The Nexus Between Electricity Consumption, Economic Growth, and CO$_2$ Emission: An Asymmetric Analysis Using Nonlinear ARDL and Nonparametric Causality Approach

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Abstract: This article examines the asymmetric relationship between electric consumption, economic growth, and carbon dioxide emission in 15 countries over the period 1971–2014. We employed a nonlinear auto-regressive distribution Lag (NARDL) model approach to investigate the asymmetric cointegration between variables. Additionally, we applied the asymmetric causality approach to determine the causal relationship between variables. Results confirm nonlinear cointegration between variables in Cameroon, Congo Republic, Zambia, Canada, and the UK. The Wald test results confirm a long-run asymmetric link between electricity consumption, economic growth, and carbon emission in Canada and Cameroon, while a short-run asymmetric effect in the Congo Republic and the UK. Findings from the granger causality test are volatile across variables. The result provides strong support for the symmetric relationship between electric consumption, economic growth, and carbon emission in the short and long run. This study provides new evidence for policymakers to formulate country-specific policies to obtain better environmental quality while achieving sustainable economic growth.

Keywords: electricity consumption; economic growth; carbon emission; asymmetric causality; asymmetric cointegration

1. Introduction

Greenhouse gas emission (GHG) in the atmosphere poses a severe threat to sustainable development as its impact affects climate change globally in numerous ways like ecosystem destruction and the melting of polar ice, causing a rise in sea levels. It also causes temperature increase leading to disasters like floods and drought. The main component of this GHG is carbon dioxide (CO$_2$) emission. For some decades now, the topic of the causal relationship between the impact of CO$_2$ emission on gross domestic products (GDP) and electric consumption (ECON) has been of high interest among researchers [1,2]. Some factors like increased electricity demand and services, goods and economic growth have led to the increase in CO$_2$ emissions especially in the sub-Saharan region of Africa over the decades [3] which has a high population of close to 1 billion people and has the most inadequate access to electricity [4]. World Development Indicators show that CO$_2$ emissions for some years now

have been on the increase due to electricity transmission, which has led to a decrease inefficiency of the power sector. Algeria, which is not part of the sub-Saharan countries, is the third-highest emitter of CO_2 in Africa [5]. Additionally, the G7 countries have 47% of the global GDP, and these countries are rated as the part of the world's advanced economies attached to the energy–growth relationship which impacts on energy consumption, economic growth and has led to climate change response strategies. To help combat these consequences of CO_2 emission, many countries, both developing and developed countries, have signed the Kyoto Protocol aimed at reducing carbon emission globally [6].

As early as the 1970s, some scholars started researching the relationship between carbon emission, electric consumption, and gross domestic product [7]. Numerous studies have checked the Environmental Kuznets Curve (EKC) that analyzes the environmental quality and economic growth. According to the EKC hypothesis, environmental degradation transitions from an upward trend to a downward trend once the economic level reaches a certain threshold. If carbon emissions increase with economic growth, economic development still occurs at the expense of the environment. It goes ahead to say that environmental degradation increases firstly then starts to reduce as growth per capita continues to rise. The link between energy consumption, economic growth, and carbon emission has undoubtedly ranked first among the studies common in the empirical energy economics literature [6,8–10].

Most previous studies on the energy-carbon-economy have focused on the relationship between economic growth and carbon emission or energy consumption in a linear framework. However, the variations in the findings have failed to provide a consistent solution for policymakers. A comprehensive literature review can be seen in Table 1.

Table 1. Empirical studies on the relationships between CO_2 emissions, energy consumption, and economic growth.

Author/Year	Period of Study	Country/Region	Methods	Results
[11]	1980–2006	ASEAN (five countries)	Panel vector error correction model	The long run shows Unidirectional Granger causality running from electricity consumption and emissions to economic growth while the short run shows emissions to electricity consumption
[12]	1970–2008	Nigeria	Multivariate Vector Error Correction Model (VECM)	In the long run, economic growth is associated with increasing electricity consumption, while an increase in electricity consumption leads to an increase in carbon emissions
[13]	1971–2012	Ghana	Autoregressive distributed lag model by employing a time–series data	Bidirectional causality from electricity production from hydroelectric sources to carbon dioxide emissions and unidirectional causality from carbon dioxide emissions to the total energy production
[14]	1960–2010	G-7 (seven countries)	Time-varying granger causality test, Times series, ADF unit root test	In Italy, France, Japan, USA, and energy consumption contributes to carbon emission
[2]	1990–2012	58 countries	Dynamic panel data	The positive impact of CO_2 emissions on energy consumption. Economic growth has a positive impact on energy consumption
[15]	1973–2008	15 countries	Panel unit root tests, panel cointegration	No causal link between GDP and EC; and between CO_2 emissions and EC in the short run. In the long run, there is a unidirectional causality running from GDP and CO_2 emissions to EC
[10]	1990–2010	Five countries	Panel causality analysis	Electricity consumption is found to Granger cause CO_2 emissions in India

Table 1. *Cont.*

Author/Year	Period of Study	Country/Region	Methods	Results
[5]	1970–2010	Algeria	Autoregressive Distributed Lag model	Increase electricity consumption increase CO_2 emissions
[16]	1990–2014	Six countries	Vector Error Correction Model (VECM)	Increase in energy use and population growth cause an increase in CO_2
[4]	1970–2016	Ghana	Linear regression	This means that GDP influences the CO_2 emission level in Ghana
[17]	1971–2014	Cameroon	Autoregressive distributed lag bounds test ARDL	Unidirectional causality running from CO_2 emissions to economic growth
[6]	1971–2010	12 Countries	Bounds test to cointegration and Granger causality test	Long-run energy consumption and economic growth cause CO_2 to increase economic growth causing CO_2 emissions in the short run in Congo Dem Rep, Ghana, and Nigeria
[9]	1980–2009	14 countries	Panel cointegration and panel vector error correction	Short-run unidirectional causality from economic growth to CO_2 emissions, long-run bidirectional causality between electricity consumption and CO_2 emissions, economic growth, and CO_2 emission

Based on a comparative analysis between developing and developed countries on the relationship between carbon dioxide emission, energy consumption, and economic growth by [18] based on panel data from 1971–2014 using an ordinary least squares method, the results confirm a high correlation between CO_2, GDP, energy consumption, energy intensity, and trade openness. The results do not support the EKC hypothesis. The authors of [19] investigated the existence of the Environmental Kuznets Curve (EKC) in China from 1970 to 2015. The ARDL (Autoregressive Distributed Lag) model, FMOLS (Fully Modified Ordinary Least Squares), DOLS (Dynamic Ordinary Least Squares), impulse response and variance decomposition models were employed to examine the nexus between CO_2 emissions, economic growth, and energy consumption. The result supports the Environmental Kuznets Curve (EKC) hypothesis from different techniques; long-run economic growth in favor of environmental quality was confirmed. In [20] the authors used a panel cointegration and vector error-correction model to discuss the dynamic economy–energy–environment nexus for 188 countries for the period of 1993–2010. Results show the existence of long-run relationships between economic growth, energy consumption, and CO_2 emissions for all countries; energy consumption negatively affects GDP worldwide as a whole; unidirectional causality from energy consumption to carbon dioxide emissions exists. They investigated the effects on the economy of a feed-in-tariff policy mechanism aimed to foster investments in renewable energy production. The authors of [21] employed a Eurace macroeconomic model. Findings confirm that the feed-in tariff policy was effective in promoting the sustainability transition of the energy sector and that it increases investment level with a positive impact on the unemployment rates. Additionally, it was observed that GDP increases the share of the investment sector in the economy, due to the building-up of renewable production capacity, with a resulting crowding out of consumption, higher rates, and prices.

Over the years, many researchers have investigated the nexus between energy consumption, carbon emissions, and economic growth, without a consensus. Due to the mixed results, many countries have been put in a difficult situation when formulating and adopting energy policies [22]. The diversity in recent findings is as a result of the different methodologies applied, the different time frames, and diverse countries studied according to [23].

This study contributes to existing literature, majorly in the field of energy and ecology. Firstly, instead of using a sample that only includes a single type of country, this study selects a heterogeneous sample composed of both developed and developing countries. Six out of the seven

G7 constituting developed and industrialized countries in the world, namely Canada, France, Italy, Japan, the UK, and the US, were studied. Additionally, we assessed eight African countries making up our sample for developing nations, namely: Algeria, Cameroon, Congo Democratic Republic, Congo Republic, Ghana, Kenya, Nigeria, Zambia, and India. Given this, a diverse sample is necessary and useful for country-specific energy policymaking and formulation.

