		(2.9884)
410	$\Delta(\ln EC^+(-1))$	-1.7991**
411		(-2.4913)
412	$\Delta(\ln EC^-(-2))$	0.4680***
413		(3.0539)
414	$\Delta(\ln RGDP^+(-1))$	2.7198
415		(0.8174)
416	$\Delta(\ln RGDP^+(-2))$	0.7251
417		(1.2174)
418	$\Delta(\ln RGDP^-)$	0.7546***
419		(3.0251)
420	$\Delta(\ln RGDP^-(-1))$	-0.2632
421		(-0.9601)
422	$\Delta(\ln RGDP^-(-2))$	-0.4251*
423		(-1.7854)
424	$\Delta(\ln PG)$	0.6651**
425		(2.1439)
426	$\Delta(\ln PG(-1))$	-1.0735*
427		



428		(-2.0479)
429	$\Delta(\ln PG (-2))$	0.3226
430		(1.2043)
431	ECT1(-1)	-0.9380***
432		(-5.8774)

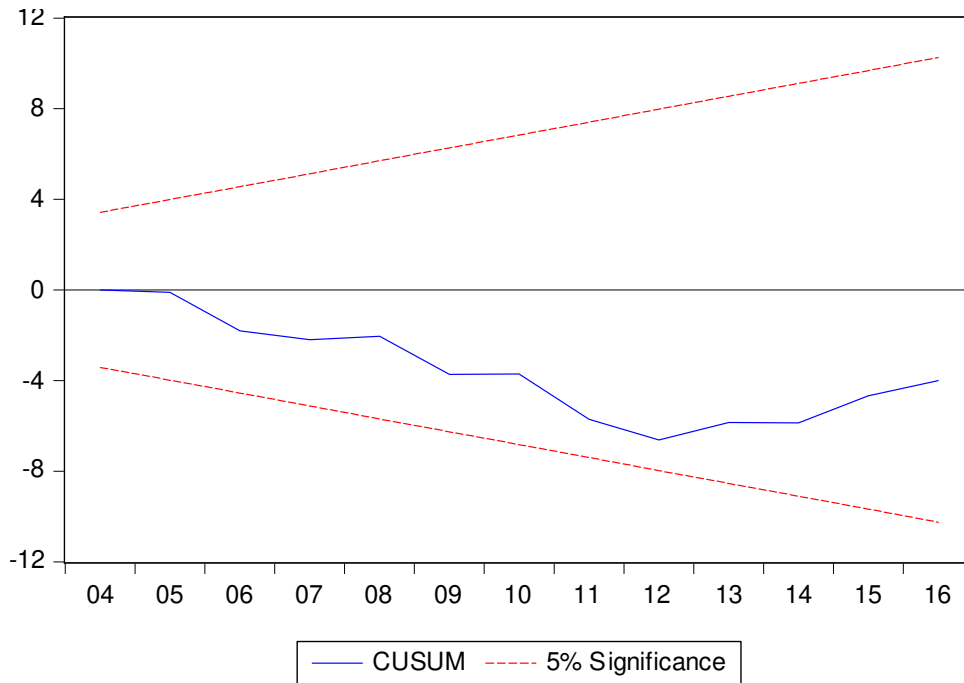
433  
434 Note: \*\*\* and \*\* indicates significance at 1% and 5% levels, respectively. T-statistic are reported in parenthesis.  
435  $\Delta$ =differencing.

436 For sound, reliable and accurate empirical results, we conducted several diagnostic tests as shown in  
437 Table 6. We applied serial correlation, heteroskedasticity, reset test and normality test. More  
438 importantly, we tested the model's parameter stability. Nevertheless, no serial correlation,  
439 misspecification model (reset test), heteroskedasticity and non-normality problems are detected,  
440 implying the findings are reliable for policy formulation. The value of adjusted R-squared (0.60)  
441 denotes that energy, economic growth and population growth explain 60% of variations in  
442 environmental degradation. Moreover, CUSUM and CUSUM square tests presented in Figure 2  
443 confirm that the parameters of the study are stable over time.

