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The Impact of Renewable Energy, Economic and Population Growth on CO_2 Emissions in the East African Region: Evidence from Common Correlated Effect Means Group and Asymmetric Analysis

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Abstract: This study aims to examine the asymmetric nexus between CO_2 emissions and renewable energy and economic and population growth in seven East African countries (EACs) at the regional level and country levels. Common correlated effect means group (CCEMG), nonlinear autoregressive distributed lagged (NARDL), and causality tests were employed for the panel data from 1980 to 2016. The main findings are as follows: (1) Renewable energy consumption negatively affects CO_2 emissions, while economic and population growth positively affect CO_2 emissions at the regional level. (2) The findings of asymmetric and symmetric linkages between CO_2 emissions and its determinants (economic and population growth and renewable energy) are very volatile across the country levels. (3) The causality hypotheses are different across the country and regional levels. (4) This study shows the renewable energy growth nexus, wherein renewable energy positively affects economic growth at the regional level. Lastly, the study suggests potential policy implications for effectively reducing CO_2 emissions as well as growing the economy at the regional level.

Keywords: CO_2 emissions; renewable energy; economic growth; East African countries; asymmetric analysis; common correlated effect means group

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1. Introduction

The mitigation of CO_2 emissions to ensure environmental and public health safety is a long-term global aim that relies on facing the consequences resulting from world economic development, including those of rapid industrialization and urbanization. Dong et al. [1] suggested that economic and population growth positively contributes to the increase of CO_2 emissions at both global and regional levels. The use of renewable energy has been proposed in policy as an alternative energy to fossil fuel [2,3] to stabilize environmental relief through CO_2 emissions reduction [4]. As a result, renewable energy use has led to a significant reduction of CO_2 emissions at the global level and regional levels [1,5–7].

In the case of Africa, Asongu et al. [8] argued that economic and population growth coupled with energy consumption have increased CO_2 emissions in 24 countries. Adams et al. [9] added that both renewable and nonrenewable energy contributes to CO_2 emissions and that urbanization has increased CO_2 emissions in 28 Sub-Saharan countries. These findings are due to the insufficient exploration of mainstream renewable energy resources [10], fossil fuel dependence [11], and insufficient technological tools for measuring CO_2 emission intensities [12] in African countries compared to developed and developing countries [13,14]. However, alternative energy use, such as nonrenewable and wood biomass, are degrading the environment through deforestation and CO_2 emissions and lead to negative effects on economic growth [15].

On the other hand, some studies have argued that economic growth and environmental degradation makes an inverted-U-shaped relationship, which has negative side effects on economic growth [16,17]. Other studies confirm that the negative side effects from environmental externalities affect energy use and lead to a decrease in economic growth. In addition, studies have revealed that the influence of energy consumption on economic growth can vary with structural economic fluctuations [18–20]. From these facts, it is clear that changes in energy use and economic growth can lead to changes in CO_2 emissions; however, these changes are not necessarily equal. Thus, it is interesting to examine the asymmetric linkage between CO_2 emissions and renewable energy use and economic and population growth.

In the case of the East African region, a few renewable energy resources have been used to try to reduce CO_2 emissions and energy poverty and improve environmental and public health [21,22]; however, approximately three-quarters of the population cannot access electricity as compared to other parts of Africa [23]. To increase the accessibility of electricity and sustainable economic development as well as meet sustainable development goals (SDGs) [24], East African countries (EACs) established joint renewable energy projects, such as the Eastern Africa power pool (EAPP) (based on hydro), non-hydro power plants, and the Eastern Africa power trade (EAPT). As a result, the standard of life of the population continues to be improved due to a better quality of the environment and income generation. Approximately $7.6 billion U.S. has been generated through these initiatives, and this number could potentially reach $18.6 billion U.S. An expenditure of $6.6 billion U.S. (3.8 times lower than the previously specified expected economic benefits) will result inCO_2 emissions reduction targets being achieved by 2030 [22,25]. Accordingly, there is a need to increase renewable energy production, as it is coupled with economic growth and a reduction in CO_2 emissions in East African countries. However, in order to propose an adequate energy policy and income generation structures for the growing population in this area, it is necessary to examine the impact of renewable energy consumption and economic and population growth on CO_2 emissions among the East African countries.

Although several studies have discussed CO_2 emissions in relation to renewable resources and economic and population levels at global and continental levels, there are no studies on CO_2 emissions and its determinants (economic and population growth and renewable energy) at the East African regional or country levels. Some studies have used methodologies that assume asymmetric linkages, such as an autoregressive distributed lagged model (ARDL), for country-specific research for EACs (see [26–29]). Other studies have used first-generation estimators, such as dynamic ordinary least square (DOLS), fully modified ordinary least square (FMOLS), generalized methods of the moment (GMM), and others. Adams et al. [9] used FMOLS and GMM to detect the nexus between CO_2 emissions, renewable and nonrenewable energy, and economic growth in 28 countries. Asongu et al. [8] conducted a similar study in 24 countries by using a pooled mean group (PMG), which is in the group of panel approaches, and showed a bidirectional causal link between GDP per capita and CO_2 emissions as well as a positive effect from CO_2 emissions to energy consumption. All the above methods provided the linear relationships between CO_2 emission and its determinants; however, to the best of our knowledge, no study examined the asymmetric (nonlinear causal) link among CO_2 emissions, renewable energy use, and economic and population growth in all EACs.

Knowing the above background information and existing studies gives a better understanding of the nexus between CO_2 emissions and its determinants and is useful for policymakers, for advancing health safety, and for achieving environmental relief. This knowledge not only helps to reduce CO_2 emissions but also promotes the renewable energy industry as well as the national economy. However, three main features that differentiate this study from the existing studies were identified and contribute to filling the gap in the literature. First, there is no cross-national study conducted on this topic in all selected countries from the East African region. Thus, based on historical data from various databases, this study considers seven EACs and examines the effect of renewable energy and economic and population growth on CO_2 emissions at the regional level (panel of all selected countries). This is useful predominantly for regional policymakers to establish effective policies related to renewable energy use to mitigate CO_2 emissions. Second, the literature has focused on the linear relationship between CO_2 emissions and its determinants; however, this study investigates the nonlinear causal link between CO_2 emissions and renewable energy and economic and population growth. Third, in contrast to several studies that have applied approaches that ignore cross-sectional dependence and collinearity, this study uses the most recent common correlated effect means group (CCEMG) proposed by Pesaran (2006) [30] and extended by Chudik et al. (2015) [31], which estimates the effect of cross-sectional average regressors on the variable of interest. This method provides a more robust analysis of the impact of renewable energy and economic and population growth on CO_2 emissions at the East African regional level. Additionally, we examined the economic growth–renewable energy nexus, since there is a lack of literature in the case of the East African region.

2. Literature View

2.1. Review of Research on CO_2 Emissions, Renewable Energy, and Economic and Population Growth Nexus

Based on the intensive mechanisms for reducing CO_2 emissions, much of the literature has investigated the impact of energy consumption (total, renewable, and nonrenewable) and economic and population growth on CO_2 emissions at both global and regional levels (see [1,32] for review on global and regional levels). This literature showed mixed results; whereas economic and population growth positively affect CO_2 emissions, renewable energy consumption negatively affects CO_2 emissions [1,8], and total and nonrenewable positively affect CO_2 emissions (see [33,34] and others). In the case of Africa, a study conducted in 28 Sub-Saharan countries suggested that nonrenewable energy and economic growth contribute to an increase in CO_2 emissions in the long- and short-term, whereas a percentage increase in nonrenewable energy leads to approximately a two percent increase in CO_2 emissions [9]. A similar study conducted in 24 countries showed that economic growth positively affects CO_2 emissions and vice-versa, and energy consumption positively affects CO_2 emissions [8]. Zoundi [32] found that in 25 countries, an increase in economic growth leads to an increase in CO_2 emissions, and showed evidence that renewable energy consumption reduces CO_2 emissions, while population growth weakly and positively affects CO_2 emissions.