Secondly, this study utilizes the recently developed nonlinear autoregressive distributed lag model (NARDL) developed by [24]. The nonlinear ARDL is very important to explain the asymmetric relationship that exists between electric consumption, economic growth, and carbon emission. Unlike other models applied in previous studies, the NARDL allows testing the long run and short run asymmetries in the variables. The bounds testing approach exhibits robustness to small sample sizes and concurrently identifying asymmetries existing in the dynamic adjustment allowing regressors of mixed order I(0) and I(1) [24–26].

Thirdly, the study incorporates the nonlinear Granger causality presented in [27] instead of the widely used nonlinear causality test presented in [28] to examine the causality relationship between electric consumption, economic growth, and carbon emission in a nonlinear framework. In [27] the nonlinear Granger causality was adopted as a result of the shortcomings pointed out by Dicks and Panchenko in the Hiemstra and Jones test that it may over reject the null hypothesis of noncausality.

The remaining sections of this article are structured as follows. Section 2 reports the data sources and methodology used for the analysis. Section 3 summarizes the empirical results. Section 4 deals with the discussion. Section 5 presents the conclusion.

2. Data and Methodology

2.1. Data

The data used in this research is from the World Bank Development Indicators (WDI). Annual data was used that covers a period of 44 years, from 1971 to 2014, based on the availability of data. The multivariate framework included CO_2 emissions (CE) (measured metric tonne per capita) as our dependent variable, gross domestic product (GDP) per capita current 2010 US dollars (as a proxy for economic growth) (EG), and electric power consumption KW per capita (EC). All variables were converted into logarithms before analysis. Summary statistics are provided in Table 2.

<div align="center">**Table 2.** Summary statistics.</div>

Countries	Descriptive Statistics	CE	EC	EG	Countries	Descriptive Statistics	CE	EC	EG
Algeria	Mean	2.922897	2.706138	3.305227	Canada	Mean	1.217516	4.165246	4.279594
	Maximum	3.73552	3.134455	3.747584		Maximum	1.261646	4.23716	4.720509
	Minimum	1.255271	2.126695	2.53325		Minimum	1.168529	3.962212	3.655154
	Std. Dev.	0.55274	0.259778	0.274772		Std. Dev.	0.02182	0.075963	0.288002
Cameroon	Mean	0.290618	2.285986	2.890544	France	Mean	0.827528	3.752776	4.251049
	Maximum	0.696833	2.439645	3.187681		Maximum	0.987179	3.888445	4.656425
	Minimum	0.090935	2.18277	2.265908		Minimum	0.660218	3.439631	3.500927
	Std. Dev.	0.163003	0.079939	0.220521		Std. Dev.	0.087691	0.134177	0.31244
Congo Democratic Republic	Mean	0.082502	2.08556	2.454593	India	Mean	−0.130583	2.445387	2.600466
	Maximum	0.151241	2.229148	2.789566		Maximum	0.237461	2.905534	3.196972
	Minimum	0.017264	1.945406	2.011139		Minimum	−0.440656	1.990218	2.074097
	Std. Dev.	0.050656	0.093504	0.197494		Std. Dev.	0.202198	0.274709	0.305116
Congo Republic	Mean	0.493308	2.0636	3.006853	Italy	Mean	0.843616	3.606875	4.159629
	Maximum	1.088754	2.33168	3.516191		Maximum	0.914686	3.765927	4.608956
	Minimum	0.173913	1.751072	2.37261		Minimum	0.721882	3.332998	3.361351
	Std. Dev.	0.214249	0.169441	0.279814		Std. Dev.	0.046015	0.131279	0.363219
Ghana	Mean	0.493308	2.0636	3.006853	Japan	Mean	0.94055	3.801452	4.289991
	Maximum	1.088754	2.33168	3.516191		Maximum	0.996039	3.940019	4.686667
	Minimum	0.173913	1.751072	2.37261		Minimum	0.869882	3.533478	3.356423
	Std. Dev.	0.214249	0.169441	0.279814		Std. Dev.	0.041254	0.124557	0.377017
Kenya	Mean	0.280366	2.067376	2.616954	UK	Mean	0.973617	3.722652	4.210788
	Maximum	0.382519	2.215705	3.119191		Maximum	1.072729	3.797336	4.701511
	Minimum	0.189649	1.889894	2.181357		Minimum	0.812742	3.628864	3.423213
	Std. Dev.	0.053723	0.075615	0.223473		Std. Dev.	0.058711	0.050998	0.381046
Nigeria	Mean	0.647774	1.914257	2.882562	US	Mean	1.288325	4.056198	4.359856
	Maximum	1.009958	2.195338	3.508219		Maximum	1.352387	4.136866	4.740623
	Minimum	0.32556	1.455917	2.204795		Minimum	1.212467	3.876062	3.748915
	Std. Dev.	0.189814	0.184298	0.329372		Std. Dev.	0.033216	0.075537	0.292382
Zambia	Mean	0.395191	2.905056	2.753087					
	Maximum	0.993839	3.074348	3.273904					
	Minimum	0.154271	2.754684	2.366496					
	Std. Dev.	0.243848	0.102734	0.232855					

2.2. Methodology

This study investigates the relationship that exists between electricity consumption, economic growth, and carbon emission using a nonlinear (asymmetric) approach to determine the short- and long-run asymmetric relationships.

$$\log CE_{i,\,t} = \alpha + \alpha_1 \log EC_{i,\,t} + \alpha_{i,\,t} \log EG_{i,t} + \mu_{i,\,t} \tag{1}$$

where i represents the countries and years, log denotes logarithm. *CE* denotes carbon emission, *EC* represents electric consumption, and *EG* is economic growth.

We adopted the nonlinear ARDL bounds testing approach developed by [29], which considers nonlinear and asymmetric cointegrations between variables. Additionally, it differentiates the long-run effects and short-run effects of the independent variables on the dependent variables. It is applicable irrespective of whether the variable is stationary at the level, or first difference l(0) or l(1) provided none of these variables is l(2) by [30]. This article employs this NARDL cointegration to investigate the relationship between carbon emission (CO), electric consumption (EC), and gross domestic product (EG). This method enables us to determine the functional relationship between carbon emission, electric consumption, and gross domestic products.

$$\Delta CE_t = \alpha_0 + pCE_{t-1} + \theta_1^+ EC_{t-1}^+ + \theta_2^- EC_{t-1}^- + \theta_3^+ EG_{t-1}^+ + \theta_4^- EG_{t-1}^- + \sum_{i=1}^{p} \alpha_1 \Delta CE_{t-1}$$

$$+ \sum_{i=0}^{q} \alpha_2 \Delta EC_{t-1}^+ + \sum_{i=0}^{q} \alpha_3 EC + \sum_{i=0}^{q} \alpha_4 \Delta EG_{t-1}^+ + \sum_{i=0}^{q} \alpha_5 \Delta EG_{t-1}^- + D_t \tag{2}$$

$$+ \mu_t$$

From the first equation, θ_i depicts long-run coefficients, α_i depicts short-run coefficients, with $i = 1\ldots.8$. Long-run coefficients give the reaction time and speed time of the adjustment towards the equilibrium level. At the same time, the immediate effect of independent variables on dependent variables were determined using the short-run. We used the Wald test to determine the short-run asymmetry ($\alpha = \alpha^+ = \alpha^-$) and long-run asymmetry ($\theta = \theta^+ = \theta^-$) for variables E_t, Kt, and C_t where E_t is electric power consumption, K_t represents GDP per capita, and C_t represents CO_2 emission. Dt denotes a dummy variable used to know the impact of the break date (t). The Akaike information criterion (AIC) helps to determine p and q, which are the optimal lags for the independent variables (E_t, K_t) and the dependent variable C_t.

Decomposing the independent variables into positive and negative sums, we have

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} \max\left(\Delta x_j, 0\right) \textit{ and } x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j-1}^{t} \min\left(\Delta x_j, 0\right) \tag{3}$$

To conduct a combined test for all lagged levels of regressors, we performed a proposed bound test by [29] to check whether an asymmetric long-run cointegration exists. We applied two tests in this part of the article namely F-statistics the null hypothesis of $\theta = 0$ against alternative hypothesis $\theta < 0$ by [26] and T- statistics by [31] in this the null hypothesis tests the null hypothesis at $\theta = 0$ against alternative hypothesis $\theta < 0$. To estimate long-run asymmetric coefficients, we used L$mi^+ = \theta^+ / \rho$ and L$mi^- = \theta^- / \rho$, where these long-term coefficients reveal the positive and negative charges of the exogenous variables and show the long-run relationship between the variables. To estimate the asymmetric dynamic multiplier effects, the below equation is used.