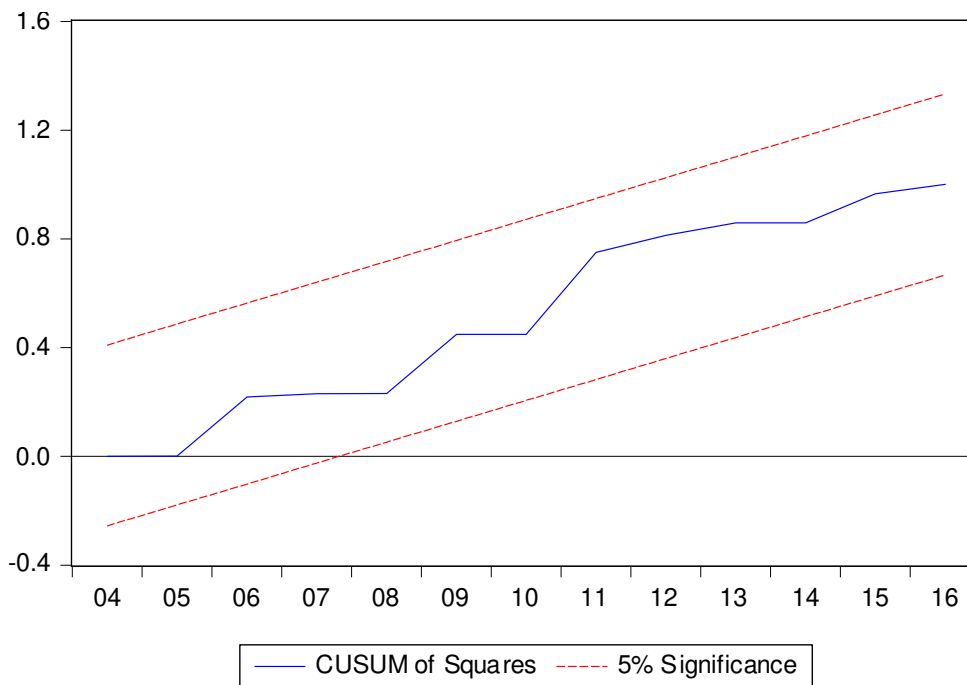
444 Table 6: Diagnostic Tests

445		
446	LM Test	0.0857
447		(0.8489)
448	Heteroskedasticity Test	0.4892
449		(0.8013)
450	Normality Test	3.7737
451		(0.1516)
452	Reset Test	0.0119
453		(0.9146)
454	Adjusted R <sup>2</sup>	0.6071

455  
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464

Figure 2. Model Stability (a) CUSUM Test (b) CUSUM Square Test

466

467 **3.3. Results of Granger Causality**

468 To determine the direction of causation among the investigated variables, we utilized Granger causality  
 469 test. The result presented in Table 7 reveal unidirectional causation from environmental pollution to  
 470 positive change in energy consumption, whereas negative change in economic growth causes positive

471 shock in economic growth. Moreover, bidirectional causality is established between population growth  
 472 and negative change in economic growth. Additionally, negative change in economic growth is also  
 473 caused by negative shock in energy consumption which verifies the conservative hypothesis. A  
 474 unidirectional causality is observed from positive shock in economic growth to population growth.  
 475 On the other hand, positive change in economic growth unidirectionally granger causes positive shock  
 476 in energy consumption. Finally, another unidirectional is established from a negative change in energy  
 477 consumption to population growth.

478 Table 7: Results of Granger Causality Tests

479	Null Hypothesis:	F-Statistic	Prob.
480	LRGDPC <sup>-</sup> → LDEFO	1.0626	0.3613
481	LDEFO → LRGDPC <sup>-</sup>	0.1215	0.8862
482	LRGDPC <sup>+</sup> → LDEFO	0.6526	0.5297
483	LDEFO → LRGDPC <sup>+</sup>	1.4164	0.2621
484	lnPG → LDEFO	1.2487	0.3042
485	lnDEFO → lnPG	0.9381	0.4047
486	lnEC <sup>+</sup> → lnDEFO	0.0725	0.9303
487	lnDEFO → lnEC <sup>+</sup>	4.2353	0.0266**
488	lnEC <sup>-</sup> → lnDEFO	0.2471	0.7830
489	lnDEFO → lnEC <sup>-</sup>	0.0323	0.9683
490	lnRGDPC <sup>+</sup> → lnRGDPC <sup>-</sup>	1.1055	0.3467
491	lnRGDPC <sup>-</sup> → lnRGDPC <sup>+</sup>	5.0725	0.0142**
492	lnPG → lnRGDPC <sup>-</sup>	14.9304	5.E-05***
493	lnRGDPC <sup>-</sup> → lnPG	25.9674	8.E-07***
494	LEC <sup>+</sup> → LRGDPC <sup>-</sup>	0.6667	0.5223
495	LRGDPC <sup>-</sup> → lnEC <sup>+</sup>	1.1224	0.3414
496	lnEC <sup>-</sup> → lnRGDPC <sup>-</sup>	10.5826	0.0005***
497	lnRGDPC <sup>-</sup> → LEC <sup>-</sup>	0.26341	0.7705
498	lnPG → lnRGDPC <sup>+</sup>	1.9635	0.1614
499	lnRGDPC <sup>+</sup> → lnPG	6.51176	0.0053***
500	lnEC <sup>+</sup> → lnRGDPC <sup>+</sup>	1.0492	0.3651
501	lnRGDPC <sup>+</sup> → lnEC <sup>+</sup>	4.8494	0.0166**
502	LEC <sup>-</sup> → LRGDPC <sup>+</sup>	0.8418	0.4428