In the case of the East African region (see Table 1 for a summary of literature), the main focus of our study, few country-specific studies have been conducted using the four most common hypotheses (bidirectional, two unidirectional (growth and conservative), and neutral); nevertheless, these hypotheses were used in several studies, including [9,27,28] and others. Albiman et al. [26] revealed the one-way directional causal relationship running from economic growth and energy consumption to CO_2 emissions in Tanzania. Kebede and Hundie [27,28] used ARDL and Granger causality tests, and results showed a reciprocal relationship between energy and CO_2 emissions, and the causation from economic growth to CO_2 emissions in Ethiopia. Asumadu-Sarkodie et al. [29] argued that in Rwanda, an increase in economic growth leads to a decrease in CO_2 emissions, while population growth promotes CO_2 emissions and negatively affects economic growth. Appiah et al. [35] indicated that a rise in economic growth leads to the rise of CO_2 emissions, while higher energy intensity leads to a decline in CO_2 emissions in Uganda. In the case of Sudan, Kenya, and other countries, results revealed that as the economy and population grow, CO_2 emissions tend to increase, while there is a mixed effect of energy consumption on CO_2 emissions (see [9,33,34] and others). However, to the best of our knowledge, there has been no study examining the impact of renewable energy and economic and population growth on CO_2 emissions in the East African region. Furthermore, few studies have examined the linear effect of renewable energy consumption and CO_2 emissions on a national level. Therefore, it would be interesting to examine how renewable energy and economic and population growth linearly or nonlinearly affect CO_2 emissions in different EACs under the use of nonlinear approaches, such as nonlinear ARDL proposed by Shin et al. [36].

Table 1. Summary of selected existing studies on the nexus of CO_2 emissions, renewable energy, and economic and population growth for the East African region.

Authors	**Country**	**Period**	**Variables**	**Methods**	**Findings (Effect of Covariates on CO_2)**			
					Hypotheses	**GDP**	**REC/EC**	**PS**
Adams et al. [9]	28 Sub-Saharan Africa	1980–2014	RE, NRE, GDP, CO_2	FMOLS and GMM	$NRE \longrightarrow CO2$ $GDP \longrightarrow CO2$	positive	positive	-
Albiman et al. [26]	Tanzania	1975–2013	CO_2, EC, GDP	Causality-Toda-Yamamoto	$EC \longrightarrow CO2$ $GDP \longrightarrow CO2$	positive	positive	-
Kebede [27], Hundie [28]	Ethiopia	1970–2014	CO_2, EC, PS, GDP	ARDL and Toda-Yamamoto causality	$EC \leftrightarrow CO2$ $GDP \longrightarrow CO2$ $PS \longrightarrow CO2$	positive	positive	positive
Asongu et al. [8]	24 African countries	Not specified	CO_2, EC, GDP	P-ARDL/PMG	$GDP \longrightarrow CO2$ $CO2 \longrightarrow EC$	positive	negative	-
Asumadu-Sarkodie [29]	Rwanda	1965–2011	CO_2, GDP, PS, and industrialization	ARDL	$PS \longrightarrow CO2$ $PS \longrightarrow GDP$	negative	-	positive
Appiah et al. [35]	Uganda	1990–2014	CO_2, GDP, PS, and industrialization	ARDL	mixed	positive	negative	-
Al-Mulali et al. [33] and Sahb et al. [34]	MENA countries	1980–2009	CO_2, EC, Urbanization, RE, NRE, GDP	POLS, FMOLS	mixed	U-shape	mixed	-
Zoundi [32]	25 African countries	1980–2012	CO_2, EC, RE, PS, GDP	Panel cointegrations analysis	mixed	positive	negative	Weak positive
Jebli et al. [37]	24 African countries	1980–2010	CO_2, GDP, RE, Trade	Panel cointegration analysis	mixed	positive	positive	-
Akinlo et al. [38]	11 Sub-Saharan countries	1980–2003	GDP, EC	ARDL	mixed	-	-	-

EC: energy consumption, RE: renewable energy consumption, GDP: gross domestic product (economic growth), NRE: nonrenewable energy consumption, and PS: population size/growth.

2.2. *Review of Estimation Approaches*

The nexus of CO_2 emissions, renewable energy, and economic and population growth has been examined using various panel cointegration analysis methods, which are first-generation estimators, such as fully modified ordinary least square (FMOLS), dynamic OLS (DOLS), GMM estimators, mean group (MG), dynamic fixed effect (DFE), pooled mean group (PMG). Some of these estimators do not allow cross-sectional dependence and heterogeneity. For example, Zoundi [32] used panel cointegration analysis to investigate the impact of renewable energy on CO_2 emissions in 25 selected African countries. Al-Mulali et al. [33] and Sahb et al. [34] used FMOLS and POLS to examine the relationship between CO_2 emissions, energy consumption, economic growth, and urbanization in MENA (Middle-east and North-African) countries. Adams et al. [9] used DOLS and FMOLS to examine the causal relationship between renewable and nonrenewable energy and economic growth, and CO_2 emissions in 28 African countries. Panel ARDL and ARDL have been widely used to examine the effects of economic and population growth as well as total, renewable, and nonrenewable energy on CO_2 emissions in East African countries (see [26,28,29] and others). The findings of the above literature suggest a linear relationship between covariates and the variable of interest. However, there is a gap in the literature for investigating the nonlinear relationship of renewable energy and economic and population growth with CO_2 emissions, which is analyzed using the nonlinear ARDL approach. Therefore, by using the NARDL approach proposed by Shin et al. [36], we seek to contribute to the literature by investigating the nonlinear causal link among CO_2 emissions, renewable energy, and economic and population growth in individual EACs. Furthermore, the most recent second-generation estimator, known as the common correlated effect means group (CCEMG), as proposed by Pesaran (2006) [30] and extended by Chudik et al. (2015) [31], which estimates the effect of cross-sectional average regressors on the variable of interest, will be used to examine the impact of renewable energy and economic and population growth on CO_2 emissions at the East African regional level.

The rest of the study is presented as follows: Section 2 presents the literature review, Section 3 introduces the methodology and data, Section 4 provides the empirical results and discussion, and Section 5 outlines the conclusions.

3. Materials and Methods

3.1. Methods

3.1.1. Mathematical Model

Dietz and Rosa proposed a mathematical model (stochastic impacts by regression on population, affluence, and technology) that suggested that economic and population growth are essential sources of CO_2 emissions [39]. In addition to these two variables, we adopt the belief that renewable energy leads to CO_2 emissions reduction. To effectively access the explicit impact of renewable energy consumption and economic and population growth on CO_2 emissions (ES), the mathematical model is written as follows:

$$ES_{it} = f(GDP_{it}, RE_{it}, PS_{it}) \tag{1}$$

For i country and t time, and to diminish the heteroskedasticity disturbance, the variables were transformed into natural logarithms; thus, the model can be rewritten as follows:

$$\ln(ES_{it}) = \alpha_0 + \alpha_1 \ln(GDP_{it}) + \alpha_2 \ln(RE_{it}) + \alpha_3 \ln(PS_{it}) + u_{it} \tag{2}$$

where $\alpha_0 - \alpha_3$ are the regression parameters to be estimated and u_{it} is the error term. Additionally, the impact of renewable energy use and population growth on economic growth can be determined using Equation (1) and changing the dependent variables.

3.1.2. Cross-Sectional Dependence Test

Goldin [40] suggested that cross-sectional dependence is a crucial issue in panel data; when it is ignored, it leads to inconsistent estimates and misleading information. In this case, Pesaran [41] and Breusch and Pagan [42] proposed the Pesaran cross-sectional dependence (CD) and Breusch–Pagan Lagrange multiplier (LM) tests, respectively, for cross-sectional dependence. These tests are initially used to detect the cross-sectional dependence of panel data. The standardized test proposed by Pesaran has the potential for large N and T and can be calculated as follows:

$$\mathrm{LM} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T_{ij}\delta_{ij}^2 - 1\right) \rightarrow N(0,1) \tag{3}$$

In contrast, the Breusch–Pagan LM test is efficient for small size and T; it can be estimated as follows:

$$\mathrm{LM} = \sum\nolimits_{i=1}^{N-1} \sum\nolimits_{j=i+1}^{N} T_{ij}\delta_{ij}^{2} \longrightarrow \chi^{2}\left(\frac{N(N-1)}{2}\right) \tag{4}$$

The alternative cross-sectional dependence test proposed by the Pesaran CD is effective for large N and fixed T and can be calculated as follows:

$$\mathrm{CD} = \sqrt{\frac{2}{N(N-1)}} \sum\nolimits_{i=1}^{N-1} \sum\nolimits_{j=i+1}^{N} T_{ij}\delta_{ij}^{2} \rightarrow N(0,1) \tag{5}$$

where N is the panel data size, T is the length of time, and δ_{ij}^{2} indicates the correlation coefficients obtained from the residuals of the Equation (3), which can be calculated as follows:

$$\delta_{ij} = \delta_{ji} = \frac{\sum_{t-1}^{T} \varepsilon_{ij}\varepsilon_{ji}}{\left(\sum_{t-1}^{T} \varepsilon_{ij}^{2}\right)^{\frac{1}{2}} \left(\sum_{t-1}^{T} \varepsilon_{jt}^{2}\right)^{1/2}} \tag{6}$$

3.1.3. Unit Root Tests for Country Levels

In this study, we are interested in examining the nonlinear asymmetric nexus among CO_2 emissions, GDP, population growth, and renewable energy consumption in individual countries. In this case, the unit root tests proposed by Dickey and Fuller (ADF) [43] and Phillips and Perron (PP) [44] are applied under the null hypothesis, which says that the series has a unit root. Therefore, the ADF and PP test results are usually compared with those estimated using the test suggested by Kwiatkowski et al. (KPSS) [45] to see whether the findings offer the same conclusion. These tests depend on the following equation:

$$\Delta y_t = \psi y_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta y_{t-i} + u_t \tag{7}$$

where $\psi = 1$ (null hypothesis using ADF test), $\varphi_i = 1, 2, \ldots, p$, unit root at maximum lags (p) using ADF and PP tests, Δ indicates the differencing operator, and u is the error term.