The equation shown below is used to estimate the asymmetric dynamic multiplier effects.

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial CE_{t+j}}{\partial EC_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial CE_{t+j}}{\partial EC_t^-}, m_h^+ = \sum_{j=0}^{h} \frac{\partial CE_{t+j}}{\partial EG_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial CE_{t+j}}{\partial EG_t^-} \tag{4}$$

$h \to \infty$, $m_h^+ \to Lm^+$ and $m_h^- \to Lm^-$ shows asymmetric responses from the dependent variable to the positive and negative variation in the independent variables. We notice a constant change in the adjustments from the initial to the new equilibrium between system variables based on estimated multipliers following the variation that affects the system.

The asymmetric causality test, as proposed by [27], is used to get the asymmetric causal relationship between the variables. He goes ahead to say that variables which are integrated can be given in a random walk process in a generalized form below:

$$CE_t = CE_{t-1} + e_{1t} = CE_0 + \sum_{i=1}^{t} e_{1i} \text{ and } X_t = X_{t-1} + e_{2t} = X_0 + \sum_{i=1}^{t} e_{2i} \tag{5}$$

where $t = 1,2,3.\ldots\ldots, T$, CE_0 and X_0 are initial values, error terms are represented by e_{1t} and e_{2t}. The positive shocks are given as $e_{1i}^+ = \max(e_{1i}, 0)$ and $e_{2i}^+ = \max(e_{2i}, 0$ while the negative shocks are given by $e_{1i}^- = \min(e_{1i}, 0)$ and $e_{2i}^- = \min(e_{2i}, 0)$

$$CE_t = CE_{t-1} + e_{1t} = CE_0 + \sum_{t=1}^{t} e_{1i}^+ + \sum_{t=1}^{t} e_{1i}^- \text{ and } X_t = X_{t-1} + e_{2t} = X_0 + \sum_{t=1}^{t} e_{2i}^+ + \sum_{t=1}^{t} e_{2i}^-$$

Equation (3) below uses a cumulative form to show the effect of positive and negative shocks of all the variables.

$$CE_t^+ = \sum_{i=1}^{t} e_{1i}^+, CE_t^- = \sum_{i=1}^{t} e_{1i}^-, EC_t^+ = \sum_{i=1}^{t} e_{2i}^+, EC_t^- = \sum_{i=1}^{t} e_{2i}^-, EG_t^+ = \sum_{i=1}^{t} e_{3i}^+, EG_t^- = \sum_{i=1}^{t} e_{3i}^- \tag{6}$$

In 1969, Granger proposed a causality test to describe the dependence relations between economic time series. According to this, if two variables $\{X_t, Y_t, t \geq 1\}$ are strictly stationary, $\{Y_t\}$ Granger causes $\{X_t\}$ if past and/or current values of X contain additional information on future values of Y.

Suppose that $X_t^{lx} = (X_{t-1} \ X_{+1}, \ldots, X_t)$ and $Y_t^{ly} = (Y_{t-1} \ y_{+1}, \ldots, Y_t)$ are the delay vectors—where $l_X, l_Y \geq 1$. Diks and Panchenko (2006) examine the null hypothesis that past observations of X_t^{lx} contain any additional information about Y_{t+1} (beyond that in Y_t^{ly}):

$$H_0 : Y_{t+1} \ \bigg| \ \left(X_t^{lX} ; Y_t^{lY} \right) \sim Y_{t+1} \ \bigg| Y_t^{lY} \tag{7}$$

The test statistic can be represented by the following equation:

$$T_n(\varepsilon_n) = \frac{n-1}{n(n-2)} \cdot \sum_i (\hat{f}_{\cdot X,Z,Y}(X_i, Z_i, Y_i)\hat{f}_{\cdot Y}(Y_i) - \hat{f}_{\cdot X,Y}(X_i, Y_i)\hat{f}_{\cdot Y,Z}(Y_i, Z_i)) \tag{8}$$

where $f_{X,Y,Z(x,y,z)}$ is the joint probability density function. For $l_X = l_Y = 1$ and if $\varepsilon_n = Cn^{-\beta}(C > 0, \frac{1}{4} < \beta < \frac{1}{3})$, Diks and Panchenko (2006) prove that the test statistic in Equation (2) satisfies the following:

$$\sqrt{n} \frac{(T_n(\varepsilon_n) - q)}{S_n} \xrightarrow{D} N(0,1) \tag{9}$$

where $\xrightarrow{D}$ denotes convergence in distribution, and S_n is an estimator of the asymptotic variance of $T_n(.)$ [27]. In this study, following the Diks and Panchenko's suggestion, we implemented a two-tailed version of the test.

3. Empirical Results

3.1. Stationarity Test

In this research, we used both the Augmented Dickey–Fuller (ADF) test proposed by [32], and Phillips and Perron (PP) test proposed by [33] without the structural break to test the tendency of a unit root test over a time series. Additionally, if the integration instructions of the selected variables were identified, the appropriate model was selected. The null hypothesis of the stationarity in both tests is the existence of the unit root under the alternative hypothesis. By testing the stationarity of all selected variables (CE, EC, and EG) with intercept or along intercepts and trends, this provided the variables following I(0) or I(1) processes.

Table 3 shows the unit root test for stationarity to determine if variables are integrated of order one. C and T in the diagram above stand for 'Constant' and 'Constant + Trend' options for ADF and PP, respectively.

Table 3. Stationarity test results.

Variables	Test	Algeria		Cameroon		Congo Dem Rep		Congo Rep		Ghana		Kenya		Nigeria			
		C	T	C	T	C	T	C	T	C	T	C	T	C	T		
CE	ADF	I(0)	I(0)	I(0)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)		
	PP	I(0)	I(0)	I(0)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)		
EC	ADF	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)	I(1)		
	PP	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)		
EG	ADF	I(0)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)		
	PP	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)		

Variables	Test	Zambia		Canada		France		Italy		Japan		UK		USA		India	
		C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T
CE	ADF	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
	PP	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
EC	ADF	I(1)	I(1)	I(0)	I(1)	I(0)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)
	PP	I(1)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)
EG	ADF	I(1)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(1)	I(1)
	PP	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)	I(0)	I(1)	I(1)	I(1)

3.2. Cointegration Analysis

Since the variables were integrated of order one, we proceeded to perform the cointegration test to examine the long term relationship between the variables. Table 4 demonstrates the results of the Johansen cointegration test between electricity consumption, economic growth, and carbon emission for each country.

Results from the Johansen cointegration test presented in Table 4 show a nonrejection of the null hypothesis of no cointegration between the variables in the case of Cameroon, Congo Democratic Republic, Congo Republic, Ghana, Kenya, Nigeria, Zambia, UK, and India at the usual level of statistical significance. This means there is no long-run equilibrium relationship between 44 years of carbon emissions, electricity consumption, and economic growth in these countries. Therefore, long term carbon emissions, electricity consumption, and economic growth do not share a common stochastic trend during the stipulated sample time frame. This might be due to a nonlinear relationship between these variables, which could be determined by using a nonlinearity test.

Table 4. Cointegration test analysis.

