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Research article

# Natural disasters, deforestation, and emissions affect economic growth in Somalia

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ABSTRACT

This study ascertains the effect of natural disasters, deforestation, and emissions on economic growth in Somalia using annual time series spanning 1990–2018. Contrary to previous attempts, this study utilized the kernel regularized least squares (KRLS) technique, robust Granger causality in the presence of instabilities, and novel supremum right-tail Augment Dickey-Fuller unit root to test explosive behaviors in data series. While two date-stamped explosive behaviors are detected in economic growth (2003–2012, 2014–2016) and FDI (2004, 2016–2018), one explosive behavior is observed in capital formation (2010–2018) and population density (2010–2018). Moreover, time-varying granger causalities among sampled variables are observed. The empirical results show natural disasters and deforestation significantly undermine economic growth, whereas GHG emissions stimulate economic growth. Besides, while GHG emissions have increasing marginal effects, natural disasters and deforestation have decreasing marginal effects. The marginal effect of the interaction between natural disasters and temperature change is close to zero, implying that temperature changes do not mediate the disaster-growth nexus. Nevertheless, the study underscores the need for the implementation of environmental and economic policy reforms related to natural disaster preparedness, eliminating deforestation for charcoal exports while implementing a paradigm shift from domestic charcoal and firewood energy consumption to clean and renewable energy.

## 1. Introduction

Natural catastrophes are becoming more severe and frequent in both poor and wealthy nations around the world, resulting in a staggering loss of lives and property in recent decades. Tragedies lead to economic damage, among other things, in the form of the destruction of infrastructure at the disaster site [1]. Natural catastrophes are reported to affect income inequality and poverty levels, particularly in developing economies [2]. Due to a growing knowledge of the devastating effects of climate change events, and the need for post-disaster restoration, research on the impact of natural disasters on disaster-prone areas has received a lot of consideration [3]. Climate-related disasters are reported to impede economic growth, hence, affecting livelihoods [3]. For example, existing literature shows economic growth significantly impacts disaster losses in 31 Chinese provinces (municipal governments, and independent states), specifically in Western, Central, and Eastern areas [4]. Other studies demonstrate that disaster damages can increase more

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quickly than wealth while least developed nations experience numerous, low-cost disasters compared to developed nations with more infrequent high-cost occurrences [5].

Asia and the Pacific are the regions that are most frequently hit by natural catastrophes. The most populated nations experience the largest fatalities and economic consequences. But in terms of magnitude, the poorest nations and tiny island emerging states experience the highest effects on the economy [6]. Somalia is a country located in the Greater Horn of Africa. Since the civil war broke out in 1991, the transitional Federal governments of Somalia have become weakened to enforce natural disaster protection and mitigation policies. Somalia is considered one of the least equipped nations to cope with the impacts of climate change [7]. Hence, it has been classified as among the most vulnerable nations to climate change in the world. The extreme dry periods in winter are always followed by wet periods in the spring and autumn—in which the country observes substantial amounts of rains that promote agricultural growth and the restoration of grassland and water supplies. However, the intense precipitation and consequent floods have also resulted in casualties, widespread evictions, and devastation of farmland and infrastructures due to a lack of water management systems such as dams. In the foreseeable future, it is anticipated that needs will rise in floodplain areas and locations of resettlement [7]. During 1980–2020, the most frequent natural disaster in Somalia was flooding, which accounts for ~45.25% of the natural hazard occurrences. The other natural disasters include epidemics (28.5%), droughts (12.63%), storms (7.37%), earthquakes (1.05%), and miscellaneous accidents (5.26%) [5]. Recognizing these historical vulnerabilities requires knowledge of the incidence of natural hazards as well as historical changes in climate in connection to socioeconomic settings.

The existing empirical investigations have mostly focused on determining the short- and long-term consequences of natural disasters on economic development while accounting for variables that may enhance or lessen these impacts. The reported consequences of natural disasters on economic growth in empirical studies vary significantly. Previous studies found a positive association between the magnitude of disasters and the resultant effects of physical disasters including the number of fatalities and financial damages to infrastructures [8]. Further, Kumar et al. [9], observed in India that floods impede economic growth both in the short and long run. Similar results have been reported by Parida & Prasad Dash [10], in Indian states and De Oliveira [11], in the Ceará state of Northeastern Brazil. They found that floods and natural disasters (as aggregate) inhibit economic growth in the long run. They further highlighted that agriculture and service are the most susceptible sectors to natural disasters. Indirect estimates of disaster effects on economic progress are determined by the expected impact of natural hazards. While most investigations generally found detrimental impacts of natural disasters on economic growth in the year of the disaster (in the short run), a substantial portion of the figures is statistically insignificant in a meta-analysis comparing 750 estimates observed in 22 studies [12]. Hydro-meteorological and climatic phenomena-induced disasters have the most detrimental impact on economic growth in developing economies. The findings from studies that examined the detrimental external costs of storms on economic development demonstrated that the severity of storms has a significant impact on the balance of trade and government revenue accountancy structure in 21 Caribbean countries [13]. This shows that equitable environmental and socio-economic policies are essential for long-term growth.

Somalia is a protracted crisis country with over three decades of civil unrest and political instability. Consequently, it has led to severe and harsh environmental conditions mainly in the form of forest degradation and natural resource extractions. For instance, Somalia's forest area decreased from 13% in 1990 to 9.5% of the total land area in 2020 [14]. Energy consumption, charcoal exports, and unsustainable agricultural cultivations are the main drivers of forest degradation in the country [15]. Sustainable economic development and growth enhance social welfare and standard of living. Hence, environmental pollution and degradation are topical issues in the economic development and growth process. The aggravating environmental conditions have a direct impact on economic performance, livelihoods, and quality of life [16]. Long-term environmental pollution has an extreme impact on natural resources, health, and natural disasters which in turn hampers economic growth. Land degradation, noise pollution, atmospheric pollution, and water pollution are among the key forms of pollution. Few studies have concentrated on the effect of air pollution on economic growth by demonstrating how pollution limits growth (i.e., industrial air pollution affects agricultural output) [17]. Some of these studies noted that environmental quality enhances economic growth and welfare. By measuring the welfare loss caused by environmental pollution in Europe, a reduction in air pollution is predicted to improve welfare by 37–49 billion Euros in 18 Western European countries [18].

The environmental Kuznets curve (EKC) theory has been widely used to ascertain the effect of economic development on environmental pollution and land degradation [19]. The EKC in the context of deforestation shows an initial increase in deforestation parallel to economic expansion. However, the amount of forested land may rise quickly at a doubling rate of income level, reducing forest exploitation [20,21]. The higher economic expansion which intensifies the rate of deforestation is evidenced in several nations including India [22], Australia [23], Somalia [24], and DR Congo [25]. The fundamental causes of deforestation in relation to economic progress may vary across countries and economic structures. A strand of the existing literature argues that economic growth is driven by environmental pollution – this implies a direct effect of environmental pollution on production and employment [26,27]. The majority of studies have emphasized the unidirectional relationship between environmental pollution and economic development. Other literature shows environmental pollution is the greasing wheel of economic growth. For instance, $CO_2$ emissions are reported to stimulate economic development in Pakistan [28] and a panel of countries [29].

On the contrary, the relationship between $CO_2$ emissions and economic growth is inconsequential and may have no mutual effects in the Gulf Cooperation Council (GCC) countries [30], India [31], Malaysia [32], and Sub-Saharan Africa [33]. Several studies found a mutual coupling between environmental pollution and economic development. For example, the bidirectional relationship between total local product per capita and sulfur dioxide emissions was found in 286 Chinese and 228 South Korean cities and counties. An inverted U-shaped pattern between output and emissions was reported in metropolitan zones, whereas a U-shaped pattern was found in non-metropolitan zones in both countries [34]. Finally, ample studies have reported that an increase in global GHG emissions adversely affects economic growth [35].