503	LRGDPC <sup>+</sup> → LEC <sup>-</sup>	1.4990	0.2428
504	lnEC <sup>+</sup> → lnPG	2.5406	0.0990*
505	lnPG → LEC <sup>+</sup>	0.2798	0.7583
506	lnEC <sup>-</sup> → LPG	48.6573	2.E-09***
507	lnPG → LEC <sup>-</sup>	0.5739	0.5706
508	lnEC <sup>-</sup> → lnEC <sup>+</sup>	0.5267	0.5970
509	lnEC <sup>+</sup> → lnEC <sup>-</sup>	1.9318	0.1659

510 Notes: → indicates the null hypothesis that variable “x” does not granger cause variable  
511 “y”, \*\*\*, \*\*, \* represent statistical significance at 1, 5, 10% levels.

## 512 4. Conclusion and Policy Implications

513 Sustainable development goal 7 and 8 outline affordable and clean energy, and decent work and  
514 economic growth, respectively. However, nonrenewable energy and economic growth seem to  
515 undermine environmental quality. This study assessed asymmetric impact of energy consumption and  
516 economic growth on environmental degradation in Somalia. The study employed a recent econometric  
517 methodology of NARDL model. Hence, this study revealed that positive shocks of energy  
518 consumption and economic growth degrade environmental quality in the long-run, whilst negative  
519 shock of energy consumption and economic growth is statistically insignificant in the long-term. Also,  
520 population growth has no significant influence on environmental degradation in the long-term. In the  
521 short-term, positive change in energy consumption enhances environmental quality in the short-run,  
522 whereas negative shock in energy consumption and economic growth undermines environmental  
523 quality, but positive change in economic growth is statistically insignificant in the short-term.  
524 Moreover, population growth significantly inhibits environmental quality in the short-term.

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

532 positive shock in energy consumption. Finally, another unidirectional is found from a negative change  
533 in energy consumption to population growth.

534 This study suggests several policy implications based on the empirical findings. First, reducing biomass  
535 energy consumption would contribute to environmental quality. Hence, policymakers could  
536 implement policies by encouraging investments in renewable and clean energy production such as  
537 solar, wind, hydroelectric power, and among others. Thus, this will not only improve environmental  
538 quality but also enhances economic growth. Implementing energy conservative policies will not hurt  
539 economic growth. Moreover, raising awareness towards adverse effect of forest depletions would help  
540 decline deforestation, which ultimately inhibits environmental pollution. Since Somalia's GDP is  
541 mainly based on agriculture production, policymakers could implement good agricultural cultivation  
542 methods, technologies, and improved grazing land policies for livestock will lead to sustainable  
543 economic growth and enhance environmental quality while reducing inefficient farming expansion  
544 and overgrazing.

545  
546 *Data availability*

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

549 *Compliance with ethical standards*

550 *Ethical approval*  
551 Not applicable.

552 *Competing interests*  
553 The authors declare that they have no conflicts of interest.

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555 Not applicable.

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557 Not applicable.

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563 original draft .