Trace Statistic	H0:NO OF CE(s)	Eigenvalue	Trace Statistic	Critical Value (5%)	Prob
Algeria	None	0.365236	30.37804	29.79707	0.0428 **
	At most 1	0.166102	11.28894	15.49471	0.1943
Cameroon	None	0.29695	25.95364	29.79707	0.1301
	At most 1	0.203942	11.15588	15.49471	0.2021
Congo Dem Rep	None	0.256361	20.54377	29.79707	0.3867
	At most 1	0.146507	8.103374	15.49471	0.4544
Congo Rep	None	0.225797	23.63666	29.79707	0.2162
	At most 1	0.209306	12.88795	15.49471	0.119
Ghana	None	0.301613	20.03568	29.79707	0.4205
	At most 1	0.105791	4.958435	15.49471	0.8132
Kenya	None	0.290905	21.88823	29.79707	0.3047
	At most 1	0.156141	7.450056	15.49471	0.5259
Nigeria	None	0.293901	23.80702	29.79707	0.2087
	At most 1	0.139925	9.19106	15.49471	0.348
Zambia	None	0.257435	24.82933	29.79707	0.1676
	At most 1	0.212006	12.32823	15.49471	0.1419
Canada	None	0.366401	31.36772	29.79707	0.0327 **
	At most 1	0.236336	12.2015	15.49471	0.1475
France	None	0.479654	38.678	29.79707	0.0037 ***
	At most 1	0.226027	11.24103	15.49471	0.1971
Italy	None	0.415557	36.0706	29.79707	0.0083 ***
	At most 1	0.195721	13.51258	15.49471	0.0973 *
Japan	None	0.34359	35.13987	29.79707	0.011 **
	At most 1	0.239756	17.45914	15.49471	0.025 **
UK	None	0.227995	16.03352	29.79707	0.7099
	At most 1	0.11482	5.165407	15.49471	0.791
USA	None	0.413801	32.89273	29.79707	0.0213 **
	At most 1	0.215557	10.4607	15.49471	0.247
India	None	0.298482	19.45833	29.79707	0.4603
	At most 1	0.090786	4.568985	15.49471	0.8527

Notes: *, **, *** indicate statistically significant at 10%, 5%, and 1%, respectively.

3.3. Granger Causality Test

From examining the causal relationship between electric consumption, economic growth, and carbon emissions, the granger causality test was employed. The null hypothesis states there is no Granger causality, and an alternative hypothesis suggests the existence of linear Granger causality. The results are reported in Table 5,

As presented in the table, we obtained interesting findings using the linear Granger causality relationships. In the case of Algeria, we find the unidirectional symmetric causality running from energy consumption to carbon emissions. We also identified a unidirectional linear Granger causality from economic growth to carbon emission in Algeria. Furthermore, energy consumption caused increased carbon emission in the Congolese Democratic Republic economy. For the Congolese Republic economy, a unidirectional symmetric causality relationship from carbon emission to economic growth is confirmed. We can also see that economic growth in Congo Republic Granger causes energy consumption. In Kenya, our results show a unidirectional linear Granger causality running from economic growth to carbon emissions. Based on our analysis, we document that the economic growth Granger causes energy consumption in Nigeria. In the case of Zambia, we find a unidirectional linear causality from carbon emission to economic growth. In the Canadian economy, energy consumption Granger causes economic growth. Our findings also show that energy consumption Granger causes carbon emission and a bidirectional linear Granger causality relationship between economic growth and carbon emission exists in the French economy. Furthermore, economic growth Granger causes energy consumption in France. In respect to Italy, we find the presence of unidirectional causality running from energy consumption to economic growth. Economic growth causes an increase in carbon

emission in the Italian economy, and energy consumption Granger causes economic growth. In India, our results show that energy consumption contributes to carbon emissions. Economic growth Granger causes carbon emissions, and economic growth contributes to increased energy consumption in the Indian economy. This result implies that in India, energy consumption Granger causes economic growth, and economic growth (energy consumption) causes carbon emissions. In Japan, bidirectional symmetric causality relationships exist between energy consumption and carbon emission. We find a unidirectional causality running from economic growth to carbon emissions. Based on our findings, we also report a unidirectional linear Granger causality from carbon emission to economic growth in the UK. Finally, we find a bidirectional linear causality link between energy consumption and economic growth in the American economy. Our results also show that economic growth Granger causes carbon emission in America.

Table 5. Granger causality test results.

Countries	Null Hypothesis	F-Statistic	Prob.	Countries	Null Hypothesis	F-Statistic	Prob.
Algeria	EC → CE	3.73024	0.0334 **	Canada	EC → CE	0.74139	0.4834
	CE → EC	0.08119	0.9222		CE → EC	0.72094	0.493
	EG → CE	3.27775	0.0489 **		EG → CE	1.63525	0.2087
	CE → EG	0.74281	0.4827		CE → EG	0.79083	0.461
	EG → EC	0.23354	0.7929		EG → EC	1.78988	0.1811
	EC → EG	1.6241	0.2108		EC → EG	2.75741	0.0765 *
Cameroon	EC → CE	0.214	0.8083	France	EC → CE	2.77659	0.0752 *
	CE → EC	0.18237	0.834		CE → EC	0.27136	0.7638
	EG → CE	0.60465	0.5516		EG → CE	4.31595	0.0207 **
	CE → EG	0.00533	0.9947		CE → EG	2.66944	0.0826 *
	EG → EC	1.25546	0.2968		EG → EC	3.20115	0.0522 *
	EC → EG	0.48177	0.6215		EC → EG	1.92822	0.1597
Congo Dem Rep	EC → CE	6.24997	0.0046 ***	Italy	EC → CE	3.65751	0.0355 **
	CE → EC	1.23849	0.3016		CE → EC	1.18316	0.3176
	EG → CE	2.20409	0.1246		EG → CE	4.02528	0.0262 **
	CE → EG	0.71053	0.498		CE → EG	1.65053	0.2058
	EG → EC	0.37974	0.6867		EG → EC	0.30598	0.7382
	EC → EG	0.57248	0.569		EC → EG	3.31447	0.0474 **
Congo Rep	EC → CE	0.10508	0.9005	India	EC → CE	6.89505	0.0028 ***
	CE → EC	0.87121	0.4269		CE → EC	1.0526	0.3592
	EG → CE	0.21994	0.8036		EG → CE	4.26296	0.0216 **
	CE → EG	2.83068	0.0718 *		CE → EG	0.50571	0.6072
	EG → EC	4.06945	0.0253 **		EG → EC	3.24986	0.0501 *
	EC → EG	1.62577	0.2105		EC → EG	0.09422	0.9103
Ghana	EC → CE	1.84932	0.1716	Japan	EC → CE	6.9755	0.0027 ***
	CE → EC	1.6038	0.2148		CE → EC	2.86315	0.0698 *
	EG → CE	1.47154	0.2427		EG → CE	2.77791	0.0752 *
	CE → EG	0.17242	0.8423		CE → EG	0.83034	0.4439
	EG → EC	0.22212	0.8019		EG → EC	2.1134	0.1352
	EC → EG	0.82095	0.4479		EC → EG	0.47837	0.6236
Kenya	EC → CE	0.01659	0.9836	UK	EC → CE	1.07729	0.351
	CE → EC	0.78295	0.4645		CE → EC	1.03759	0.3644
	EG → CE	2.93706	0.0655 *		EG → CE	0.20035	0.8193
	CE → EG	0.14195	0.8681		CE → EG	3.51439	0.0401 **
	EG → EC	2.19865	0.1252		EG → EC	0.66932	0.5181
	EC → EG	1.06938	0.3536		EC → EG	1.75129	0.1876
Nigeria	EC → CE	2.22935	0.1219	USA	EC → CE	2.49945	0.0959 *
	CE → EC	2.13579	0.1325		CE → EC	2.56572	0.0905 *
	EG → CE	0.45624	0.6372		EG → CE	4.51722	0.0176 **
	CE → EG	0.40931	0.6671		CE → EG	0.6751	0.5153
	EG → EC	3.04042	0.0599 *		EG → EC	0.84132	0.4392
	EC → EG	0.41647	0.6624		EC → EG	0.2421	0.7862
Zambia	EC → CE	1.10585	0.3416				
	CE → EC	4.43946	0.0187 **				
	EG → CE	0.45031	0.6409				
	CE → EG	1.60523	0.2145				
	EG → EC	0.81827	0.449				
	EC → EG	2.43537	0.1015				

Note: This table shows the linear Granger causality test between economic growth, electric consumption, and carbon emission. → Represents (does not Granger cause) *, **, *** indicate statistically significant at 10%, 5%, and 1%, respectively.

3.4. BDS Test

The BDS test developed by [34] is a nonparametric test initially designed to test identical and independent distribution (*iid*). It is widely used as a general test of model misspecification when applied for residuals from fitted models [35]. Table 6 shows BDS statistical results of economic growth, electric consumption, and carbon emission. The result of the BDS Statistics for Carbon emission, energy consumption, and economic group show a significant nonlinearity trend in all dimensions. This is due to the rejection of the null hypothesis that linear dependencies exist in these variables at a 1% level of significance.

Table 6. BDS Test Result.