 

Notably, a section of existing literature employed $CO_2$ and GHG emissions as proxies for environmental pollution [30–33,36]. However, a few studies have utilized deforestation as a measurement of environmental pollution, which is a global threat to sustainability and also has a dreadful effect on growth [37]. Due to the importance of deriving a coherent climate change policy to address the environmental harsh conditions, empirical studies on this theme in Somalia (a fragile and vulnerable country to climate change) are scanty. To fill that gap, we examine the impacts of natural disasters, population dynamics, renewables, capital formation, and GHG emissions on economic growth in Somalia. Our empirical strategy contributes to the literature by the inclusion of vital drivers such as changes in temperature, and deforestation, which were excluded from previous studies. Besides, these studies employed traditional econometric methods that suffer from heterogeneity issues and model misspecification to examine the causal effects between the environment and growth [10,11,35]. In contrast, we utilize estimation methods that control misspecification bias, classification, and regression problems while we derive the marginal effects of the regressors. Unlike other conventional regression methods, the Kernel regularized least squares (KRLS) method can effectively and efficiently estimate complex models with interaction effects, non-additivity, and non-linearities [38]. Our study further applies the supremum right-tail Augment Dickey-Fuller unit root technique for detecting explosive behaviors and time-varying granger causality for estimating granger causality in the presence of instabilities [39]. The standard VAR models and other causality methods are inadequate to estimate the causation among variables due to instabilities resulting from regime shifts and structural breaks. Time-varying granger causality outperforms the standard causality by addressing the presence of instabilities and re-establishes the significance of test statistics in various time periods.

The remainder of this study entails data and empirical methodologies covered in Section 2, data analyses, key findings, and discussion presented in Section 3, and the conclusion captured in Section 4.

## 2. Methods

### *2.1. Data*

This study emphasizes the connotation of natural disasters, deforestation, GHG emissions, and economic growth using annual time series data spanning 1990–2018 in Somalia. Somalia is a prone-conflict country with a lower per capita income along with exposure to climate change consequences including droughts, and floods. Somalia is considered one of the most susceptible countries to climate change in the world, even though, it contributes a negligible proportion to the global GHG emissions [40]. However, Somalia's forest area has been dramatically plummeting since 1990 [41]. We incorporate other endogenous variables essential to assess economic dynamics such as renewable energy, FDI, capital, urban population, rural population, population density, and temperature change [42,43]. It is argued that changes in temperature have both direct and indirect effects on natural disasters which in turn hamper economic growth. Because the doubling of natural disasters and temperature effects could undermine economic growth, we include the square of natural disasters and the interaction between natural disasters and temperature change. Our adopted variables namely population density, urban population, rural population, renewable energy, GHG emissions, FDI, and deforestation were extracted from the World Development Indicators of the World Bank. Capital and real gross domestic product were retrieved from the Organization of Islamic Cooperation (OIC) database of SESRIC. Temperature change and natural disasters were sourced from the Food and Agriculture Organization (FAO) and the United Nations Environment Program, respectively. The selection of variables is in line with the indicators of the sustainable development goals (SDGs). The detailed sources and descriptions of the interesting variables are reported in Table 1 whereas the trends of the sampled variables of the study are presented in Fig. 1(a–k). The descriptive statistics of the series are reported in Table 2. FDI (3.22) and natural disasters (2.7) have the highest standard deviations, which indicate their volatilities compared to renewable energy (0.0149) and GHG emissions (0.032). Capital formation, deforestation, and natural disasters are positively skewed whereas real GDP, population density, GHG emissions, FDI, temperature changes, and rural and urban population are negatively skewed. More importantly, all the variables except deforestation are normally distributed as confirmed by the probability of the Jarque-Bera.

**Table 1**
Variable description.

| Code | Indicator Name | Source |
|---|---|---|
| POPDEN | Population density (people per sq. km of land area) | Worldbank |
| URB | Urban population | Worldbank |
| RNEW | Renewable energy consumption (% of total energy consumption) | Worldbank |
| GHG | Total greenhouse gas emissions (thousand metric tons of $CO_2$eq) | Worldbank |
| RUR | Rural population | Worldbank |
| FDI | Foreign direct investment, net inflows (BoP, current US$) | Worldbank |
| TEMP | Temperature change | FAO |
| K | Gross capital formation in the current US dollar | SESRIC |
| DEFO | Deforestation measured for arable land | Worldbank |
| RGDP | Real gross domestic product | SESRIC |
| DISASTER | Natural disasters, total people affected | UNEP |

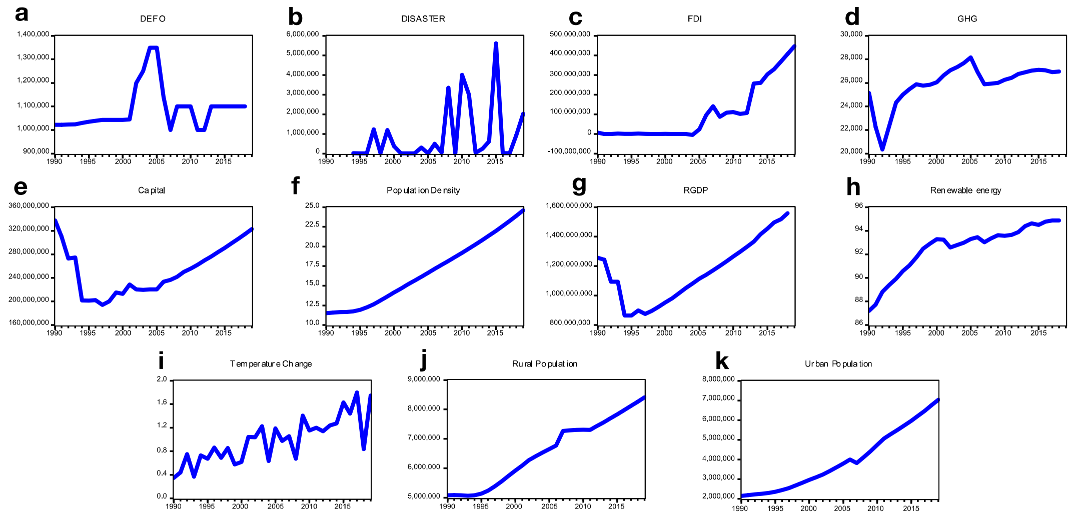


**Fig. 1.** Trend of the sampled variables: (a) Deforestation (b) Natural disasters (c) FDI (d) GHG (e) Gross capital formation (f) Population density (g) Economic growth (h) Renewable energy use (i) Temperature change (j) Rural population (k) Urban population.

**Table 2**
Summary statistics of the interested variables.

| | Mean | Median | Maximum | Minimum | SD | Skewness | JB | Prob |
|---|---|---|---|---|---|---|---|---|
| RGDP | 20.86765 | 20.89397 | 21.16792 | 20.5777 | 0.202198 | −0.12446 | 1.750487 | 0.416761 |
| POPDEN | 2.84282 | 2.885526 | 3.174865 | 2.464036 | 0.23197 | −0.28596 | 1.701526 | 0.427089 |
| K | 19.30777 | 19.29313 | 19.56643 | 19.08406 | 0.152813 | 0.142199 | 1.469529 | 0.479619 |
| GHG | 10.18039 | 10.18659 | 10.24566 | 10.09905 | 0.0321 | −0.5654 | 1.429563 | 0.489299 |
| FDI | 16.59076 | 18.41017 | 19.82678 | 10.59663 | 3.228545 | −0.6866 | 2.823951 | 0.243661 |
| DISASTER | 11.3467 | 10.55478 | 15.54189 | 7.082549 | 2.706944 | 0.138373 | 1.80935 | 0.404673 |
| DEFO | 13.89477 | 13.91082 | 14.11562 | 13.81551 | 0.067184 | 1.618113 | 20.56913 | 0.000034 |
| RNEW | 4.534829 | 4.537083 | 4.552563 | 4.498788 | 0.014876 | −0.94666 | 3.319581 | 0.190179 |
| RUR | 15.71971 | 15.80071 | 15.9268 | 15.44124 | 0.159473 | −0.5307 | 2.18662 | 0.335105 |
| TEMP | 0.023666 | 0.048281 | 0.587787 | −0.482886 | 0.300683 | −0.0412 | 0.72229 | 0.696878 |
| URB | 15.20271 | 15.21384 | 15.72496 | 14.64426 | 0.356766 | −0.14679 | 1.66803 | 0.434302 |

### 2.2. Estimation method

Political and economic shocks in global and regional contexts induce unusual effects on production and consumption that lead to explosive behaviors. The term "explosive behavior" indicates the presence of unusual behaviors in environmental and macroeconomic variables across time [37]. To address this issue, we utilized the novel supremum right-tail Augment Dickey-Fuller unit root technique based on the null hypothesis of unit root— a rejection indicating the existence of outliers, viz. explosive behaviors [37,44]. Due to the presence of explosive behaviors, we further applied time-varying granger causality to estimate granger causality to capture instabilities [39]. The existing traditional VAR techniques are inadequate to estimate causations due to instabilities resulting from regime shifts and structural breaks. Hence, time-varying granger causality outperforms conventional techniques by addressing this challenge (presence of instabilities) while providing robust test statistics in various time periods. We applied reduced-form VAR with at most 2 lags and a trimming parameter of 0.15 while assuming homoskedasticity in idiosyncratic shocks. The estimate four tests namely robust exponential Wald (ExpW), robust mean Wald (MeanW), optimal Nyblom (Nyblom), and quasi-likelihood ratio (QLR) based on the null hypothesis of no Granger-causality [39].