3.1.4. Panel Pesaran CIPS Unit Root Test

In the case of panel data, the Pesaran CIPS panel unit root test [46] allows calculation of the cross-sectional dependence by considering the averages of lagged levels and differences for each unit. This approach is denoted as cross-sectionally augmented Dickey–Fuller and can be expressed as follows:

$$\Delta y_{it} = \psi_i + \alpha_i y_{i,\,t-1} + \beta_i \overline{y}_{t-1} + \sum\nolimits_{j=0}^{p} d_{ij} \Delta\overline{y}_{t-j} + \sum\nolimits_{j=1}^{p} \xi_{ij} \Delta y_{i,t-j} + u_{it} \tag{8}$$

where $\overline{y}_{t-1}$ and $\Delta\overline{y}_{t-j}$ are the cross-sectional averages of lagged levels and first difference, respectively. The cross-sectionally augmented Dickey–Fuller (CADF) statistics are used to estimate the CIPS statistic in the following equation:

$$\mathrm{CIPS} = \frac{1}{N} \sum\nolimits_{i=1}^{N} \mathrm{CADF}_i \tag{9}$$

3.1.5. Panel Cointegration Test

In this study, we used the error correction panel cointegration test proposed by Westerlund [47]. This approach is effective for cross-sectional dependence by applying an error correction term (ECT); it is expressed as follows:

$$\Delta z_{it} = \acute{\alpha}_i d_i + \vartheta_i \left(z_{i(t-1)} + \acute{\pi}_i y_{i(t-1)}\right) + \sum\nolimits_{j=1}^{m} \phi_{ij} \Delta z_{i(t-1)} + \sum\nolimits_{j=0}^{m} \varphi_{ij} \Delta y_{i(t-1)} + \omega_{it} \tag{10}$$

where ϑ_i is the adjustment term, d_i is a vector of deterministic components, and other parameters introduce the nuisance in the variable of interest. Therefore, referring to the estimates of ϑ_i, the statistics of the Westerlund-ECT–based panel cointegration tests can be determined as follows:

$$G_\tau = \frac{1}{N}\sum\nolimits_{i=1}^{N} \frac{\vartheta_i}{SE(\hat{\vartheta}_i)} \tag{11}$$

$$G_\alpha = \frac{1}{N}\sum\nolimits_{i=1}^{N} \frac{T\vartheta_i}{\hat{\vartheta}_i(1)} \tag{12}$$

where G_τ and G_α are group mean statistics that judge the null hypothesis, which states that there is no presence of cointegration in the cross-sectional panel. The rejection of this hypothesis implies the presence of cointegration for at least one cross-sectional unit in the panel. The panel statistic can be calculated as follows:

$$P_\tau = \frac{\hat{\vartheta}_i}{SE(\hat{\vartheta}_i)} \tag{13}$$

$$P_\alpha = T\hat{\vartheta}_i \tag{14}$$

The rejection of the null hypothesis implies no cointegration for the whole panel.

3.1.6. Common Correlated Effect Means Group (CCEMG)

The panel CCEMG was proposed by Pesaran (2006) [30] and extended by Chudik et al. (2015) [31]. This estimator estimates the effect of cross-sectional average regressors on the variables of interest. This is a unique feature that makes CCEMG superior to other panel approaches, such as DOLS, FMOLS, MDG, and others. CCEMG can be estimated using the following equation:

$$y_{it} = \alpha_i + \sum_{l=0}^{p} \beta_{il} y_{it-l} + \sum_{l=0}^{q} \delta_{il} x_{it-l} + \sum_{l=0}^{Z} \mu_{il} \overline{z}_{it-l} + u_{it} \tag{15}$$

where $\overline{z}_t = (\overline{y}_t, \overline{x}_t)'$, $\overline{y}_t = n^{-1}\sum_i^N y_t$ and $\overline{x}_t = n^{-1}\sum_i^N x_t$, for (p, q, z) are the lags.

The long-rung coefficients can be estimated using the following equation:

$$\hat{\theta}_{cs-DL} = \frac{\sum_{l=0}^{q} \hat{\delta}_{il}}{1 - \sum_{l=1}^{p} \hat{\beta}_{il}} \tag{16}$$

In the CCEMG estimator, the linear combinations of the cross-sectional averages of the variable of interest and regressors, which are the observed common effects, are employed with the coefficients presented in Kapetania et al. [48].

3.1.7. Nonlinear ARDL Approach

The nonlinear ARDL is an extension of ARDL proposed by Shin et al. [36] that efficiently accesses the nonlinear asymmetric and symmetric relationship between variables. This approach is sensitive to small sample size data and can be used for variables co-integrated at one or zero, (I(1) or I(0)) orders, and their combination is taken as a prior assumption. With the use of the Hatemi-J approach [49] for decomposing variables into random walk processes, through negative and positive changes, the nonlinear asymmetric nexus of GDP per capita, renewable energy (RE), and population size (PS) on CO_2 emissions was examined at the country level. Using this approach, positive and negative shocks can be written as follows:

$$y_{it}^{+} = \sum_{j=1}^{t} \Delta y_{ij}^{+} = \sum_{j=1}^{t} man(\Delta x_{ij}, 0),\ y_{it}^{-} = \sum_{j=1}^{t} \Delta y_{ij}^{-} = \sum_{j-1}^{t} min(\Delta y_{ij}, 0) \tag{17}$$

$$x_{it}^{-} = \sum_{j=1}^{t} \Delta x_{ij}^{-} = \sum_{j-1}^{t} min\left(\Delta x_{ij}, 0\right),\ x_{it}^{-} = \sum_{j=1}^{t} \Delta x_{ij}^{-} = \sum_{j-1}^{t} min\left(\Delta x_{ij}, 0\right) \quad (18)$$

where y_{it} represents the variable of interest and x_{it} represents all regressors, including lags. In our case, variable decomposition has been made on regressors, even though it is possible to detect the impact of negative and positive changes of regressors on the negative and positive shocks of the variable of interest. Thus, from ARDL to NARDL, the summarized equation can be written as follows:

$$\begin{gathered}\Delta \ln(ES_{it}) = \delta_0 + \sum_{l=1}^{p} \rho_1 \Delta \ln ES_{it-l} + \sum_{l=0}^{q} \beta_1^{+} \Delta \ln x_{it-l}^{+} + \sum_{l=0}^{q} \beta_1^{-} \Delta \ln x_{it-l}^{-} + \sum_{l=0}^{q} \beta_2^{+} \ln x_{it-l}^{+} + \sum_{l=0}^{q} \beta_2^{-} \ln x_{it-l}^{-} \\ + \rho_2 \ln ES_{it-1} + \theta_1^{+} \ln x_{it-1}^{+} + \theta_2^{-} \ln x_{it-1}^{-} + m_{it}\end{gathered} \quad (19)$$

where x_{it} indicates the GDP, RE, and PS, and positive and negative shocks of regressors are from Equations (16) and (17). See [36,49] for more detail.

3.1.8. Causality Test

Hatemi-J [49] proposed the asymmetric causality test, which takes possible asymmetries into account by calculating the cumulative sums of positive and negative changes in underlying variables. In our study, this test is used to examine the nonlinear asymmetric causality by considering individual countries; it can be expressed as follows:

$$Wald = (cb)' \left[c \left(z'z \right)^{-1} \otimes S_u \right) c)^{-1} \right] (cb) \quad (20)$$

where b is the vector representation of matrix coefficients of the vector autoregressive (VAR) model, c is a $p \times n(1 + np)$ indicator matrix using 1 for constrained parameters and 0 for the remaining parameters, $\otimes$ indicates the Kronecker product, and S_u is the variance-covariance matrix of the VAR model. See [49] for more detail.