Countries	Dimension	CE		EC		EG	
		BDS Statistic	Prob.	BDS Statistic	Prob.	BDS Statistic	Prob.
Algeria	2	0.105003	0.00	0.193952	0.00	0.170057	0.00
	3	0.199553	0.00	0.331602	0.00	0.284167	0.00
	4	0.260678	0.00	0.427578	0.00	0.353515	0.00
	5	0.297169	0.00	0.499455	0.00	0.399866	0.00
	6	0.321721	0.00	0.555203	0.00	0.428102	0.00
Cameroon	2	0.107452	0.00	0.128301	0.00	0.181131	0.00
	3	0.175527	0.00	0.202189	0.00	0.304475	0.00
	4	0.200206	0.00	0.236603	0.00	0.398374	0.00
	5	0.225961	0.00	0.235713	0.00	0.45754	0.00
	6	0.229277	0.00	0.215287	0.00	0.502727	0.00
Congo Dem Rep	2	0.162146	0.00	0.156763	0.00	0.101517	0.00
	3	0.282315	0.00	0.2707	0.00	0.173873	0.00
	4	0.35722	0.00	0.345889	0.00	0.211222	0.00
	5	0.403951	0.00	0.386062	0.00	0.220255	0.00
	6	0.43287	0.00	0.403532	0.00	0.20939	0.00
Congo Rep	2	0.055223	0.00	0.143762	0.00	0.155829	0.00
	3	0.059604	0.00	0.238804	0.00	0.249817	0.00
	4	0.069555	0.00	0.291545	0.00	0.306989	0.00
	5	0.099616	0.00	0.334446	0.00	0.32828	0.00
	6	0.113852	0.00	0.355971	0.00	0.350033	0.00
Ghana	2	0.076573	0.00	0.024998	0.0002	0.158845	0.00
	3	0.109389	0.00	0.045023	0.0014	0.248843	0.00
	4	0.130795	0.00	0.066833	0.0025	0.290209	0.00
	5	0.164108	0.00	0.086105	0.0047	0.294131	0.00
	6	0.171535	0.00	0.102613	0.008	0.260864	0.00
Kenya	2	0.086154	0.00	0.169199	0.00	0.164273	0.00
	3	0.142116	0.00	0.283358	0.00	0.258597	0.00
	4	0.164537	0.00	0.366134	0.00	0.304532	0.00
	5	0.179836	0.00	0.422513	0.00	0.326773	0.00
	6	0.186924	0.00	0.459999	0.00	0.320852	0.00
Nigeria	2	0.114579	0.00	0.161318	0.00	0.141255	0.00
	3	0.196433	0.00	0.270383	0.00	0.221377	0.00
	4	0.239216	0.00	0.336179	0.00	0.25643	0.00
	5	0.259247	0.00	0.377794	0.00	0.263086	0.00
	6	0.254886	0.00	0.40926	0.00	0.247394	0.00
Zambia	2	0.200475	0.00	0.178221	0.00	0.147771	0.00
	3	0.343935	0.00	0.306271	0.00	0.225614	0.00
	4	0.445896	0.00	0.39345	0.00	0.254843	0.00
	5	0.514128	0.00	0.44653	0.00	0.245413	0.00
	6	0.558996	0.00	0.479374	0.00	0.201134	0.00
Canada	2	0.080204	0.00	0.206258	0.00	0.199779	0.00
	3	0.103005	0.00	0.3539	0.00	0.336459	0.00
	4	0.084996	0.00	0.457202	0.00	0.431374	0.00
	5	0.078235	0.00	0.525923	0.00	0.497456	0.00
	6	0.068592	0.00	0.56914	0.00	0.547155	0.00
France	2	0.163412	0.00	0.204949	0.00	0.196726	0.00
	3	0.289459	0.00	0.350851	0.00	0.331367	0.00
	4	0.380143	0.00	0.45149	0.00	0.423886	0.00
	5	0.4408	0.00	0.522092	0.00	0.487027	0.00
	6	0.485373	0.00	0.569992	0.00	0.532607	0.00

Table 6. *Cont.*

Countries	Dimension	CE		EC		EG	
		BDS Statistic	**Prob.**	**BDS Statistic**	**Prob.**	**BDS Statistic**	**Prob.**
	2	0.189838	0.00	0.202638	0.00	0.170306	0.00
	3	0.321817	0.00	0.341536	0.00	0.27571	0.00
India	4	0.412688	0.00	0.439773	0.00	0.336546	0.00
	5	0.480644	0.00	0.511783	0.00	0.363189	0.00
	6	0.531615	0.00	0.565432	0.00	0.362527	0.00
	2	0.124107	0.00	0.205388	0.00	0.198287	0.00
	3	0.199055	0.00	0.347467	0.00	0.337188	0.00
Italy	4	0.255769	0.00	0.445715	0.00	0.432288	0.00
	5	0.304765	0.00	0.513719	0.00	0.49981	0.00
	6	0.348158	0.00	0.561999	0.00	0.548191	0.00
	2	0.130974	0.00	0.20226	0.00	0.19826	0.00
	3	0.214075	0.00	0.342598	0.00	0.332145	0.00
Japan	4	0.279849	0.00	0.438075	0.00	0.423417	0.00
	5	0.328569	0.00	0.502306	0.00	0.485776	0.00
	6	0.360967	0.00	0.547246	0.00	0.532357	0.00
	2	0.136697	0.00	0.182075	0.00	0.192947	0.00
	3	0.209694	0.00	0.313775	0.00	0.329044	0.00
UK	4	0.240209	0.00	0.403705	0.00	0.422667	0.00
	5	0.226817	0.00	0.456634	0.00	0.488736	0.00
	6	0.231836	0.00	0.487238	0.00	0.537163	0.00
	2	0.108404	0.00	0.196528	0.00	0.207598	0.00
	3	0.157763	0.00	0.336914	0.00	0.352866	0.00
USA	4	0.174652	0.00	0.43523	0.00	0.454769	0.00
	5	0.174586	0.00	0.498253	0.00	0.527503	0.00
	6	0.186507	0.00	0.540499	0.00	0.579837	0.00

Note: This table shows BDS statistical results for economic growth, electric consumption, and carbon emission.

3.5. NARDL Estimated Result

We proceeded to analyze the existence of cointegration by using critical statistic values to determine if variables are affected by each other in the long run at different significant levels. Here a nonlinear long-run relationship between electric consumption, economic growth, and carbon emission was tested using the t_{BDM}-statistics developed by [31] and F-test proposed by [26]. The results are displayed in Table 7.

Table 7. Cointegration test results.

Countries	NARDL Model	
	FPSS Nonlinear	***t* BDM**
Algeria	1.484	−2.596
Cameroon	3.4408	−3.3761 *
Congo Dem Rep	2.2482	−2.82
Congo Rep	4.9467 **	−3.443 *
Ghana	3.1382	−2.6191
Kenya	2.0282	−2.0245
Nigeria	2.6851	−1.2945
Zambia	5.8399 **	−1.6406
Canada	3.8426	−4.1233 ***
France	1.3881	−2.0747
India	2.2959	−2.4902
Italy	2.9466	−0.2466
Japan	2.4658	−0.7259
UK	3.3391	−3.811 **
USA	1.0729	−1.0617

*, **, *** indicate statistically significant at 10%, 5%, and 1%, respectively. tBDM statistics for 10% are (−2.57/−3.21), for 5% are (−2.86/−3.53), and for 1% (−3.43/−4.10) significance level these values were obtained from [26] table CII(iii) number 2 page number 303. Furthermore, the values for F-PSS statistics for 10% are (3.17/4.14), for 5%(3.79/4.85), and 1% (5.15/6.36) significance level, these values too were also obtained from [26] table CI(iii) number 2 page 300.

In the results, we report that the null hypothesis of no cointegration is rejected in the case of the Congo Republic, Zambia, Canada, UK, and Cameroon at the usual significant levels for these countries. It implies that it is significant to study a long run asymmetrical relationship over the long term in these countries.

3.6. Diagnostic Tests

Table 8 shows the results of the diagnostic checking in terms of Serial correlation (SC), Heteroscedasticity (HT), Functional Form (FF), and Jarque–Bera (JB) generated by estimating the cointegration relationship. All of the variables satisfy the statistical requirements, which are the absence of serial correlation (*SC*) and White heteroscedasticity (*HT*), and the Ramsey test (*FF*) shows the model suffers from no misspecification at a 5% level of statistical significance.

Table 8. Diagnostic checking result.