To examine the relationships between economic growth and the interested independent variables, we adopted the KRLS technique designed based on machine learning to fix challenges of regression and classification without additive or linear assumptions [38]. Its interpretation is analogous to the generalized linear model while deriving the marginal effects of regressors. The KRLS method outperforms other traditional linear regression methods that are exposed to misspecification bias. First, it produces accurate results based on initial flexibility in modeling the conditional expectation function and the mean derivative of the parameters–which allows the detection of changes in the regressors. Second, unlike other conventional regression methods, KRLS addresses the over-fitting issue of the model by optimizing the model with a penalty attributed to the optimal regularization function. Third, the KRLS can effectively and efficiently estimate complex models with interaction effects, non-additivity, and non-linearities [38]. We investigate the effect of natural disasters (lnDISASTER), deforestation (lnDEFO), renewable energy (lnRNEW), foreign direct investment (lnFDI), gross capital formation (lnK), urban (lnURB), and rural (lnRUR) population on economic growth (lnRGDP) in Somalia utilizing the KRLS estimation method. The selection of the interesting indicators is in line with these studies [36,45,46]. We develop two models—where in the first model, we assess the role of natural disasters and environmental degradation in economic growth. The first model is formulated as follows:

$$lnRGDP_t = \beta_0 + \beta_1 lnRNEW_t + \beta_2 lnDISASTER_t + \beta_3 lnFDI_t + \beta_4 lnURB_t + \beta_5 lnRUR_t + \beta_6 lnK_t + \beta_7 lnDEFO_t + \varepsilon_t \quad (1)$$

In the second model, we drop disaggregate population and gross capital formation but incorporate additional variables such as GHG emissions (lnGHG), population density (lnPOPDEN), and the square and interactions of some interesting parameters ($lnTEMP \times lnDISASTER$, $lnDISASTER^2$, $lnTEMP^2$)—since KRLS is good at capturing interaction effects, nonlinearity, and complex models. The second model is expressed as:

$$lnRGDP_t = \beta_0 + \beta_1 lnRNEW_t + \beta_2 lnDISASTER_t + \beta_3 lnDISASTER_t^2 + \beta_4 lnFDI_t + \beta_5 lnTEMP_t + \beta_6 lnTEMP_t^2 + +\beta_7 lnPOPDEN_t + \beta_8 lnGHG_t + \beta_9 lnTEMP \times lnDISASTER_t + \beta_{10} lnDEFO_t + \varepsilon_t \quad (2)$$

Where *ln* is the logarithmic transformation, $\beta_0$ is the constant, $\beta_2 \ldots \beta_{10}$ are the estimated parameters, and $\varepsilon_t$ is the error terms in time *t*.

### 2.3. Model validation

To validate the estimated models, several post-estimation tests of the machine learning algorithm were conducted including lambda, tolerance, goodness-of-fit, and looloss as reported in Table 3. Lambda is intended to control the trade-off between complexity and fitness of the model via optimization, whereas tolerance tends to accomplish convergence by limiting the sensitivity of lambda via optimization. Goodness-of-fit is used to measure how much the explanatory variables explain the dependent variable. Looloss is the combination of squared of leave-out-one error. The estimated residuals of the data are normally and identically distributed in both models as shown in Fig. 7(a–b). In contrast, the BDS test examined the independence of the residuals whereas the CUSUM tests presented in Fig. 8(a–d) investigated the parameter stability. The results confirm the residual independence of the estimated models whereas the CUSUM plots within the 95% confidence band imply the residuals of the model are stable over time without structural breaks.

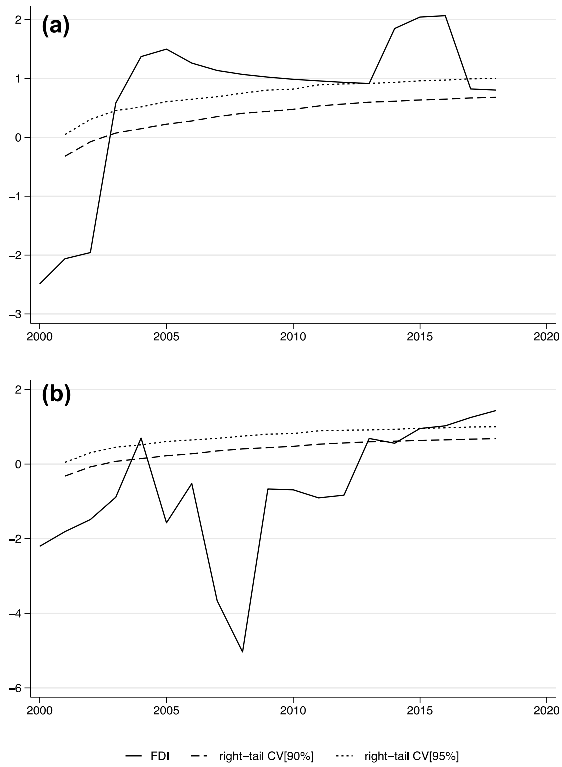


**Fig. 2.** Date-stamping episodes for explosive behavior of (a) economic growth (b) FDI. Legend: ADF0, SADF (PWY, 2011), GSADF (PSY, 2015) tests with right-tail tabulated critical values for 90, 95 confidence levels from Vasilopoulos et al. (2020).

## 3. Empirical results

### 3.1. Explosive behavior and time-varying causality

The presence of political instabilities and civil unrest in Somalia could lead to explosive behaviors in certain macroeconomic and environmental variables. To address this issue, we utilized the novel supremum right-tail Augment Dickey-Fuller unit root technique [37,44]. The results reported in Figs. 2–3 show rejection of the null hypothesis of unit root corresponding to the right-tail 90–95% confidence interval. This implies the existence of outlier values of explosive behaviors across the variables. In Fig. 2(a–b), two explosive behaviors are detected in economic growth (2003–2012, 2014–2016) and FDI (2004, 2016–2018). Moreover, one explosive behavior is observed in capital formation (2010–2018) and population density (2010–2018) in Fig. 3(a–b). After determining the presence of structural breaks in some main variables, using the standard granger causality will not produce robust results. To overcome this shortfall, a novel and robust time-varying granger causality in the presence of instabilities was utilized [39]. The standard VAR models and other causality methods are inadequate to estimate the causation among variables due to the instabilities resulting from regime shifts and structural breaks. This method outperforms the standard causality in several perspectives. First, it addresses the presence of instabilities and re-establishes the causality test statistical significance of various time periods of the sample. Second, it is good at determining the validity tests for both VAR-based direct multistep (VAR-LP) predicting models and reduced-form VAR models.

The results of the time-varying causality of the parameters are presented in Figs. 4–6. The Full Wald statistics (i.e., MeanW, ExpW, Nyblom, and QLR) highlight information about when the causality occurs. Notably, the Wald statistics over time are above the 5% critical value, which indicates renewable energy granger causes economic growth during the period (1993–2018) as shown in Fig. 4. Thus, this confirms the renewable energy-led growth hypothesis. Gross capital formation granger causes economic growth in all-sample periods. But the peak, in terms of causal association happens during the 1990–1992 periods. The causal relationship declines as the time period increases (see Fig. 5a). Additionally, population density causes economic growth from 1991 to 2011. But 1992 is the peak period that population density causes economic growth, whereas, from 2012 onwards, the causality vanishes as shown in Fig. 5b. GHG emissions granger causes economic growth in all-sample periods (1990–2018). The peak causal relationship between the two variables spans from 1990 to 1992—however, the causal relationship decreases as the time period increases (Fig. 6a). The causal effect of GHG emissions on growth from 2011 tends to increase. Similarly, temperature change causes economic growth in all-sample periods (1990–2018). Also, its causality effect on growth declines as the time period rises (see Fig. 6b). Noticeably in the time-varying causality results, climate variables – GHG emissions and temperature change – induce a larger cause on economic growth, but their