3.2. Data

The data used in this study to examine the nexus of CO_2 emissions, renewable energy, and economic and population growth for the selected East African countries in the region, (Ethiopia, Tanzania, Uganda, Rwanda, Kenya, Burundi, and Sudan) were mined from the World Bank database and U.S. Energy Information Administration agency EIA [21]. Descriptive statistics of indicators are illustrated in Table 2. Renewable energy consumption data were mined from the U.S. Energy Information Administration database and translated from quadrillion Btu to equivalent kg of oil [36]. Gross domestic product (GDP) per capita is measured in constant 2010 U.S. dollars. Coe emissions and population growth data were mined from the World Bank database for the years from 1980 to 2016. GDP is used as the measure for economic growth and CO_2 emissions are measured in metric tons. To avoid the heteroscedasticity issue and minimize the variability, all variables have been used after being transformed into a natural logarithm.

Table 2. Descriptive statistics.

Country	Variables	Mean	Median	Maximum	Minimum	Skewness	Kurtosis	Observations
Kenya	ES	3.896404	3.901371	4.253087	3.576304	0.094836	2.024984	37
	GDP	10.42125	10.40578	10.74362	10.16466	0.278036	2.160223	37
	PS	7.47121	7.480732	7.690654	7.215299	−0.17257	1.880171	37
	RE	8.946629	8.964667	9.300186	8.528232	−0.30521	2.845384	37
Rwanda	ES	2.768248	2.734573	3.047184	2.657733	1.262506	4.274144	37
	GDP	9.537367	9.453735	9.966093	9.116997	0.54296	2.441799	37
	PS	6.884246	6.862661	7.067027	6.712086	0.151706	1.824434	37
	RE	7.586918	7.60801	7.959589	7.178709	−0.37871	5.350332	37
Ethiopia	ES	3.590849	3.499314	4.172302	3.170692	0.513203	2.4082	37
	GDP	10.19393	10.09083	10.76605	9.889738	0.785034	2.274956	37
	PS	7.786999	7.795934	8.015374	7.545823	−0.10071	1.782567	37
	RE	8.683829	8.611325	9.445573	8.093121	0.448456	2.300542	37

Table 2. *Cont.*

Country	Variables	Mean	Median	Maximum	Minimum	Skewness	Kurtosis	Observations
Burundi	ES	2.376389	2.363651	2.694645	2.166371	0.706129	2.983194	37
	GDP	9.225063	9.211746	9.38293	9.061992	0.261158	2.433079	37
	PS	6.807876	6.791379	7.020693	6.618811	0.206757	2.042773	37
	RE	7.407436	7.484665	7.650231	6.569494	−2.01151	6.124392	37
Tanzania	ES	3.564942	3.414344	4.111716	3.275274	0.832032	2.241584	37
	GDP	10.30752	10.23027	10.7197	10.05603	0.569341	1.890267	37
	PS	7.499775	7.50412	7.724692	7.268069	−0.05347	1.853452	37
	RE	8.642991	8.641102	8.843939	8.413764	−0.15539	1.815359	37
Sudan	ES	3.839958	3.717821	4.301026	3.480238	0.416274	1.5568	37
	GDP	10.50359	10.48186	10.87136	10.18018	0.183393	1.566054	37
	PS	7.399964	7.415233	7.6004	7.161592	−0.22795	1.840502	37
	RE	8.601663	8.460563	9.332013	8.115229	1.178475	2.956667	37
Uganda	ES	3.155698	3.10464	3.754362	2.722673	0.439712	1.795032	37
	GDP	10.10709	10.10007	10.57367	9.723944	0.143129	1.632562	37
	PS	7.34655	7.348125	7.598216	7.094902	−0.02695	1.834753	37
	RE	8.465604	8.487607	8.925913	8.069456	0.146604	2.090493	37
Panels	ES	3.564942	3.414344	4.111716	3.275274	0.832032	2.241584	259
	GDP	10.30752	10.23027	10.71970	10.05603	0.569341	1.890267	259
	PS	7.499775	7.504120	7.724692	7.268069	−0.053472	1.853452	259
	RE	8.642991	8.641102	8.843939	8.413764	−0.155387	1.815359	259

ES: CO_2 emission, GDP: economic growth, PS: population growth/size, and RE: renewable energy consumption.

4. Results and Discussion

This section presents our findings as follows. First, the cross-sectional dependence and unit root tests results are analyzed. Next, the results of panel cointegration, CCEMG, NARDL, and causality tests are analyzed. Finally, a robustness check is performed. In this section, we occasionally present the impact of renewable energy and population growth on economic growth as an additional input to our results. All findings were obtained from R-programming, STATA, and Eviews 10.

4.1. Cross-Sectional Dependence and Unit Root Test Results

The results presented in Table 3 were obtained using the cross-sectional dependence tests proposed by Pesaran [41] and Breusch and Pagan [42]. Results showed that the null hypothesis of no cross-sectional independence is rejected at a 1% significance level, indicating the presence of cross-sectional dependence. With this knowledge, methods that consider cross-sectional dependence were prioritized to analyze the relationship between variables at the regional level. In this case, the Pesaran CIPS panel unit root test was used to examine the stationarity and integration levels of all selected variables. Table 4 presents the results obtained from the CIPS unit root test proposed by Pesaran [46], which show that the null hypothesis of the unit root was rejected for all variables at the first difference. This indicates that the selected variables were integrated on the order one, I(1) of integration, implying that the appropriate tests to examine whether a long-run equilibrium relationship exists among variables are the error-correction term-based panel cointegration tests proposed by Westerlund [47].

Table 3. Cross-sectional dependence results.

Variable	Breusch-LM	Pesaran-CD	Pesaran LM
ES	441.420 *	20.296 *	64.972 *
RE	342.097 *	16.348 *	49.546 *
GDP	629.128 *	24.967 *	93.836 *
PS	742.820 *	27.242 *	111.379 *

* indicates significant cross-sectional dependence at a 1% significance level, ES: CO_2 emissions, RE: renewable energy consumption, GDP: economic growth, PS: population size/growth

Table 4. Pesaran CIPS unit root test with cross-sectional dependence test results.

	Levels		**1st Difference**		**Cointegration Order**
Variable	**C**	**C-T**	**C**	**C-T**	
ES	−1.553	−2.576	−4.687 *	−3.743 *	I(1)
RE	−1.586	−1.586	−2.931 **	−3.043 **	I(1)
GDP	−0.958	−2.011	−3.461 **	−3.973 **	I(1)
PS	−3.807	−2.710	−4.791	−3.911 **	I(1)

C: constant and C-T: constant and trends. *, and ** 1%, and 5% significance levels, respectively.

In the case of country-specific data, Table 5 shows the results obtained using ADF, PP, and KPSS unit root tests; these results imply that ES, GDP, and RE are stationary at the first difference in all countries, while PS is stationary at the second difference in all countries, except Rwanda, where it is stationary at first difference. The results indicate that, except for PS, all selected variables are integrated at first order, I(1), fulfilling the assumption of the NARDL approach for examining the nonlinear asymmetric and symmetric relationships between variables.

Table 5. Unit root test results for individual countries.

Country	**Test**	**GDP**		**CO_2-Emission**		**Renewable Energy**		**Population Size**	
		C	**C-T**	**C**	**C-T**	**C**	**C-T**	**C**	**C-T**
Ethiopia	PP	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)
	ADF	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(2)	I(2)
	KPSS	I(1)	I(0)	I(1)	I(1)	I(0)	I(1)	I(2)	I(2)
Tanzania	PP	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(1)
	ADF	I(1)	I(1)	I(1)	I(0)	I(1)	I(0)	I(2)	I(2)
	KPSS	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(2)	I(2)
Sudan	PP	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)
	ADF	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(2)	I(2)
	KPSS	I(1)	I(1)	I(1)	I(0)	I(0)	I(0)	I(2)	I(2)
Burundi	PP	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)
	ADF	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)
	KPSS	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)
Rwanda	PP	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	ADF	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	KPSS	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)
Kenya	PP	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)
	ADF	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)
	KPSS	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(2)	I(2)
Uganda	PP	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)
	ADF	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)
	KPSS	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(2)	I(2)

I(0) represents level stationarity, I(1) indicates first-difference stationarity, C: constant, and C-T: constant and trend.

4.2. Panel Cointegration Results

Table 6 presents the results from the Westerlund panel cointegration test [47] for the East African region. All Westerlund test statistics confirmed the long-run cointegration relationships among the selected variables. This implies the presence of a long-run equilibrium causal relationship of renewable energy and economic and population growth on CO_2 emissions, and also economic growth on renewable energy, within the regional panel countries from 1980–2016. The presence of a panel cointegration causal link among selected variables assisted the prior objective of this study and allowed us to examine the effects of economic and population growth and renewable energy on CO_2 emissions, and then the effect of renewable energy on economic growth.