Countries	Diagnostics	*t*-Statistics	Countries	Diagnostics	*t*-Statistics
Algeria	SC	19.45 (0.3648)	Canada	SC	19.7 (0.3499)
	HT	0.5752 (0.4482)		HT	0.42 (0.517)
	FF	0.5179 (0.675)		FF	0.4713 (0.7071)
	JB	0.9748 (0.6142)		JB	2.415 (0.2989)
Cameroon	SC	16.59 (0.4824)	France	SC	14.38 (0.7613)
	HT	1.303 (0.2537)		HT	1.25 (0.2635)
	FF	4.825 (0.0813)		FF	0.341 (0.7959)
	JB	1.303 (0.5213)		JB	1.568 (0.4566)
Congo Dem Rep	SC	11.5 (0.9058)	India	SC	11.24 (0.8838)
	HT	0.5148 (0.4731)		HT	0.1308 (0.7176)
	FF	1.268 (0.3076)		FF	0.4375 (0.7287)
	JB	3.927 (0.1404)		JB	0.342 (0.8428)
Congo Rep	SC	18.8 (0.3353)	Italy	SC	23.74 (0.1636)
	HT	1.25 (0.2635)		HT	0.3765 (0.5395)
	FF	3.592 (0.0592)		FF	0.5003 (0.6881)
	JB	0.5108 (0.7746)		JB	0.01372 (0.9932)
Ghana	SC	17.5 (0.5561)	Japan	SC	17.54 (0.4866)
	HT	0.6912 (0.4057)		HT	2.095 (0.1478)
	FF	0.7177 (0.5511)		FF	0.01084 (0.9984)
	JB	0.1825 (0.9128)		JB	1.713 (0.4246)
Kenya	SC	16.15 (0.513)	UK	SC	17.51 (0.5552)
	HT	0.2476 (0.6187)		HT	0.5324 (0.4656)
	FF	1.506 (0.27)		FF	1.84 (0.1668)
	JB	1.421 (0.4914)		JB	0.01132 (0.9944)
Nigeria	SC	17.3 (0.5026)	America	SC	12.06 (0.7964)
	HT	0.5741 (0.4486)		HT	0.2597 (0.6103)
	FF	1.542 (0.2362)		FF	1.391 (0.3476)
	JB	1.67 (0.4339)		JB	1.565 (0.4573)
Zambia	SC	21.13 (0.2204)			
	HT	1.263 (0.2611)			
	FF	0.8364 (0.5401)			
	JB	2.531 (0.2822)			

Notes: This table reports the diagnostic checking results. The numbers in parentheses represent *p*-values.

3.7. Wald Statistics

Short- and long-run asymmetric effects are reported in Table 9. This table shows symmetry and asymmetry restrictions in the long- and short-run relationships between economic growth, electric consumption, and carbon emissions. WLR-E denotes Wald statistics for long-run symmetry, and WSR-E denotes Wald statistics for short-run symmetry. Numbers in parentheses are the *p*-values.

Table 9. Results for symmetry and asymmetry restrictions.

Countries	Wald Statistics	EC	EG
Cameroon	WLR-E	23.42 (0.002) ***	20.22 (0.003) ***
	WSR-E	1.717 (0.231)	1.889 (0.212)
Congo Rep	WLR-E	0.1894 (0.671)	0.5281 (0.481)
	WSR-E	0.1184 (0.737)	9.392 (0.01) **
Zambia	WLR-E	0.3459 (0.575)	0.2628 (0.624)
	WSR-E	1.585 (0.248)	2.357 (0.169)
Canada	WLR-E	5.377 (0.033) **	12.05 (0.003) ***
	WSR-E	0.1241 (0.729)	0.4578 (0.508)
UK	WLR-E	0.5955 (0.447)	1.79 (0.192)
	WSR-E	2.562 (0.121)	3.887 (0.059) *

Notes: *, **, *** indicate statistically significant at 10%, 5%, and 1%, respectively.

Further, the test for asymmetry in the short-run and long-run relationship for all the countries was conducted to determine which countries are significantly asymmetric. The short-run and long-run asymmetries with the Wald restriction by imposing WSR: $\alpha = \alpha 1^+ + \alpha 2^-$ and WLR: $\theta i^+ = \theta i^- = \theta$. Table 9 reports the Wald statistics for the test of the short-run and long-run symmetry between economic growth, electric consumption, and carbon emission.

The results of the Wald test under the validity of nonlinear cointegration relationship, an asymmetric long-run relationship between electricity consumption, economic growth, and carbon emission was confirmed for Cameroon and Canada. Furthermore, we confirm an asymmetric short-run relationship between economic growth and carbon emission in the case of Congo Republic and the UK.

Table 10 clearly shows the distribution of asymmetric and symmetric relationships between electricity consumption, economic growth, and carbon emission based on the Wald statistics presented in Table 9 above. From the table, it can be seen that for very few countries, an asymmetric relationship between energy consumption, economic growth, and carbon emission, can be identified. This implies that the relationship between these variables across our sample is mostly symmetric.

Table 10. Distribution of symmetric and asymmetric relationships.

Countries	EC		EG	
	Long	Short	Long	Short
Cameroon	A	S	A	S
Congo Rep	S	S	S	A
Zambia	S	S	S	S
Canada	A	S	A	S
UK	S	S	S	A

Notes: This table summarizes asymmetric and symmetric relationships represented as A and S, respectively.

The dynamic asymmetric relationship between the given variables was further enriched by plotting the multipliers effects. These dynamic multipliers (see Figures A1–A10 in the Appendix A) show the adjustments of energy consumption and economic growth to a unit shock in carbon emission to its new long-run equilibrium following a positive or negative unitary shock in the 44 years. The positive (dashed green line) and negative (dashed red line) change curves describe the adjustment of energy consumption and economic growth to a positive and negative effect of multipliers to shocks in the 44-year carbon emissions at a given forecast horizon. The asymmetry line (continuous blue line) reflects the difference between the positive and negative effects multipliers to shocks in the 44-year energy consumption and economic growth.

3.8. Asymmetric Causality Result

Result of the short- and long-run asymmetric result were proposed by Diks and Panchenko. Table 11 shows the linear Granger causality test between economic growth, electric consumption, and carbon emission.

Table 11. Nonlinear Granger causality test.