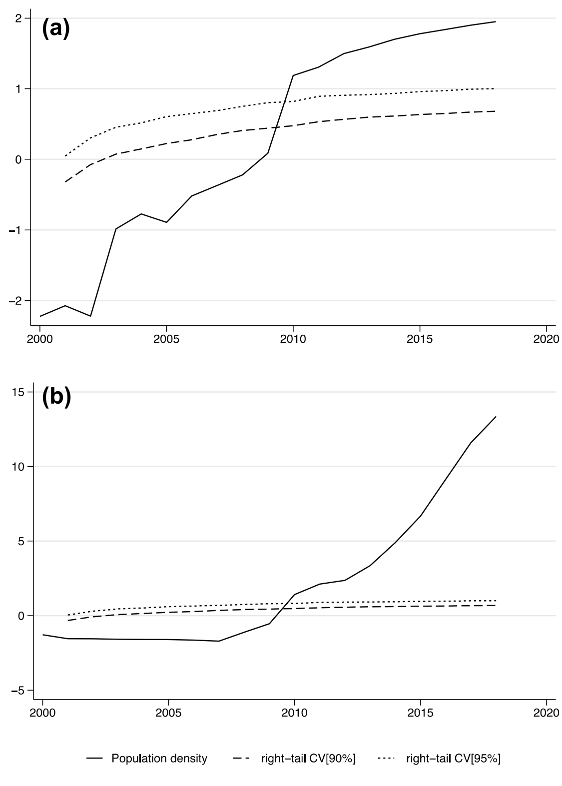


**Fig. 3.** Date-stamping episodes for explosive behavior of (a) Gross capital formation (b) Population density. Legend: ADF0, SADF (PWY, 2011), GSADF (PSY, 2015) tests with right-tail tabulated critical values for 90, 95 confidence levels from Vasilopoulos et al. (2020).

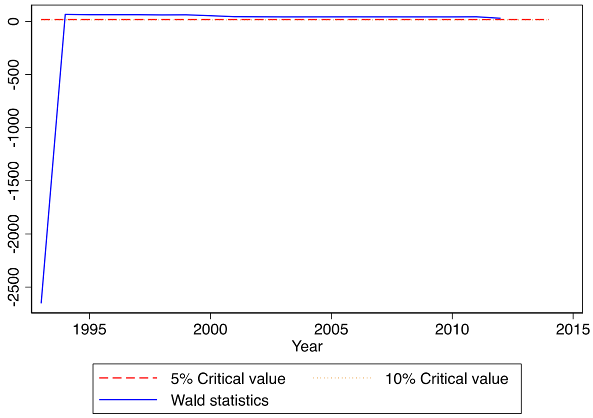


**Fig. 4.** Renewable energy Granger-causes economic growth. Robust estimation using VAR-based Granger causality test (Wald statistics) in the presence of instabilities. Lags in VAR: 1 2, *h* is 0 (reduced-form VAR), trimming parameter is 0.15 with Constant included while assuming homoskedasticity in idiosyncratic shocks. The *p-values* ($p < 0.01$) of the estimated tests namely ExpW, Nyblom, and QLR reject the null hypothesis of no Granger-causality.

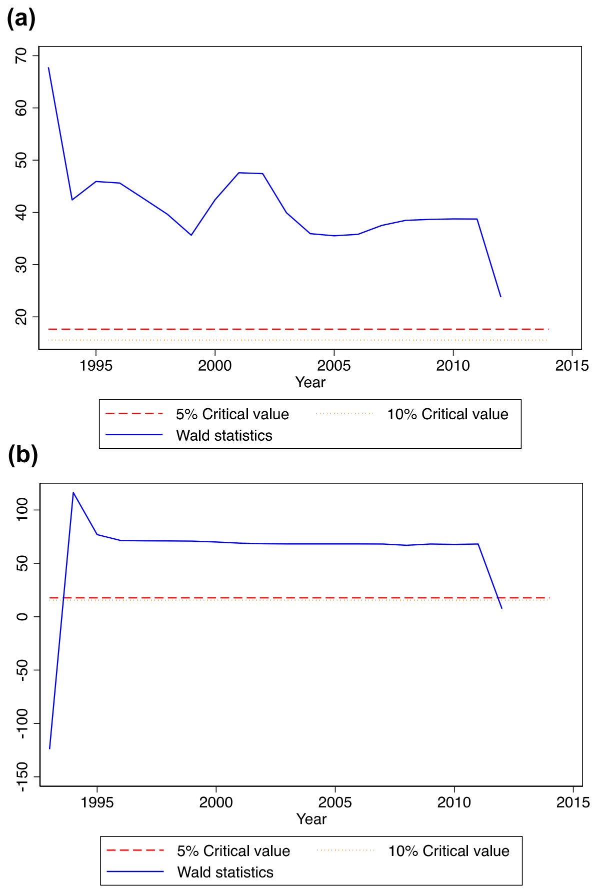


**Fig. 5.** (a) Gross capital formation Granger-causes economic growth (b) Population density Granger-causes economic growth. Robust estimation using VAR-based Granger causality test (Wald statistics) in the presence of instabilities. Lags in VAR: 1 2, *h* is 0 (reduced-form VAR), trimming parameter is 0.15 with Constant included while assuming homoskedasticity in idiosyncratic shocks. The *p-values* ($p < 0.01$) of the estimated tests namely MeanW, ExpW, Nyblom, and QLR reject the null hypothesis of no Granger-causality.

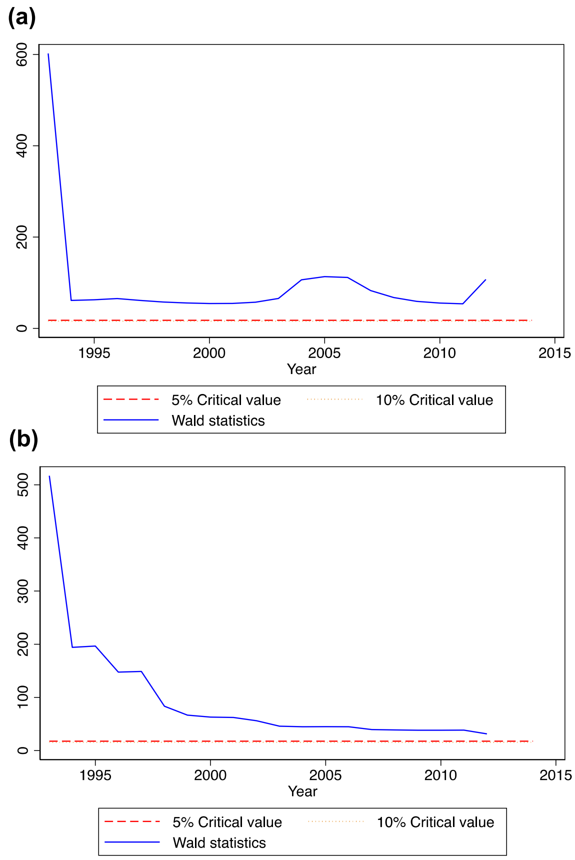


**Fig. 6.** (a) GHG emissions Granger-causes economic growth (b) Temperature change Granger-causes economic growth. Robust estimation using VAR-based Granger causality test (Wald statistics) in the presence of instabilities. Lags in VAR: 1 2, *h* is 0 (reduced-form VAR), trimming parameter is 0.15 with Constant included while assuming homoskedasticity in idiosyncratic shocks. The *p-values* ($p < 0.01$) of the estimated tests namely MeanW, ExpW, Nyblom, and QLR reject the null hypothesis of no Granger-causality.

causality effects decline as the time period increases. Additionally, gross capital formation is responsible for the largest cause of economic growth and, thus, a key driver that underpins economic growth in Somalia.

### *3.2. Parameter estimations using KRLS*

The parameter estimations of KRLS are reported in Table 3. In Model 1, the goodness-of-fit of the model is good with a predictive power of 0.99. The scrutinized predictors of the study explained 99% of variations that occur in economic growth. The heterogeneous marginal effects of the pointwise derivatives of regressors are presented as 25th, 50th, and 75th percentiles. Renewable energy, FDI, rural & urban population, and gross capital formation have significant ($p < 0.01$) positive effects on economic growth in Somalia. On the contrary, natural disasters and environmental degradation – measured using deforestation – significantly undermine economic growth. The mean pointwise marginal effects of renewable energy, FDI, rural population, urban population, and gross capital formation are 1.51, 0.005, 0.082, 0.18, and 0.25 respectively. An average increase in renewable energy, FDI, rural population, urban population, and gross capital formation enhances economic growth by about 1.51%, ~0.01%, 0.08%, 0.18%, and 0.25% on average, respectively. FDI has a less significant effect on economic growth because its marginal effects are close to zero. However, renewable energy, rural & urban population, and gross capital formation have increasing marginal effects hence essential for sustainable economic growth in Somalia. The mean pointwise marginal effects of natural disasters and deforestation are 0.003 and 0.09 respectively. An average increase in natural disasters and deforestation hamper economic growth by about 0.003% and 0.09% on average, respectively. The marginal effects of natural disasters are close to zero; and thus, do not substantially undermine growth, despite its 75th percentile turning positive. Moreover, deforestation impedes economic growth, even though, it has diminishing marginal effects.