Table 6. Westerlund error correction term (ECT) panel cointegration test results.

Dependent	Test	Gt	Gα	Pt	Pα
CO_2	Statistic	−4.644 *	−23.511 *	−12.061 *	−23.525 *
	z-value	−7.581	−6.650	−6.544	−8.067
	Variance ratio	−2.425 *			
GDP	Statistic	−4.786 *	−18.108 *	−15.801 *	−19.156 *
	z-value	−7.166	−4.084	−10.143	−2.947
	Variance ratio	−3.653 *			

Ho: null hypothesis of no cointegration, * indicates 1% significance level.

4.3. CCEMG Estimate Results

After checking cross-sectional dependence, panel unit root, and cointegration tests, the following step was to estimate the long-run coefficients between selected variables at the East African regional level. The results of the CCEMG estimator from the panel of seven EACs are presented in Table 7. The findings showed that the long-run coefficients for renewable energy consumption significantly and negatively affect CO_2 emissions, while economic and population growth significantly and positively affect CO_2 emissions at the regional level. In the long-run, a 1% increase in renewable energy consumption leads to a 0.173% decrease in CO_2 emissions, while a 5% and 10% increase in both GDP and population growth lead to a 0.485% and 0.560% increase in CO_2 emissions, respectively. The results are consistent with Zoundi [32], who suggests that renewable energy and GDP negatively and positively affect CO_2 emissions, respectively, and who shows findings similar to this study for population growth. These findings are also similar to those obtained by Dong et al. [1] and Shuai et al. [50] for the case of Africa, and are consistent with results estimated by Mariola et al. [51], which showed that renewable energy negatively affects emissions, while economic growth increases emissions, in the case of Spain.

Table 7. Long-run estimates from common correlated effect means group (CCEMG) estimators.

Dependent	CO_2 Emission		GDP		
Covariates	**Estimate**	**z-Value**	**Covariates**	**Estimates**	**z-Value**
RE	−0.173 *	−3.640	RE	0.120 *	3.120
GDP	0.485 **	2.340	CO_2	0.072 **	2.420
PS	0.560 ***	1.280	PS	1.613 *	2.690
ES_avg	0.911 *	3.020	GDP_avg	0.950 *	4.110
RE_avg	−0.037	0.250	RE_avg	−0.048	−0.640
GDP_avg	0.029	0.070	ES_avg	−0.045	−0.310
PS_avg	−0.918	348.680	PS_avg	−1.805 *	−2.740
Wald chi*2	9.660 **		Wald chi*2	24.72 *	

*, **, and *** indicate a significance level of 1%, 5%, and 10%, respectively; _avg: cross-sectional regressors effect.

In contrast, renewable energy and population growth significantly and positively affect GDP. A 1% increase in renewable energy and population lead to a 0.072% and 1.613% increase in economic growth, respectively. These findings are similar to those obtained by Chen et al. [52]. The effect of cross-sectional averaged regressors from the selected variables is presented and is significant for the variables of interest, while it is insignificant for independent variables.

4.4. The NARDL Results at the Country Level

In the case of individual countries, nonlinear ARDL (NARDL) was employed to examine the nonlinear asymmetric and symmetric causal relationships between CO_2 emissions and its determinants and also between GPD and renewable energy consumption. In the long-run, the results presented in Table 8 show that a positive shock to renewable energy negatively affects CO_2 emissions in four countries and positively affects CO_2

emissions in three countries, while a negative shock to renewable energy negatively affects CO_2 emissions in Sudan and positively affects CO_2 emissions in the remaining countries.

Table 8. Nonlinear autoregressive distributed lagged (NARDL) model coefficients for individual countries.

Dependent: CO_2 Emission							
Estimates	**Burundi**	**Ethiopia**	**Kenya**	**Rwanda**	**Sudan**	**Tanzania**	**Uganda**
Long-run coefficients							
Const	1.648 **	1.052 **	5.390 *	0.885 **	0.499	6.746 *	0.607 **
ES (−1)	−1.077 *	−0.303 **	−1.507 *	−0.328 **	−0.086	−2.040 *	−0.226 **
RE (+)	−0.272	−0.050	−0.835 *	0.116	0.176	−2.431 *	0.125
RE (−)	4.913 *	4.960	0.398 ***	0.092	−2.491	0.657 **	-
GPD (+)	5.960 *	0.516	3.397 *	0.113	−0.908	7.164 *	0.282 *
GDP (−)	−1.878 **	0.519	−5.178 *	0.153 ***	1.498	1.401 **	−0.520
PS (+)	-	-	-	2.715 **	-	-	0.433
PS (−)	-	-	-	−0.017	-	-	-
Short-run coefficients							
ΔRE (+)	1.427 **	−0.077	0.342 **	-	−2.702 **	−0.392 *	−0.306 **
ΔRE (−)	−3.876 **	-	−0.707 **	-	-	0.575 **	-
ΔGDP (+)	3.080 **	−1.310 *	4.515 *	-	3.848 **	4.209 **	-
ΔGDP (−)	0.628	-	3.256 *	-	6.657 **	−0.121	-

*, **, and *** indicate a significance level of 1%, 5%, and 10%, respectively.

In contrast, a positive change to GDP negatively affects CO_2 emissions in Sudan, but positively effects CO_2 emissions in six countries, while a negative change to GDP has a negative effect on CO_2 emissions in Burundi, Kenya, and Uganda. These results are consistent with those obtained by Asongu et al. [8] and Adams et al. [9]. A positive change in population growth positively affects CO_2 emissions, while a negative change has a negative effect only in Rwanda; in the remaining countries population growth integrated at second order, which violates NARDL assumptions. These findings are similar to those obtained by Asumadu-Sarkodie [29].

Finally, the results presented in Table 9 show that a positive change to renewable energy positively affects GDP and a negative change negatively affects GDP in six countries. These findings are consistent with individual studies conducted in EACs, such as Appiah et al. [35], Kebede [27], Akinlo et al. [38], and Hundie [28].

Table 9. NARDL model coefficients for individual countries.

Dependent: GDP							
Estimates	**Burundi**	**Ethiopia**	**Kenya**	**Rwanda**	**Sudan**	**Tanzania**	**Uganda**
Long-run coefficients							
Const	0.916	1.029	1.284 **	2.796 **	0.607	2.567 **	−0.133
GDP (−1)	−0.101	−0.104	−0.125 **	−0.300 **	−0.057	−0.255 **	0.015
RE (+)	0.019	0.098	0.054	0.104	−0.019	0.134 *	0.005
RE (−)	−0.029	−1.036	−0.026	−0.126	−0.326 **	−0.069 *	0.048
Short-run coefficients							
ΔRE (+)	0.073	-	-	-	-	0.045	-
ΔRE (−)	0.020	-	0.082	-	-	-	-

*, and ** indicate a significance level of 1%, and 5%, respectively.

4.5. Long- and Short-Run Asymmetry and Symmetry Results

Table 10 shows results for the nonlinear long- and short-run asymmetric and symmetric relationships among CO_2 emissions, renewable energy, and economic and population growth in seven EACs, estimated using a modified Wald test. In the case of renewable energy and CO_2 emissions, a long-run asymmetric causal relationship is noted in Kenya, Rwanda, and Tanzania, and a short-run asymmetric causal relationship is seen in Burundi, Kenya, Sudan, Tanzania, and Uganda. Long-run symmetry is noted in Burundi, Sudan, and Uganda, and long- and short-run symmetry is noted in Ethiopia. In the case of economic growth and CO_2 emission, a long-run nonlinear asymmetric and symmetric relationship is present in six countries, with the exception of Rwanda, which presents an asymmetric relationship in the long-run.

Table 10. Wald test for long- and short-run asymmetry and symmetry restrictions.

Dependent: CO_2 Emission							
Country		**GDP**		**Renewable Energy**		**Population Size**	
	Wald Test	**Statistic**	**Causal**	**Statistic**	**Causal**	**Statistic**	**Causal**
Burundi	LR	4.824 **	A	1.142	S	-	-
	SR	-	-	2.695 ***	A	-	-
Ethiopia	LR	2.665 ***	A	1.277	S	-	-
	SR	2.799 ***	A	1.382	S	-	-
Kenya	LR	25.562 *	A	24.163 *	A	-	-
	SR	8.222 *	A	4.796 **	A	-	-
Rwanda	LR	1.523	S	2.435 ***	A	3.534 **	A
	SR	-	-	-	-	2.931 **	A
Sudan	LR	3.015 **	A	1.248	S	-	-
	SR	2.840 **	A	3.858 **	A	-	-
Tanzania	LR	14.531 *	A	13.980 *	A	-	-
	SR	6.290 *	A	5.108 *	A	-	-
Uganda	LR	4.824 **	A	1.132	S	-	-
	SR	-	-	2.695 **	A	-	-

*, **, and *** indicate significance level at 1%, 5%, and 10%, respectively. A: Asymmetry, S: Symmetry, LR: Long-run, and SR: Short-run.