Country	Null Hypothesis	Test Statistics	p-value	Causality	Country	Null Hypothesis	Test Statistics	p-value	Causality
Algeria	CE→EC	1.297	0.90272	No Causality	America	CE→EC	0.08	0.46792	No Causality
	EC→CE	1	0.15864	No Causality		EC→CE	1.091	0.13773	No Causality
	CE→EG	1.078	0.85958	No Causality		CE→EG	0.741	0.7708	No Causality
	EG→CE	1.15	0.12498	No Causality		EG→CE	1.169	0.12115	No Causality
	EC→EG	1.019	0.84601	No Causality		EC→EG	0.75	0.22651	No Causality
	EG→EC	0.615	0.26937	No Causality		EG→EC	0.777	0.22651	No Causality
Cameroon	CE→EC	0.654	0.25645	No Causality	Canada	CE→EC	0.932	0.82433	No Causality
	EC→CE	1.253	0.89487	No Causality		EC→CE	1.094	0.13707	No Causality
	CE→EG	1.308	0.90464	No Causality		CE→EG	1.295	0.90237	No Causality
	EG→CE	1.533	0.93736	No Causality		EG→CE	0.809	0.20929	No Causality
	EC→EG	1.112	0.13315	No Causality		EC→EG	0.913	0.18057	No Causality
	EG→EC	0.7	0.2421	No Causality		EG→EC	0.856	0.80411	No Causality
Congo Dem Rep	CE→EC	1.407	0.07976 *	Causality	France	CE→EC	0.701	0.75848	No Causality
	EC→CE	1.473	0.07036 *	Causality		EC→CE	1.054	0.14586	No Causality
	CE→EG	0.076	0.46961	No Causality		CE→EG	1.099	0.1358	No Causality
	EG→CE	0.591	0.27738	No Causality		EG→CE	0.808	0.20952	No Causality
	EC→EG	0.395	0.65362	No Causality		EC→EG	1.233	0.10883	No Causality
	EG→EC	0.287	0.38698	No Causality		EG→EC	0.621	0.26728	No Causality
Congo Rep	CE→EC	0.747	0.2274	No Causality	Italy	CE→EC	1.105	0.86535	No Causality
	EC→CE	1.952	0.02546 **	Causality		EC→CE	1.358	0.08725 *	Causality
	CE→EG	0.259	0.39778	No Causality		CE→EG	0.869	0.19249	No Causality
	EG→CE	0.966	0.16693	No Causality		EG→CE	0.639	0.26127	No Causality
	EC→EG	0.876	0.80953	No Causality		EC→EG	0.965	0.16735	No Causality
	EG→EC	1.867	0.03098 **	Causality		EG→EC	0.745	0.22809	No Causality
Ghana	CE→EC	0.113	0.45501	No Causality	Japan	CE→EC	1.362	0.91344	No Causality
	EC→CE	1.167	0.12154	No Causality		EC→CE	1.652	0.04925 **	Causality
	CE→EG	0.526	0.29934	No Causality		CE→EG	0.939	0.1739	No Causality
	EG→CE	1.083	0.13935	No Causality		EG→CE	1.613	0.05342 *	Causality
	EC→EG	0.954	0.16998	No Causality		EC→EG	0.745	0.22828	No Causality
	EG→EC	0.739	0.77004	No Causality		EG→EC	1.384	0.08313 *	Causality
Kenya	CE→EC	0.057	0.47716	No Causality	India	CE→EC	0.747	0.22757	No Causality
	EC→CE	1.381	0.0836 *	Causality		EC→CE	1.231	0.10916	No Causality
	CE→EG	1.208	0.88656	No Causality		CE→EG	0.828	0.20392	No Causality
	EG→CE	1.086	0.13882	No Causality		EG→CE	1.161	0.12275	No Causality
	EC→EG	0.982	0.16298	No Causality		EC→EG	0.828	0.20377	No Causality
	EG→EC	1.264	0.10315	No Causality		EG→EC	0.825	0.20463	No Causality
Nigeria	CE→EC	0.845	0.80089	No Causality	UK	CE→EC	1.144	0.12631	No Causality
	EC→CE	1.694	0.04509 **	Causality		EC→CE	1.403	0.08033 *	Causality
	CE→EG	1.124	0.13044	No Causality		CE→EG	1.099	0.86422	No Causality
	EG→CE	0.164	0.43472	No Causality		EG→CE	1.62	0.05257 *	Causality
	EC→EG	0.189	0.57493	No Causality		EC→EG	0.893	0.18586	No Causality
	EG→EC	0.037	0.51462	No Causality		EG→EC	0.762	0.22293	No Causality
Zambia	CE→EC	0.244	0.59628	No Causality					
	EC→CE	1.898	0.02882 **	Causality					
	CE→EG	0.06	0.52381	No Causality					
	EG→CE	1.113	0.86705	No Causality					
	EC→EG	0.314	0.62331	No Causality					
	EG→EC	1.086	0.86124	No Causality					

Note: → Represents (does not Granger cause) *, **, *** indicate statistically significant at 10%, 5%, and 1%, respectively.

The findings are exciting and slightly different compared with the conventional Granger test results from Table 11. In the Congo Democratic Republic, we observe a bidirectional asymmetric causality relationship that exists between carbon emission and energy consumption. While in the case of the Congo Republic, we find a unidirectional causality running from energy consumption to carbon emission. We can also see that economic growth contributes to increased energy consumption in the Congo Republic. In the case of Kenya, we have a unidirectional nonlinear Granger causality from energy consumption to carbon emission. Subsequently, our result also shows a unidirectional asymmetric causality running from energy consumption to carbon emission in Nigeria. In the Zambian economy, our findings also show that energy consumption Granger causes carbon emission. Additionally, in Italy, we find the unidirectional asymmetric causality running from energy consumption to carbon emission. Based on our analysis, we document that energy consumption Granger causes carbon emissions in Japan. We find the presence of a unidirectional causality relationship from economic growth to carbon emission in Japan. Furthermore, our results in Japan show a unidirectional linear Granger causality running from economic growth to energy consumption. Finally, we also identified a unidirectional nonlinear Granger causality from energy

consumption to carbon emissions and economic growth that contributes to increased carbon emission in the UK economy.

4. Discussion

The results presented in the previous section can be used for electricity consumption and economic growth policy analysis across Canada, France, Italy, Japan, UK, USA, India, Algeria, Cameroon, Congo Democratic Republic, Congo Republic, Ghana, Kenya, Nigeria, and Zambia. Furthermore, comparing the results of previous literature and existing studies could assist researchers in understanding whether the asymmetry matters in modelling the consumption–growth–emission nexus.

Results show a nonlinear cointegration between electric consumption, economic growth, and carbon emission in Congo Republic, Zambia, Canada, Cameroon, and the UK at the usual significant levels for these countries.

In terms of the asymmetric and symmetric relationships between variables, the findings are quite diverse. Results from Tables 9 and 10 show evidence of a long-run asymmetric link between energy consumption, economic growth, and carbon emission in Cameroon and Canada, which is in line with [36–38] who found an asymmetric nexus between energy consumption, economic growth, and carbon emission. Additionally, a short-run asymmetric relationship between economic growth and carbon emission in the Congo Republic and the UK was confirmed.

The results from our nonlinear granger causality tend to be volatile across countries. The nonlinear granger causality test in Table 11 shows that there is bidirectional Granger causality from electric consumption to carbon emission in the Congo Democratic Republic. In the Congo Republic, Kenya, Nigeria, Zambia, Italy, Japan, and the UK, electric consumption Granger causes carbon emissions. In Japan and the UK, the results reveal a unidirectional causality running from economic growth to carbon emission consistent with the results of [22] who reported a unidirectional causality between economic growth and carbon emission in Japan. A unidirectional causality is running from economic growth to electric consumption in the Congo Republic and Japan. From our findings, Congo Republic and Japan governments should search for energy exploration policies to sustain economic growth in the long run as energy consumption boosts economic growth. Local and foreign investors are encouraged to adopt green energy while producing more output. Additionally, the unidirectional causality running from economic growth to carbon emission in Japan and UK implies that economic growth is accompanied by carbon emission; this finding is consistent with [39] who report that economic expansion increases carbon emission. This means introducing environmentally friendly policies should be encouraged to reduce carbon emissions. The feedback effect between electricity consumption and carbon emission is an indication that electric consumption in Congo Democratic Republic, Congo Republic, Kenya Nigeria, Zambia, Italy, Japan, and the UK have intensified carbon emission. It confirmed that there is no causal relationship between economic growth and electric consumption, suggesting that energy policies insignificantly affect electric consumption. The neutral effect of economic growth on electric consumption in the Congo Democratic Republic means that the economic plan will not be affected by the electric consumption because economic growth has little or no role to play in enhancing electric consumption. Finally, energy conservation policy implementation to reduce carbon emission cannot hurt economic growth in Algeria, Cameroon, Ghana, Canada, USA, France, and India. These economies have no causality found between electric consumption, economic group, and carbon emission. Therefore, it implies that electric consumption and economic growth have a minimal role to play in increasing CO_2 emissions.

5. Conclusions

This paper analyzed the relationship between electric consumption, economic growth, and carbon emission for 15 countries. The empirical results are mixed across countries. To examine the short-run and long-run relationships between electric consumption, economic growth, and carbon emission over the period 1971-2014, the nonlinear ARDL model procedure proposed by [29] and the asymmetric