564 Samuel Asumadu Sarkodie: Reviewing and editing.

565

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# Figures

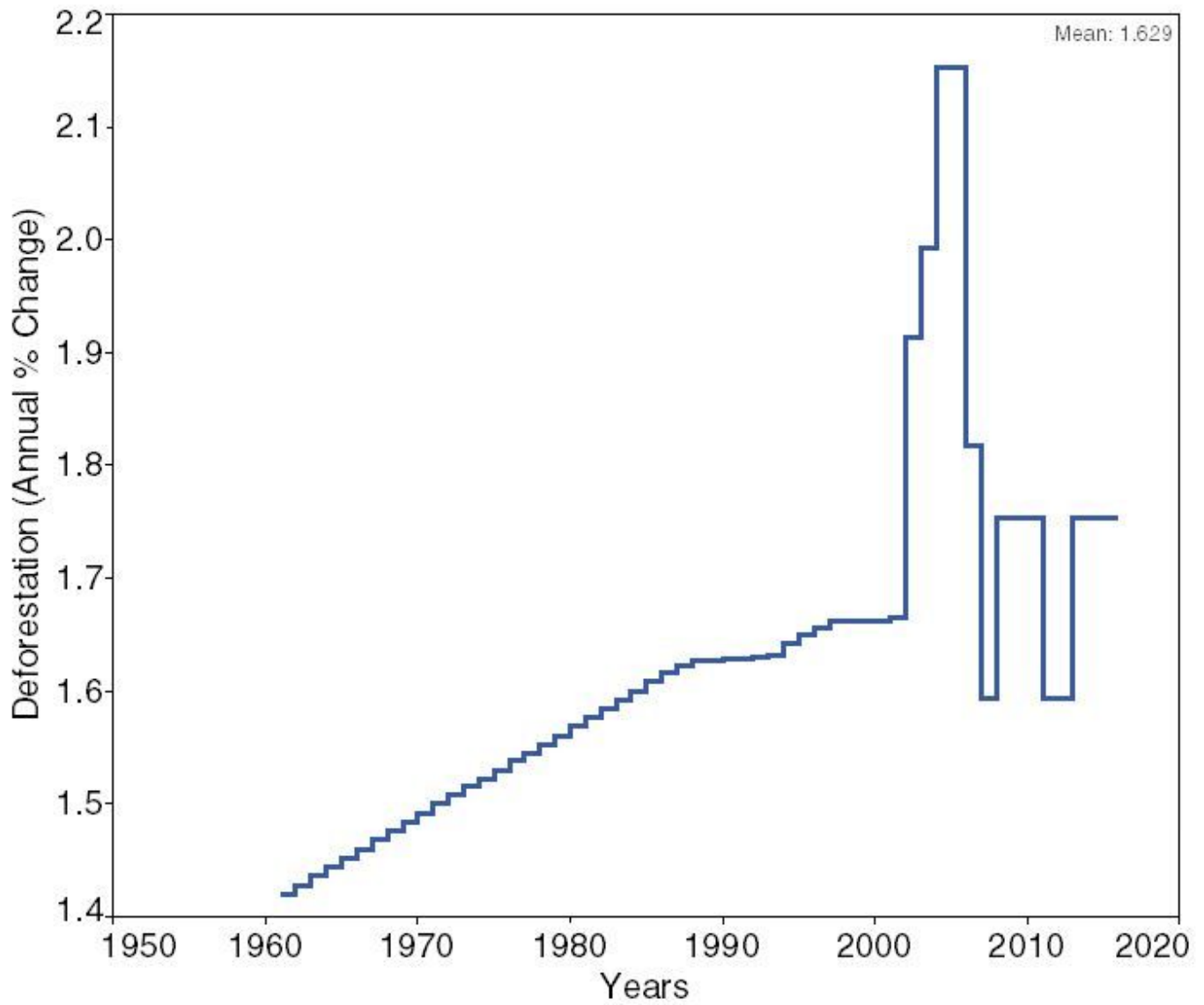
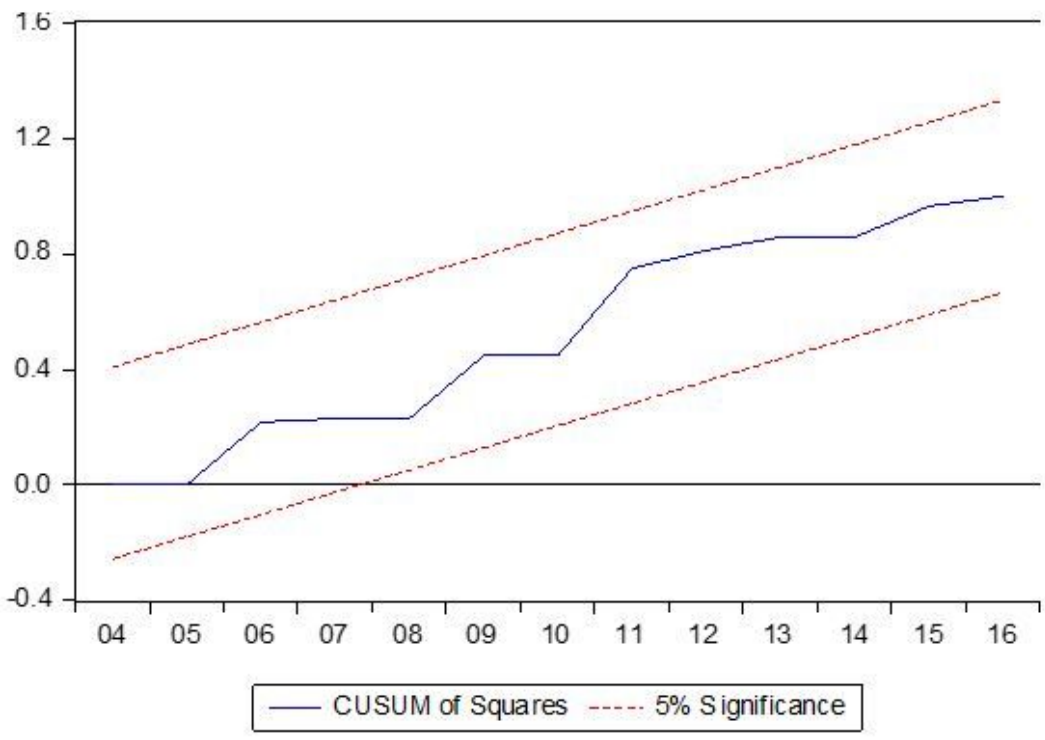