Furthermore, we incorporated additional variables such as GHGs, population density, and temperature change to assess their impacts on growth. We also examined the effects of the square of natural disaster, temperature change, and the interactions of temperature and disaster on growth to determine non-linear and interaction effects between the predictive series. The results reported in Model 2 have a predictive power of 1, which implies that the scrutinized regressors explain 100% of variations in economic growth. GHGs and population density significantly ($p < 0.01$) enhance economic growth with corresponding mean pointwise marginal effects

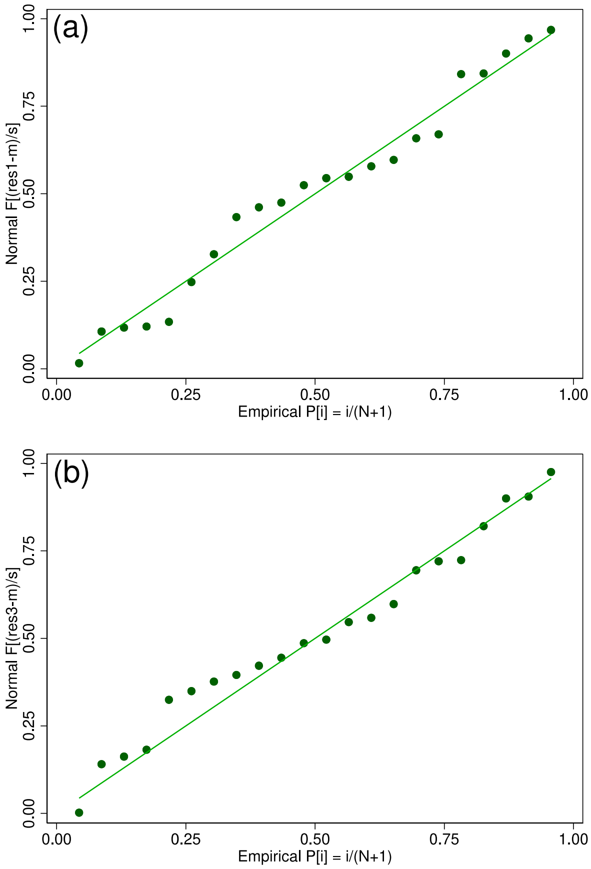


**Fig. 7.** Normal distribution of the estimated residuals (a) Model 1 (b) Model 2.

of 0.223 and 0.534, respectively. An average increase in population density and GHG emissions increase economic growth by ~0.223% and 0.534% on average, respectively (both have increasing marginal effects). One striking result is that temperature change is insignificant and has a zero average marginal effect, hence, it does not exert any effect on growth. Moreover, temperature change at the 25th percentile is insignificant, at the median and 75th percentiles it turns positive and insignificant. On the contrary, the square of temperature change significantly enhances economic growth. It has an average pointwise marginal effect of 0.193. But at the 25th percentile, it turns negative, thus significantly impeding economic growth whereas at the median and 75th percentiles, it turns positive, hence, significantly improving economic growth. However, this proves the presence of heterogeneous marginal effects of temperature change. Natural disasters and their nonlinear do not affect economic growth because they have zero marginal effects in all percentiles. Considering the interaction of natural disasters and temperature change, their marginal effect is close to zero—which implies that it does not exert any substantial effect on economic growth. Thus, confirming that temperature change does not exert any mediating effect on the disaster-growth nexus.

After considering the nonlinearity and interaction of temperature and natural disasters, deforestation has a larger inhibiting effect on economic growth. It has an average marginal effect of 0.234. An average increase in deforestation inhibits economic growth by ~0.23%. Deforestation has a decreasing marginal effect which is in line with the results of Model 1. The control variables of renewable energy and FDI have average pointwise marginal effects of 2.44% and 0.01% respectively. FDI has marginal effects close to zero, while renewable energy has increasing marginal effects. This further shows that FDI has a negligible effect on growth, whereas renewable energy substantially impacts growth.

A striking result of the study is that deforestation has a diminishing marginal effect on economic growth whereas GHG emissions have increasing marginal effects on growth. Environmental degradation results in biodiversity loss, natural resource exploitation, and anthropogenic GHG emissions. Notably, forests are sources of cultural integrity and livelihoods for 1.6 billion globally, with 13.2 million people depending on forests as a source of direct income. Meanwhile, 80% of the world's terrestrial biodiversity and 80% of the world's land-based species live in forests. Besides, the forest is a vital source of shelter, fiber, timber, and medicine [41]. However, clearing forests contributes to environmental pollution by releasing carbon and leading to soil erosion, the water cycle, and global warming—which ultimately hampers agriculture production, economic growth, and livelihoods. For instance, Mohamed & Nageye [47] documented that land degradation, which is taken as a proxy for environmental degradation, impedes agriculture production in Somalia. This undermines economic growth in Somalia since agriculture production constitutes 75% of Somalia's gross domestic product (GDP) [48,49]. This is further supported by the study of Tan et al. [50], in European countries.

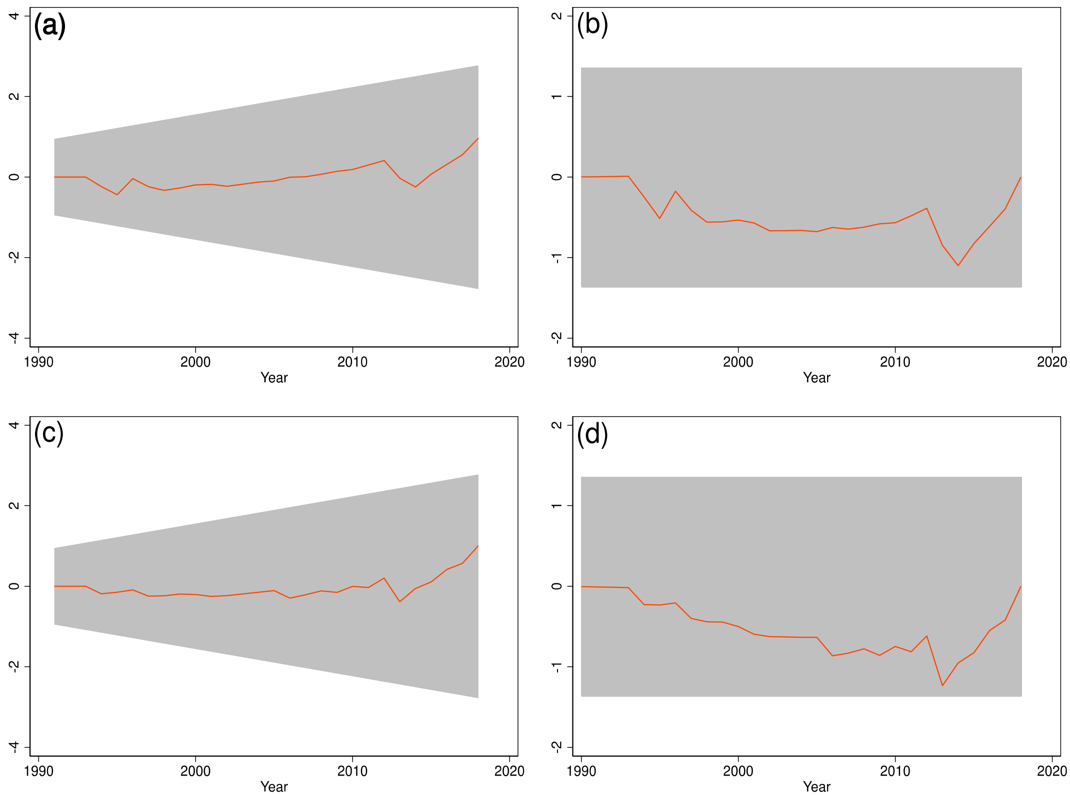


**Fig. 8.** Parameter stability of the estimated residuals (a) Recursive CUSUM of Model 1 (b) OLS CUSUM of Model 1 (c) Recursive CUSUM of Model 2 (d) OLS CUSUM of Model 2.