A long-run nonlinear asymmetric causal relationship between CO_2 emissions and population growth is noted in Rwanda. According to the reliability results from Wald statistics shown in Table 10 (causal columns), the distribution of asymmetric and symmetric causal relationships among CO_2 emissions, renewable energy, and economic and population growth is visibly present in the seven EACs, based on the estimates of the co-integrated mathematical model.

Figures 1–3 present the dynamic multiplier adjustment results and show that the CO_2 emissions adjustment is running towards the long-run equilibrium in terms of positive and negative shocks to GDP and nonrenewable energy consumption in seven countries. GDP is also running towards the long-run equilibrium in terms of positive and negative shocks to renewable energy. These figures show the distinct dimension of nonlinear asymmetric and symmetric relationships among the selected variables.

Figure 1 shows the results for Sudan and Kenya. It implies that there exists a significant negative nonlinear asymmetric nexus between CO_2 emissions and GDP, a positive asymmetric relationship between CO_2 emissions and renewable energy, and a positive nonlinear asymmetric relationship between GDP and renewable energy in Sudan. In the case of Kenya, significant positive nonlinear asymmetry is noted between CO_2 emissions and GDP, a negative nonlinear asymmetry is noted between CO_2 emissions and renewable energy, while a significant positive nonlinear asymmetry is noted between GDP and renewable energy. The results are similar to those obtained in previous studies of sampled African countries [19] and Kenya [13].

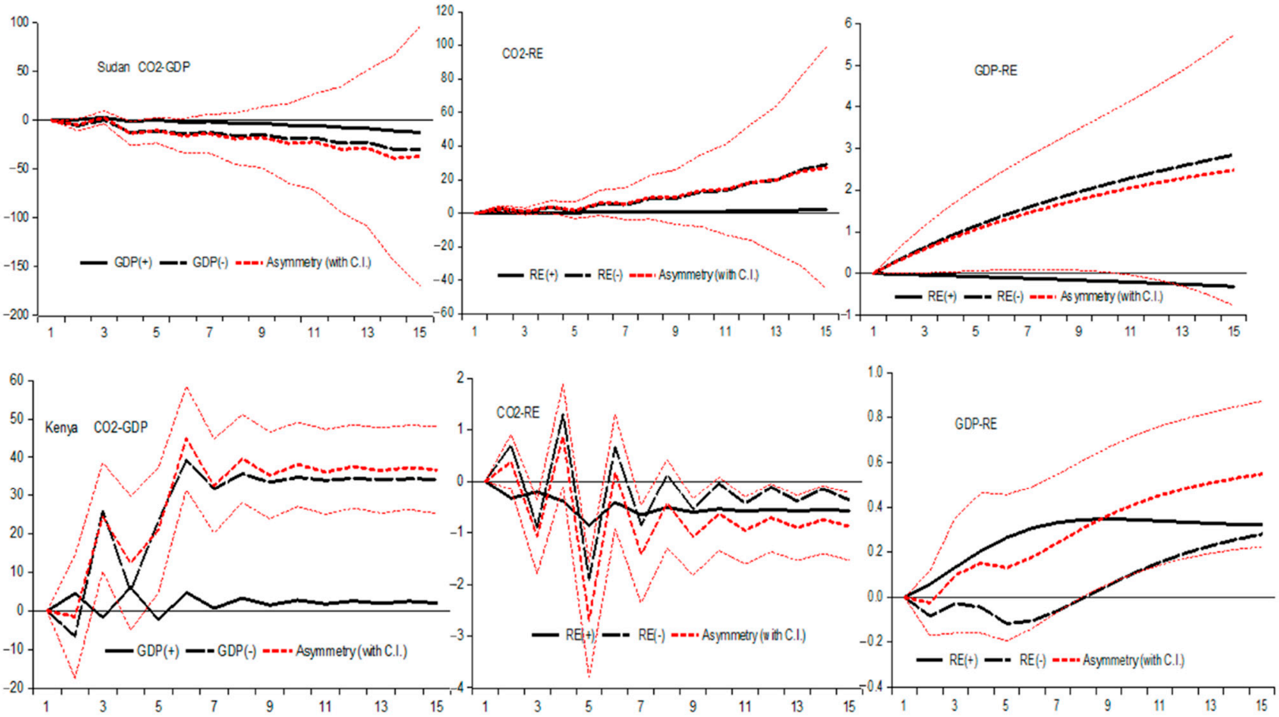

Figure 1. Dynamic multiplier plots of the nonlinear asymmetric and symmetric relationships between CO_2 emissions and GDP, CO_2 emissions and renewable energy, and GDP and renewable energy in Sudan and Kenya.

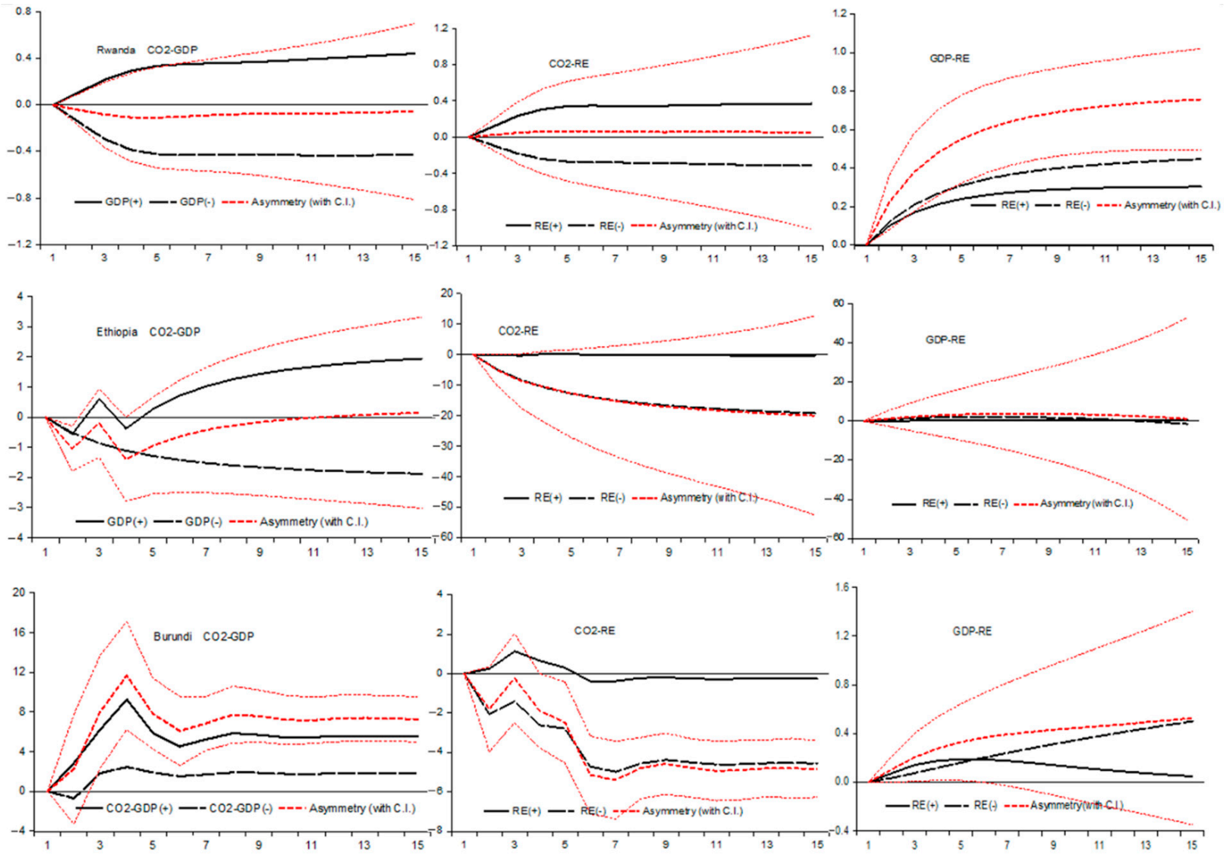

Figure 2. Dynamic multiplier plots of the nonlinear asymmetric and symmetric relationship between CO_2 emissions and GDP, CO_2 emissions and renewable energy, and GDP and renewable energy in Rwanda, Ethiopia, and Burundi.