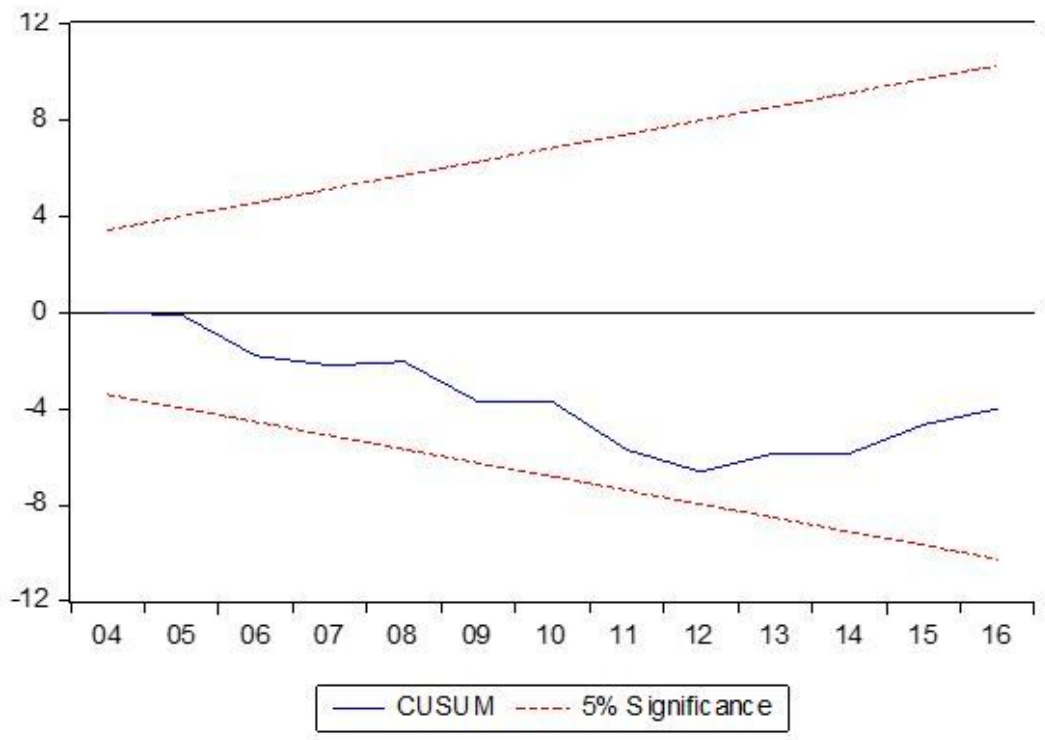


Figure 1

Annual % Change in Deforestation. Data Source: World Bank



**Figure 2**

Model Stability (a) CUSUM Test (b) CUSUM Square Test