The larger effects of GHG on economic growth will take some time to manifest but are not expected to have instantaneous larger impacts; hence, this explains the presence of increasing marginal effects of GHG emissions on economic growth. The existing literature on the GHG-growth nexus produced inconclusive results. Some studies have backed our results such as Tsaurai [51], in a panel study in Africa; Muhammad [52] in emerging and developed countries; Ghosh [26], in India; and Ahmad & Du [27], in Iran. These studies have concluded that GHG emissions are a greasing wheel of economic growth. Environmental pollution driven by industrialization, urbanization, and modernization exacerbates economic growth. Moreover, the utilization of nonrenewable natural resources improves economic growth but at the cost of environmental quality Azam et al., [53]. Somalia is one of the least polluters in the world due to low energy intensity and lack of industrial manufacturers [15]. Nevertheless, an increase in GHG emissions enhances economic growth in Somalia. On the contrary, others have found that GHGs have horrendous effects on economic growth such as Nathaniel et al. [54], in a sample of African countries; Saidi & Hammami [55], in a panel of 58 countries; Azam et al. [53], in a sample of higher $CO_2$ emitters; and Islam et al. [56], in Saudi Arabia. These studies argue that the resultant effects of emissions from burning fossil fuels hamper the environment, health, and productivity. Hence, it shows the importance of mitigating emissions by substituting nonrenewable energy for clean energy which favors environmental quality and confirms sustainable economic growth.

Deforestation and emissions instigate natural disasters including droughts, floods, winds, storms, and wildfires. These natural hazards severely undermine productivity and livelihoods. However, this justifies the negative impact of natural disasters on economic growth in Somalia. The forests in Somalia are degrading at an unprecedented rate and, hence, ranked one of the most susceptible countries to climate change in the world [40]. More than 30 climate-related natural hazards including famines, floods, and droughts occurred in Somalia since 1990 [57]. These hazards conspicuously caused extensive damage and fatalities while inhibiting the country's domestic production, and promoting migration. Our findings on the adverse effect of natural disasters on economic growth are consistent with previous studies such as Strobl [58] in Central American and Caribbean regions; Boustan et al. [59] in the United States; and Pu et al. [60] in China.

## 4. Conclusion and policy implications

Environmental pollution and degradation induce climate change, global warming, and natural disasters that undermine both livelihoods and economic growth. The available studies on environmental pollution, degradation, natural disasters, and economic growth nexus are limited in fragile conflict-prone countries including Somalia. To this end, we examined the effect of environmental pollution, degradation, and natural disasters on economic growth in Somalia. Contrary to the previous attempts, this study utilized the

**Table 3**
Parameter estimation using kernel-based regularized least squares.

| Economic growth | Model 1 | Model 2 |
|---|---|---|
| Renewable energy | | |
| Avg. | 1.511*** | 2.443*** |
| P25 | 0.715*** | 0.987*** |
| P50 | 1.737*** | 2.581*** |
| P75 | 2.198*** | 4.186*** |
| Std. | (0.142) | (0.005) |
| Natural disaster | | |
| Avg. | −0.003*** | −0.001*** |
| P25 | −0.011*** | −0.008*** |
| P50 | −0.001*** | 0.001*** |
| P75 | 0.005*** | 0.005*** |
| Std. | (0.001) | (0.000) |
| Natural disaster$^2$ | | |
| Avg. | | 0.000*** |
| P25 | – | 0.000*** |
| P50 | | 0.000*** |
| P75 | | 0.000*** |
| Std. | | (0.000) |
| Foreign direct investment | | |
| Avg. | 0.005*** | 0.008*** |
| P25 | 0.003*** | 0.003*** |
| P50 | 0.006*** | 0.008*** |
| P75 | 0.008*** | 0.012*** |
| Std. | (0.001) | (0.000) |
| Urban population | | |
| Avg. | 0.082*** | |
| P25 | 0.031*** | – |
| P50 | 0.088*** | |
| P75 | 0.136*** | |
| Std. | (0.004) | |
| Rural population | | |
| Avg. | 0.181*** | |
| P25 | 0.078*** | |
| P50 | 0.227*** | – |
| P75 | 0.275*** | |
| Std. | (0.013) | |
| Gross capital formation | | |
| Avg. | 0.252*** | |
| P25 | 0.046*** | |
| P50 | 0.301*** | – |
| P75 | 0.392*** | |
| Std. | (0.011) | |
| Deforestation | | |
| Avg. | −0.094*** | −0.234*** |
| P25 | −0.259*** | −0.480*** |
| P50 | −0.141*** | −0.292*** |
| P75 | −0.075*** | −0.047*** |
| Std. | (0.028) | (0.001) |
| Temperature change | | |
| Avg. | | 0.000 |
| P25 | – | −0.035 |
| P50 | | 0.000 |
| P75 | | 0.034 |
| Std. | | (0.000) |
| Temperature change$^2$ | | |
| Avg. | | 0.193*** |
| P25 | – | −0.063*** |
| P50 | | 0.253*** |
| P75 | | 0.441*** |
| Std. | | (0.001) |
| Population density | | |
| Avg. | | 0.223*** |
| P25 | – | 0.092*** |
| P50 | | 0.226*** |
| P75 | | 0.370*** |
| Std. | | (0.000) |
| GHG emissions | | |
| Avg. | | 0.534*** |

(*continued on next page*)

**Table 3** (*continued*)

| Economic growth | Model 1 | Model 2 |
|---|---|---|
| P25 | – | 0.317*** |
| P50 | | 0.589*** |
| P75 | | 0.783*** |
| Std. | | (0.005) |
| Temperature × disaster | | |
| Avg. | | −0.001*** |
| P25 | – | −0.004*** |
| P50 | | −0.001*** |
| P75 | | 0.002*** |
| Std. | | (0.000) |
| ***Model metrics*** | | |
| Obs | 22 | 22 |
| Lambda | 0.063 | 0.001 |
| Tolerance | 0.022 | 0.022 |
| Sigma | 7.000 | 10.000 |
| Eff. Df | 14.650 | 21.810 |
| $R^2$ | 0.998 | 1.000 |
| Looloss | 0.078 | 0.326 |
| ***Robustness*** | | |
| BDSstat | 0.7215 | −1.0908 |
| | 1.0314 | 0.4978 |
| | −1.3288 | −0.7504 |
| Pr(skewness) | 0.726 | 0.126 |
| Pr(kurtosis) | 0.297 | 0.044 |
| Adj chi$^2$ | 1.300 | 5.960 |

Attn: (.) denotes the estimated standard error, *** represents statistical significance at *p-value* $< 0.01$, P25, P50, and P75 represent the quantile (0.25, 0.50, and 0.75) specification to validate the unconditional distribution of estimated parameters. BDSstat denotes Brock, Dechert, Scheinkman test for independence (We fail to reject the null hypothesis of residual independence), Pr(skewness), and Pr(kurtosis) represent skewness and kurtosis tests for normality. Values without parenthesis are the coefficients while the values with parenthesis are the standard deviation.

KRLS estimation method– a machine learning algorithm that outweighs the traditional econometric methods in several perspectives. For robust findings, the study incorporated renewable energy, FDI, rural population, urban population, and gross capital formation as control variables. Before the coefficient parameter estimations, we tested for explosive behaviors using the novel supremum right-tail Augment Dickey-Fuller unit root technique. Two explosive behaviors were detected in economic growth (2003–2012, 2014–2016) and FDI (2004, 2016–2018). Moreover, one explosive behavior was observed in capital formation (2010–2018) and population density (2010–2018). In contrast, the time-varying granger causality revealed that renewable energy granger causes economic growth during the period 1993–2018, confirming the renewable energy-led growth hypothesis. Gross capital formation granger causes economic growth in all-sample periods but the peak of causal association happens during 1990–1992. Additionally, population density causes economic growth during the following period 1991–2011. GHG emissions and temperature change granger cause economic growth in all-sample periods (1990–2018), whereas the causality effect on growth declines as the time period rises.

The empirical results revealed that renewable energy, FDI, rural population, urban population, and gross capital formation significantly increase economic growth in Somalia. On the contrary, natural disasters and deforestation significantly undermine economic growth. An average increase in natural disasters and deforestation hamper economic growth by ~0.003% and 0.09% on average, respectively. Besides, we also examined the effects of the square of natural disaster, temperature change, and the interactions of temperature and disaster on growth to determine non-linear and interaction effects between predictive series. The mean pointwise marginal effects of population density and GHG emissions increase economic growth by ~0.223% and 0.534% respectively. Temperature change does not exert any effect on growth, but the square of temperature change significantly enhances economic growth. At the 25th percentile, the average pointwise marginal effect turns negative, thus, impeding economic growth whereas it turns positive at the median and 75th percentiles, hence, improving economic growth. However, this proves the presence of heterogeneous marginal effects of temperature change on economic growth. Natural disasters and their nonlinearity do not affect economic growth because they have zero marginal effects in all percentiles. Considering the interaction of natural disasters and temperature change, their marginal effect is close to zero, which implies it does not exert any substantial effect on economic growth. This confirms that temperature change does not exert any mediating effect on the disaster-growth nexus.