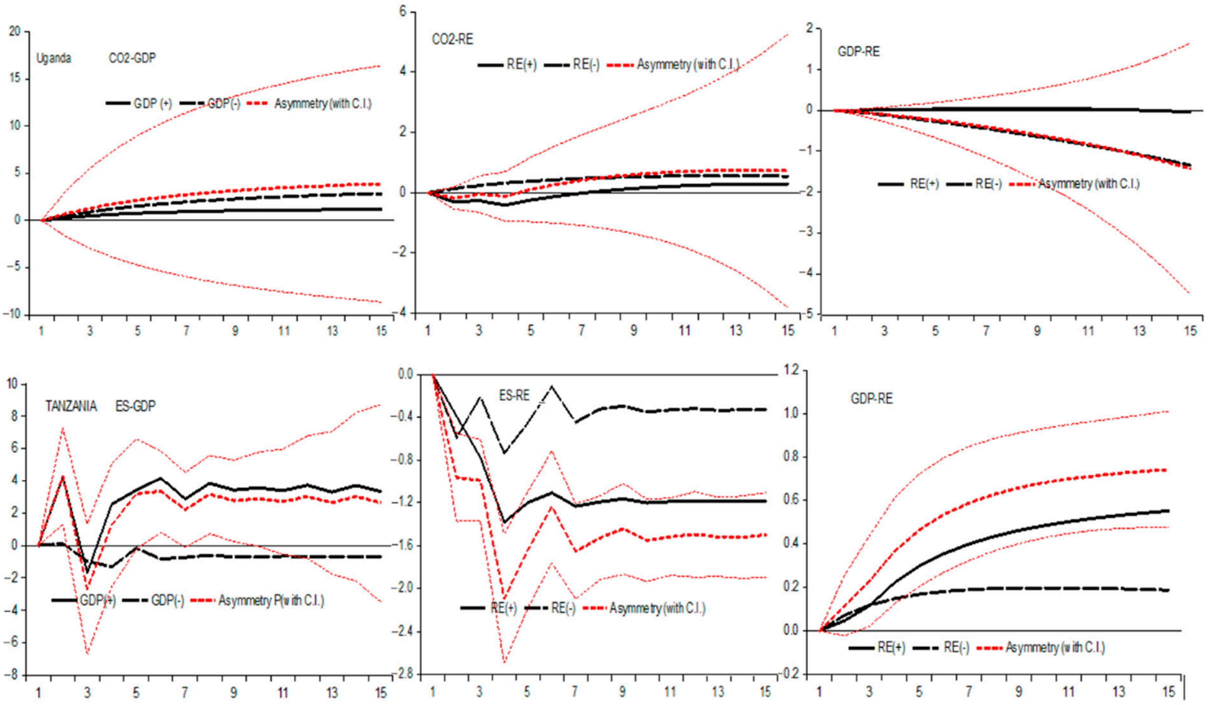

Figure 3. Dynamic multiplier plots of the nonlinear asymmetric and symmetric relationship between CO_2 emissions and GDP, CO_2 emissions and renewable energy, and GDP and renewable energy in Uganda and Tanzania.

Figure 2 demonstrates findings from Rwanda, Ethiopia, and Burundi. This figure reveals a significant positive nonlinear asymmetric relationship between CO_2 emissions and GDP in Burundi, negative asymmetry in Rwanda, and symmetry in Ethiopia. It also shows a significant negative nonlinear asymmetry between CO_2 emissions and renewable energy in all three countries. In contrast, significant positive asymmetry causation between GDP and renewable energy is noted in both Rwanda and Burundi. The results from Uganda and Tanzania are shown in Figure 3 and indicate a significant positive nonlinear asymmetric nexus between CO_2 (ES) and GDP for both countries as well as a significant negative asymmetric nexus between CO_2 and renewable energy. A positive asymmetric relationship is presented between GDP and renewable energy in Tanzania, while it is negative in Uganda. Therefore, the overall multiplier plots show how nonlinear asymmetric and asymmetric are differently distributed due to the effect of changes (positive and negatives shocks) among selected variables. Although asymmetry and symmetry relationships are presented in all countries, the dimensions are different in terms of linearity and nonlinearity. These findings indicate that the asymmetry and symmetry of GDP and renewable energy affects emissions either positively or negatively in the sampled countries. This information may help in the creation of energy policies and economic measures that take into account the possible unobserved features causing the nonlinear effects.

4.6. Causality Results

Table 11 shows the causality test results from the hypotheses tested for CO_2 emissions and its determinants in seven countries. Results show a one-way directional causation that runs from CO_2 to renewable energy in Rwanda, Sudan, and Uganda; from CO_2 to GDP in Ethiopia and Sudan; from CO_2 to PS in Ethiopia and Uganda (rows 1, 2, and 3, respectively). One-way directional causation running from renewable energy to CO_2 is noted in Ethiopia, Kenya, and Tanzania, and from renewable energy to population growth in Kenya (rows 4 and 6, respectively). One-way directional causation running from GDP to CO_2 is noted in six countries; from GDP to renewable energy is noted in five countries; from GDP to population growth is noted in four countries (rows 7, 8, and 9, respectively).

One-way directional causation running from population growth to GDP is noted in six countries; from population growth to renewable energy is noted in Uganda and Kenya; and from population growth to CO_2 is noted in Kenya and Sudan (rows 10, 11, and 12, respectively).

Table 11. Causalities between CO_2 emissions, renewable energy, and economic and population growth.

N_0	Hypothesis	Burundi	Ethiopia	Kenya	Rwanda	Sudan	Tanzania	Uganda
1	ES→RE	N	N	N	2.574 ***	5.876 *	N	3.092 **
2	ES→GDP	N	4.422 **	N	N	6.346 *	N	N
3	ES→PS	N	14.115 *	N	N	N	N	6.987 *
4	RE→ES	N	7.024 *	15.382 *	N	N	2.998 ***	N
5	RE→GDP	N	N	N	N	N	N	N
6	RE→PS	N	N	9.592 *	N	N	N	N
7	GDP→ES	N	3.618 **	8.414 *	2.743 ***	3.392 **	8.727 *	3.044 **
8	GDP→RE	3.012 **	4.645 **	3.938 **	N	4.969 **	N	4.395 **
9	GDP→PS	17.052 *	3.989 **	7.768 *	N	N	N	9.398 *
10	PS→GDP	5.112 *	N	5.439 *	6.854 *	4.118 **	3.628 **	4.221 **
11	PS→RE	N	N	3.624 **	N	N	N	4.200 **
12	PS→ES	N	N	8.152 *	N	3.209 ***	N	N
13	RE(+)→ES	N	4.635 **	3.286 **	5.038 **	N	2.884 ***	N
14	RE(−)→ES	N	N	N	2.546 ***	3.131 ***	N	N
15	ES→RE(+)	N	N	N	N	4.662 **	N	4.472 **
16	ES→RE(−)	N	N	3.286 ***	N	N	4.588 **	4.241 **
17	GDP(+)→ES	N	4.908 **	4.071 **	2.764 ***	3.048 ***	4.396 **	3.032 ***
18	GDP(−)→ES	N	N	N	N	N	N	N
19	ES→GDP(+)	N	3.828 **	N	2.654 ***	2.664 ***	N	N
20	ES→GDP(−)	N	N	N	N	5.772 *	N	N
21	PS(+)→ES	N	2.602 ***	3.384 **	N	3.312 ***	N	N
22	PS(−)→ES	N	N	N	N	3.312 ***	N	N
23	ES→PS(+)	N	12.184 *	N	N	N	N	7.732 *
24	ES→PS(−)	N	N	2.636 ***	N	N	N	N

N: neutral causality; *, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively.

In the case of positive and negative shocks to renewable energy, one-way directional causation running from positive shock to renewable energy to CO_2 is noted in four countries; from negative shock to renewable energy to CO_2 is noted in Rwanda and Sudan; from CO_2 to positive shock to renewable energy is noted in Sudan and Uganda; from CO_2 to negative shock to renewable energy is noted in three countries (rows 13, 14, 15, and 16, respectively). In the case of positive and negative shocks to GDP, one-way directional causation running positive shock to GDP to CO_2 is noted in six countries; from CO_2 to positive shock to GDP is noted in three countries; and from CO_2 to negative shock to GDP is noted in Sudan (rows 17, 19, and 20, respectively). Furthermore, one-way directional causation running from positive shock to population growth to CO_2 is noted in three countries; from negative shock to the population growth to CO_2 is noted in Sudan; from CO_2 to positive shock to population growth is noted in Ethiopia and Uganda; and from CO_2 to negative shock to population growth is noted in Kenya (rows 21, 22, 23, and 24, respectively).

Figure 4 presents the causality flow among selected variables for both the East African region and individual countries. In the case of the region, bi-directional causality is noted between CO_2 emissions and renewable energy. Unidirectional causality is seen running from GDP and PS to renewable energy, from GDP to CO_2 emissions, from PS to GDP, and from population growth to CO_2 emissions in the region.