Based on the empirical findings, the study recommends several policy implications. First, the forest area in Somalia is degrading at an alarming rate, undermining environmental quality and economic growth; hence, we suggest the prohibition of deforestation for charcoal exports whilst implementing a paradigm shift from domestic charcoal and firewood energy consumption to clean and renewable energy. Remarkably, charcoal export to foreign countries and domestic consumption are the main drivers of deforestation in Somalia. Second, investing in clean energy would stimulate environmental quality without compromising economic growth. For instance, Somalia consumes charcoal and firewood as the primary energy used for cooking. Hence, green energy will substitute biomass energy consumption. Third, the study recommends the dire need for the implementation of environmental and economic policy reforms related to natural disaster preparedness. Appropriate management before and after disaster occurrence would help mitigate the effects of natural disasters. Somalia frequently experiences climatic consequences in the form of floods and droughts yearly. Hence, building dams could contribute to the availability of water during drought periods while mitigating the flash flood effects.

As a limitation, this study only focused on the natural disaster-deforestation-economic growth nexus in Somalia where climatic consequences are evident. However, there is an avenue for future studies to consider the natural disaster-deforestation-economic growth nexus in a panel of countries. Thus, future studies could examine the effects of disaggregated natural disasters such as floods, droughts, storms, and tropical cyclones on economic growth and the agriculture sector to derive robust climate policies.

## Data availability

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

## Ethical approval

Not applicable.

## Consent to participate

Not applicable.

## Consent to publish

Not applicable.

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## CRediT authorship contribution statement

**Abdimalik Ali Warsame:** Writing – original draft, Methodology, Conceptualization. **Jama Mohamed:** Writing – original draft. **Samuel Asumadu Sarkodie:** Writing – review & editing, Funding acquisition, Formal analysis.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Samuel Asumadu Sarkodie reports a relationship with Cell Press that includes: board membership. Associate editor of Heliyon.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28214.

## References


[1] J. Hidalgo, A.A. Baez, Natural disasters, Crit. Care Clin. 35 (4) (Oct. 2019) 591–607, https://doi.org/10.1016/j.ccc.2019.05.001.
[2] J. Groeschl, I. Noy, Poverty, inequality, and disasters – an introduction to the special issue, Econ. Disasters Clim. Chang. 4 (1) (Apr. 2020) 1–3, https://doi.org/10.1007/s41885-020-00063-2.
[3] A.A. Warsame, I.A. Sheik-Ali, H.A. Hussein, G.M. Barre, Assessing the long- and short-run effects of climate change and institutional quality on economic growth in Somalia, Environ. Res. Commun. 5 (5) (2023), https://doi.org/10.1088/2515-7620/accf03.
[4] Y. Zhou, et al., Socioeconomic development and the impact of natural disasters: some empirical evidences from China, Nat. Hazards 74 (2) (Nov. 2014) 541–554, https://doi.org/10.1007/s11069-014-1198-0.
[5] S. Hallegatte, How Economic Growth and Rational Decisions Can Make Disaster Losses Grow Faster than Wealth, The World Bank, 2011.
[6] United Nations ESCAP, Disaster Resilience for Sustainable Development, 2017.
[7] Federal Government of Somalia, Environmental and Social Management Framework (ESMF), 2020.
[8] E. Cavallo, S. Galiani, I. Noy, J. Pantano, Catastrophic natural disasters and economic growth, Rev. Econ. Stat. 95 (5) (Dec. 2013) 1549–1561, https://doi.org/10.1162/REST_a_00413.
[9] P. Kumar, N. Kumari, N.C. Sahu, Floods and economic growth in India: role of FDI inflows and foreign aid, Manag. Environ. Qual. Int. J. 33 (5) (Jan. 2022) 1114–1131, https://doi.org/10.1108/MEQ-10-2021-0244.
[10] Y. Parida, D. Prasad Dash, Rethinking the effect of floods and financial development on economic growth: evidence from the Indian states, Indian Growth Dev. Rev. 13 (3) (2020) 485–503, https://doi.org/10.1108/IGDR-05-2019-0044.
[11] V.H. De Oliveira, Natural disasters and economic growth in Northeast Brazil: evidence from municipal economies of the Ceará State, Environ. Dev. Econ. 24 (3) (2019) 271–293, https://doi.org/10.1017/S1355770X18000517.
[12] J. Klomp, K. Valckx, Natural disasters and economic growth: a meta-analysis, Global Environ. Change 26 (May 2014) 183–195, https://doi.org/10.1016/j.gloenvcha.2014.02.006.