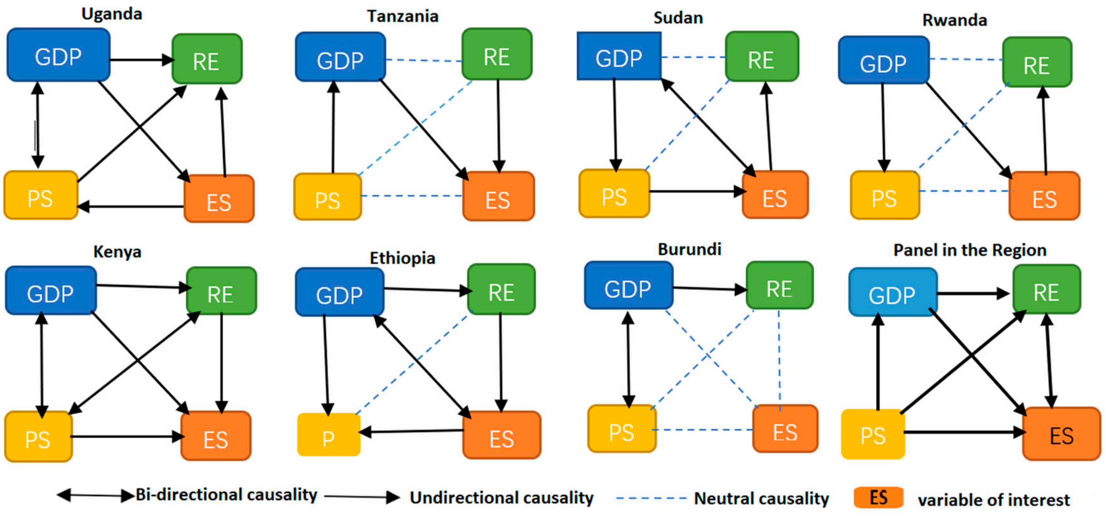

Figure 4. Graphical representation of hypotheses results.

In the case of individual countries, the bi-directional hypothesis is noted between GDP and PS as well as PS and renewable energy in Uganda, Kenya, and Burundi. This hypothesis is noted also between CO_2 emissions and GDP in Sudan and Ethiopia. The one-way directional hypothesis running from GDP to renewable energy is noted in Uganda, Kenya, Ethiopia, and Burundi. The one-way directional hypothesis running from renewable energy to CO_2 emissions is noted in Tanzania, Ethiopia, and Kenya; it is seen running from GDP to CO_2 in Uganda, Tanzania, Rwanda, and Kenya. Furthermore, the neutral hypothesis is noted among the selected variables in all countries. These findings are consistent with Kahia et al. [53], whose results showed bi-directional causation between GDP and renewable energy, and Dong et al. [1], who found mixed results in the African region.

4.7. Robustness Analysis Check

This study, conducted in seven East African countries (Ethiopia, Tanzania, Sudan, Uganda, Rwanda, Burundi, and Kenya) not only examines the causal relationship among CO_2 emissions, renewable energy use, and economic and population growth at the regional level, but also looks at nonlinear asymmetric and symmetry causations among the selected variables in individual countries. The panel data were mined from the World Bank database (CO_2 emissions and economic and population growth) and the U.S Energy Information Administration database (EIA) (renewable energy consumption) [21] over a period from 1980–2016. Panel common correlated effect means group (CCEMG), nonlinear ARDL (NARDL), and causality tests were employed. The excluded countries mostly did not report their complete historical data in the World Bank database and non-observation was found in the EIA database.

The empirical analysis was initiated by examining the levels of the variables (cross-sectional dependence and unit root); however, we rejected the null hypothesis of no cross-sectional dependence (see Table 3). Again, we reject the null hypothesis of the unit root at the 10% significance at constant trends by using the first differencing CIPS unit root test (see Table 4). The non-unit root hypothesis has been also rejected at the 10% significance level at the first difference for three variables in all countries; however, because population growth requires second difference order in six countries, it has been dropped out in the NARDL approach (see Table 5). The null hypothesis of no cointegration was rejected (see Table 6).

Our findings at the East African regional level and country levels are shown in Tables 7 and 8. These results imply that if a higher percentage of the population is predominantly using renewable energy, CO_2 emissions can reduce quickly, and significant economic growth can occur. These findings are consistent with existing studies, such as Bilgili et al. [54], who finds that the negative impact of renewable consumption on CO_2 emissions does not rely on the level of income in a country. The negative coefficients for renewable energy, and positive coefficients for population and economic growth significantly impact CO_2 emissions. These results coincide with those of Bélaïd et al. [55], which show the threshold for renewable energy effects on CO_2 emissions and economic growth, and Panwar et al. [56], whose results show the role of renewable energy resources in protecting the environment, including the reduction of CO_2 emissions. This study suggests that renewable energy consumption promotes economic growth, and as the population increases, economic growth also increases.

Through the NARDL approach used in this study, and by observing the multiplier plots, we found that there are differences within the trends, directions (positive and negative), and dimensions of nonlinear asymmetric and symmetric relationships of renewable energy consumption and economic and population growth with CO_2 emissions as well as the relationship between economic growth and renewable energy consumption among all countries (see Table 10 and Figures 1–3). Even though the neutral hypothesis is highly supported, the bi-directional and unidirectional causalities between CO_2 emissions and renewable energy and economic and population growth are different in some countries and in the region (see Table 11 and Figure 4). The supported hypotheses are similar to those tested in the study involving 24 African countries as well as those looking at individual countries (see [27,28,37]). Therefore, the causal relationship between renewable energy consumption and CO_2 emissions implies that with the rapid increase in renewable energy demand, CO_2 emissions can be efficiently lessened economic growth improved in the future. This finding is similar to the results obtained in Bélaïd et al. [55]. Therefore, efficiency improvement policies and energy conservation can be employed to reduce energy use (nonrenewable) and pollution emissions without disturbing economic growth in the region [57].

This study has some limitations. The study was intended to cover all East African countries, but due to unavailable observations for certain variables in some countries, only seven countries were selected.

5. Conclusions and Policy Implications

This study aims to examine the impact of renewable energy consumption and economic and population growth on CO_2 emissions at the East African regional level as well as the asymmetric linkage between the selected variables in seven countries from 1980 to 2016. The CCEMG and NARDL approaches and the Granger causality test were employed. The main results of this study are as follows. First, CCEMG results reveal that renewable energy negatively affects CO_2 emissions, while economic and population growth positively affect CO_2 emissions in the long-term at the regional level. Second, from the NARDL estimator, in terms of asymmetric and symmetric linkages, the results are very volatile across renewable energy proxy, economic and population growth, and time horizon in all selected countries. In addition, the dimensions and distribution of asymmetric and symmetric relationships are different based on negative and positive changes within the selected variables. Third, results from the causality hypotheses indicate that the neutral hypothesis is highly supported, followed by one-way directional causation. Bidirectional causation is noted between CO_2 emissions and GDP, between GDP and PS, and between PS and renewable energy in different countries. The overall results showed that the nexus of CO_2 emissions, renewable energy, and economic and population growth in the seven countries is influenced by either negative unobserved features or structural economic changes.

Based on our findings and limitations, policy implications are as follows. First, for the regional level, intensive investment in existing renewable energy projects and common markets can lead to significant CO_2 emissions reduction as well as environmental relief. Second, optimizing and creating interconnection through renewable energy projects (such as the Eastern Africa power pool) can intensively contribute to meeting energy demand in the region as well as result in CO_2 emissions reduction. Third, renewable energy use and economic growth predictions with regard to CO_2 emissions reduction in the seven studied countries that are not exhibited within an asymmetric/symmetric framework may mis-estimate real energy use, which may lead to unplanned energy deficiencies and the use the alternative energies that damage the environment through CO_2 emission. Fourth, with regard to country-specific plans and economic levels, energy policies and government policies related to energy generation should target emissions reduction. The study suggested that enhancing East Africa power trade optimization over current and dedicated cross-border connections and building additional integrated power systems can lead to sustainable energy generation and contribute to the growth of national economies. Therefore, further studies can be conducted in country-specific industrial sectors to deeply reduce CO_2 emissions. Additional studies are needed for further determinants of CO_2 emissions at the regional and country levels.

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Abbreviations

ES: CO_2 emissions, RE: renewable energy consumption, PS: population size/growth, GDP: gross domestic product per capita, EAPP: Eastern African Power Pool, EAPT: Eastern African Power Trade, CCEMG: common correlated effect means group, NARDL: nonlinear ARDL, EACs: East African Countries, and EIA: U.S. Energy Information Administration.

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