[13] P.S. Mohan, B. Ouattara, E. Strobl, Decomposing the macroeconomic effects of natural disasters: a national income accounting perspective, Ecol. Econ. 146 (Apr. 2018) 1–9, https://doi.org/10.1016/j.ecolecon.2017.09.011.
[14] A.A. Warsame, I.A. Sheik-Ali, J. Mohamed, S.A. Sarkodie, Renewables and institutional quality mitigate environmental degradation in Somalia, Renew. Energy 194 (2022) 1184–1191, https://doi.org/10.1016/j.renene.2022.05.109.
[15] A.A. Warsame, S.A. Sarkodie, Asymmetric impact of energy utilization and economic development on environmental degradation in Somalia, Environ. Sci. Pollut. Res. 29 (2021) 23361–23373, https://doi.org/10.1007/s11356-021-17595-z.
[16] A.A. Warsame, Environmental pollution and life expectancy in Somalia: do renewable energy, urbanization, and economic growth matter? Environ. Sci. Pollut. Res. (2023) 0123456789 https://doi.org/10.1007/s11356-023-30114-6.
[17] Z. Wang, W. Wei, F. Zheng, Effects of industrial air pollution on the technical efficiency of agricultural production: evidence from China, Environ. Impact Assess. Rev. 83 (Jul. 2020) 106407, https://doi.org/10.1016/j.eiar.2020.106407.
[18] K.-M. Nam, N.E. Selin, J.M. Reilly, S. Paltsev, Measuring welfare loss caused by air pollution in Europe: a CGE analysis, Energy Pol. 38 (9) (Sep. 2010) 5059–5071, https://doi.org/10.1016/j.enpol.2010.04.034.
[19] H.A. Hussein, A.A. Warsame, Testing environmental Kuznets curve hypothesis in Somalia : empirical evidence from ARDL technique, Int. J. Energy Econ. Pol. 13 (5) (2023) 678–684.
[20] G.M. Grossman, A.B. Krueger, Economic growth and the environment, Q. J. Econ. 110 (2) (May 1995) 353–377, https://doi.org/10.2307/2118443.
[21] R. Balado-Naves, J.F. Baños-Pino, M. Mayor, Do countries influence neighbouring pollution? A spatial analysis of the EKC for CO2 emissions, Energy Pol. 123 (Dec. 2018) 266–279, https://doi.org/10.1016/j.enpol.2018.08.059.
[22] R. Haeuber, Development and deforestation: Indian forestry in perspective, J. Develop. Area. (Jul. 1993).
[23] L.W. Braithwatte, Conservation of arboreal herbivores: the Australian scene, Austral Ecol. 21 (1) (Mar. 1996) 21–30, https://doi.org/10.1111/j.1442-9993.1996.tb00582.x.
[24] A.A. Warsame, J. Mohamed, A. Ali, The relationship between environmental degradation , agricultural crops , and livestock production in Somalia, Environ. Sci. Pollut. Res. (2023), https://doi.org/10.1007/s11356-022-22595-8.
[25] C. Megevand, H. Dulal, L. Braune, J. Wekhamp, Deforestation Trends in the Congo Basin : Transport, Washington DC, 2013.
[26] S. Ghosh, Examining carbon emissions economic growth nexus for India: a multivariate cointegration approach, Energy Pol. 38 (6) (2010) 3008–3014, https://doi.org/10.1016/j.enpol.2010.01.040.
[27] N. Ahmad, L. Du, Effects of energy production and CO2 emissions on economic growth in Iran: ARDL approach, Energy 123 (2017) 521–537, https://doi.org/10.1016/j.energy.2017.01.144.
[28] K.R. Abbasi, M. Shahbaz, Z. Jiao, M. Tufail, How energy consumption, industrial growth, urbanization, and CO2 emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach, Energy 221 (2021) 119793, https://doi.org/10.1016/j.energy.2021.119793.
[29] C. Magazzino, M. Mutascu, S.A. Sarkodie, F.F. Adedoyin, P.A. Owusu, Heterogeneous effects of temperature and emissions on economic productivity across climate regimes, Sci. Total Environ. 775 (2021) 145893, https://doi.org/10.1016/j.scitotenv.2021.145893.
[30] M. Salahuddin, J. Gow, Economic growth, energy consumption and CO2 emissions in Gulf cooperation council countries, Energy 73 (2014) 44–58, https://doi.org/10.1016/j.energy.2014.05.054.
[31] E. Akalpler, S. Hove, Carbon emissions, energy use, real GDP per capita and trade matrix in the Indian economy-an ARDL approach, Energy 168 (2019) 1081–1093, https://doi.org/10.1016/j.energy.2018.12.012.
[32] M.U. Etokakpan, S.A. Solarin, V. Yorucu, F.V. Bekun, S.A. Sarkodie, Modeling natural gas consumption, capital formation, globalization, CO2 emissions and economic growth nexus in Malaysia: fresh evidence from combined cointegration and causality analysis, Energy Strategy Rev. 31 (2020) 100526, https://doi.org/10.1016/j.esr.2020.100526.
[33] U. Al-mulali, C.N. Binti Che Sab, The impact of energy consumption and CO2 emission on the economic growth and financial development in the Sub Saharan African countries, Energy 39 (1) (2012) 180–186, https://doi.org/10.1016/j.energy.2012.01.032.
[34] M. Jiang, E. Kim, Y. Woo, The relationship between economic growth and air pollution—a regional Comparison between China and South Korea, Int. J. Environ. Res. Publ. Health 17 (8) (Apr. 2020) 2761, https://doi.org/10.3390/ijerph17082761.
[35] W. Adzawla, M. Sawaneh, A.M. Yusuf, Greenhouse gasses emission and economic growth nexus of sub-Saharan Africa, Sci. African 3 (April) (2019) e00065, https://doi.org/10.1016/j.sciaf.2019.e00065.
[36] K. Bakhsh, S. Rose, M.F. Ali, N. Ahmad, M. Shahbaz, Economic growth, CO2 emissions, renewable waste and FDI relation in Pakistan: New evidences from 3SLS, J. Environ. Manag. 196 (2017) 627–632, https://doi.org/10.1016/j.jenvman.2017.03.029.
[37] P.A.O. Sarkodie, Samuel Asumadu, Global land-use intensity and anthropogenic emissions exhibit symbiotic and explosive behavior, iScience (2022), https://doi.org/10.1016/j.isci.2022.104741.
[38] J. Hainmueller, C. Hazlett, Kernel regularized least squares: reducing misspecification bias with a flexible and interpretable machine learning approach, Polit. Anal. 22 (2) (2014) 143–168, https://doi.org/10.1093/pan/mpt019.
[39] B. Rossi, Y. Wang, Vector autoregressive-based Granger causality test in the presence of instabilities, STATA J. 19 (4) (2019) 883–899, https://doi.org/10.1177/1536867X19893631.
[40] D. Wheeler, Quantifying Vulnerability to Climate Change : Implications for Adaptation Assistance Working Paper 240 January 2011, 2011.
[41] World Wildlife Fund, Deforestation and Forest Degradation, 2021.
[42] H.S. Ali, S.P. Nathaniel, G. Uzuner, F.V. Bekun, S.A. Sarkodie, Trivariate modelling of the nexus between electricity consumption, urbanization and economic growth in Nigeria: fresh insights from Maki Cointegration and causality tests, Heliyon 6 (2) (2020) e03400, https://doi.org/10.1016/j.heliyon.2020.e03400.
[43] F.V. Bekun, F. Emir, S.A. Sarkodie, Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa, Sci. Total Environ. 655 (2019) 759–765, https://doi.org/10.1016/j.scitotenv.2018.11.271.
[44] P.C.B. Phillips, Y. Wu, J. Yu, Explosive behavior in the 1990S nasdaq: when did exuberance escalate asset values? Int. Econ. Rev. 52 (1) (2011) 201–226, https://doi.org/10.1111/j.1468-2354.2010.00625.x.
[45] S.A. Sarkodie, P.A. Owusu, How to apply the novel dynamic ARDL simulations (dynardl) and Kernel-based regularized least squares (krls), MethodsX 7 (October) (2020) 101160, https://doi.org/10.1016/j.mex.2020.101160.
[46] M. Ahmad, et al., Dynamic interactive links among sustainable energy investment, air pollution, and sustainable development in regional China, Environ. Sci. Pollut. Res. 28 (2) (2020) 1502–1518, https://doi.org/10.1007/s11356-020-10239-8.
[47] A.A. Mohamed, A.I. Nageye, Measuring the effect of land degradation and environmental changes on agricultural production in Somalia with two structural breaks, Manag. Environ. Qual. Int. J. 32 (2) (2020) 160–174, https://doi.org/10.1108/MEQ-02-2020-0032.
[48] A.A. Warsame, I.A. Sheik-Ali, A.A. Hassan, S.A. Sarkodie, Extreme climatic effects hamper livestock production in Somalia, Environ. Sci. Pollut. Res. (2022) 1–13, https://doi.org/10.1007/s11356-021-18114-w.
[49] H.A. Hussein, M.A. Khalif, A.A. Warsame, G.M. Barre, The impact of trade openness on economic growth in Somalia, Int. J. Sustain. Dev. Plann. 18 (1) (2023) 327–333, https://doi.org/10.18280/ijsdp.180134.
[50] D. Tan, F.F. Adedoyin, R. Alvarado, M. Ramzan, M.S. Kayesh, M.I. Shah, The effects of environmental degradation on agriculture: evidence from European countries, Gondwana Res. 106 (June) (2022) 92–104, https://doi.org/10.1016/j.gr.2021.12.009.
[51] K. Tsaurai, Greenhouse gas emissions and economic growth in africa: does financial development play any moderating role? Int. J. Energy Econ. Pol. 8 (6) (2018) 267–274, https://doi.org/10.32479/ijeep.6988.
[52] B. Muhammad, Energy consumption, CO2 emissions and economic growth in developed, emerging and Middle East and North Africa countries, Energy 179 (2019) 232–245, https://doi.org/10.1016/j.energy.2019.03.126.
[53] M. Azam, A.Q. Khan, H. Bin Abdullah, M.E. Qureshi, The impact of CO2 emissions on economic growth: evidence from selected higher CO2 emissions economies, Environ. Sci. Pollut. Res. 23 (7) (2015) 6376–6389, https://doi.org/10.1007/s11356-015-5817-4.

[54] S. Nathaniel, S. Barua, H. Hussain, N. Adeleye, The determinants and interrelationship of carbon emissions and economic growth in African economies: fresh insights from static and dynamic models, J. Publ. Aff. 21 (1) (2020) 1–15, https://doi.org/10.1002/pa.2141.
[55] K. Saidi, S. Hammami, The impact of energy consumption and CO2 emissions on economic growth: fresh evidence from dynamic simultaneous-equations models, Sustain. Cities Soc. 14 (1) (2015) 178–186, https://doi.org/10.1016/j.scs.2014.05.004.
[56] M.M. Islam, M. Alharthi, M.W. Murad, The effects of carbon emissions, rainfall, temperature, inflation, population, and unemployment on economic growth in Saudi Arabia: an ARDL investigation, PLoS One 16 (4) (2021) e0248743, https://doi.org/10.1371/journal.pone.0248743.
[57] Reliefweb, Somalia – Climate Change and Conflict Threaten Herders [AR], 2021.
[58] E. Strobl, The economic growth impact of natural disasters in developing countries: evidence from hurricane strikes in the Central American and Caribbean regions, J. Dev. Econ. 97 (1) (2012) 130–141, https://doi.org/10.1016/j.jdeveco.2010.12.002.
[59] L.P. Boustan, M.E. Kahn, P.W. Rhode, M.L. Yanguas, The effect of natural disasters on economic activity in US counties: a century of data, J. Urban Econ. 118 (May) (2020) 103257, https://doi.org/10.1016/j.jue.2020.103257.
[60] C. Pu, Z. Liu, X. Pan, B. Addai, The impact of natural disasters on China's macroeconomy, Environ. Sci. Pollut. Res. 27 (35) (2020) 43987–43998, https://doi.org/10.1007/s11356-020-09971-y.