causality approach developed by [27] were used to this end. Results from the NARDL bounds test estimation confirm the cointegration between electricity consumption, economic growth, and carbon emission in Cameroon, Congo Republic, Zambia, Canada, and the UK. In the case of symmetric and asymmetric causal hypotheses and relationships, the long-run results show the asymmetric relationship between electricity consumption, economic growth, and carbon emission in Cameroon and Canada, while the short-run asymmetric relationship was identified in the Congo Republic and the UK. Therefore, future attempts on this issue should consider the symmetric linkage between the variables and choose an empirical methodology accordingly. This study was limited to 15 countries made up of six of the G7 countries and eight selected African counties in addition to India. Future studies can explore the possible asymmetric relationship between energy consumption, economic growth, and carbon emission in other top global carbon dioxide emitters such as China, Russia, Germany, Iran, and Saudi Arabia.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Cameroon
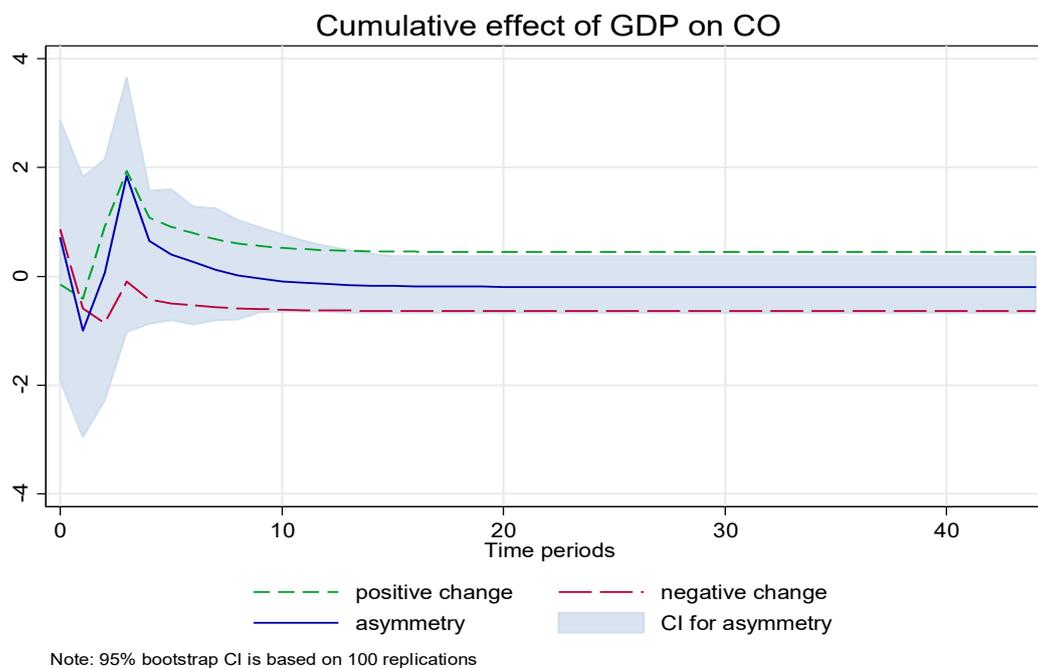
Figure A1. Cumulative effect of GDP on CO.
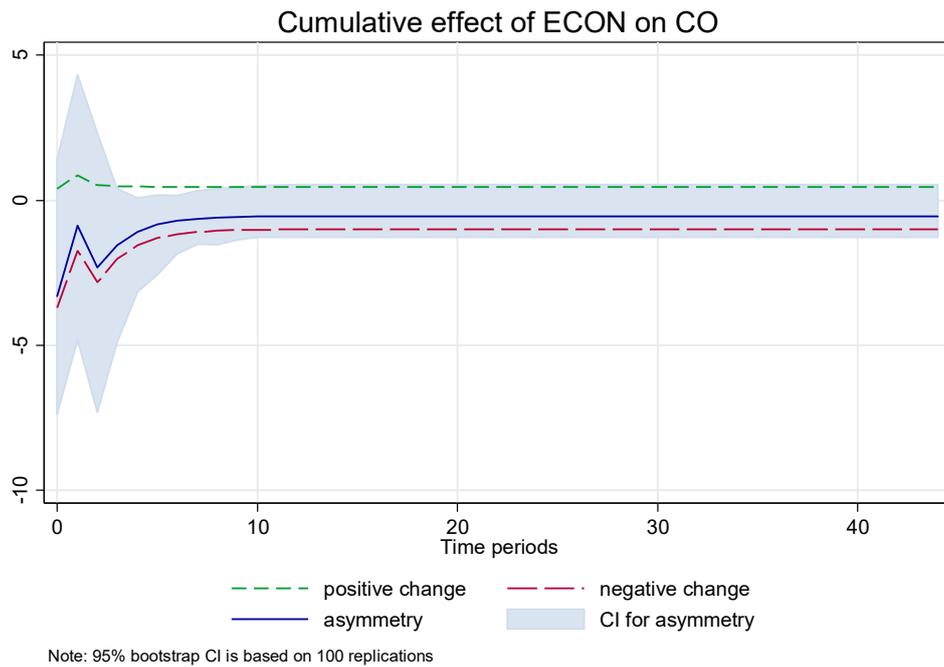
Figure A2. Cumulative effect of ECON on CO.

Canada
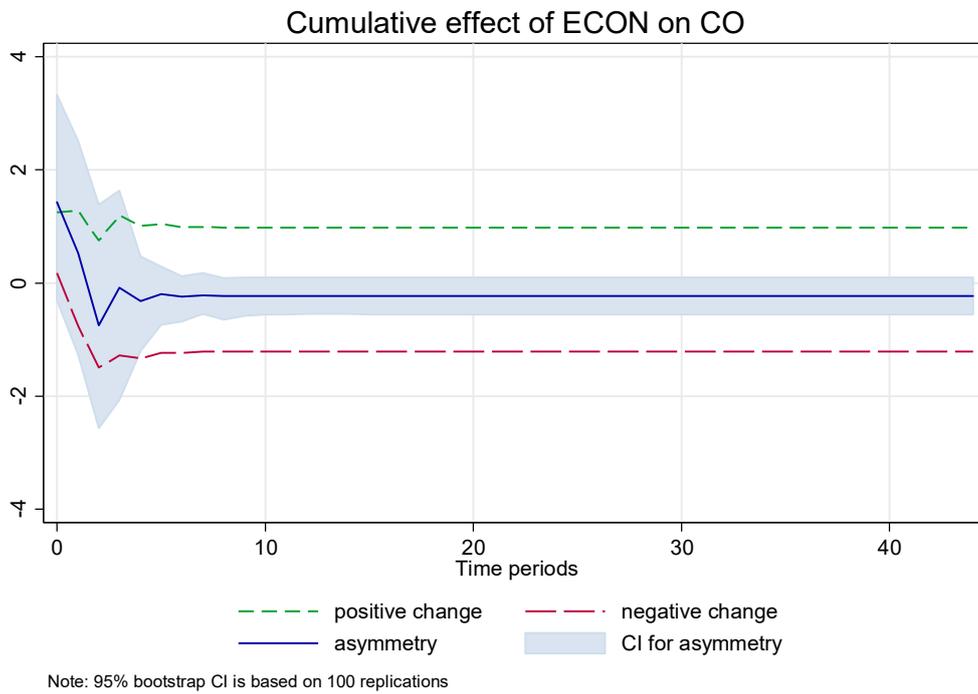
Figure A3. Cumulative effect of ECON on CO.
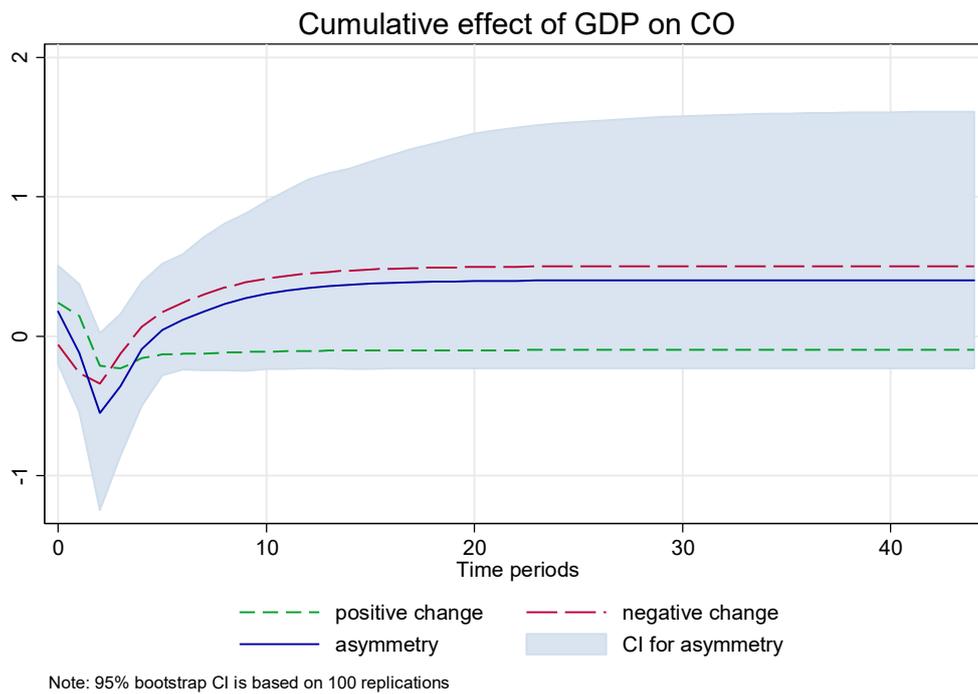
Figure A4. Cumulative effect of GDP on CO.

Congo Republic
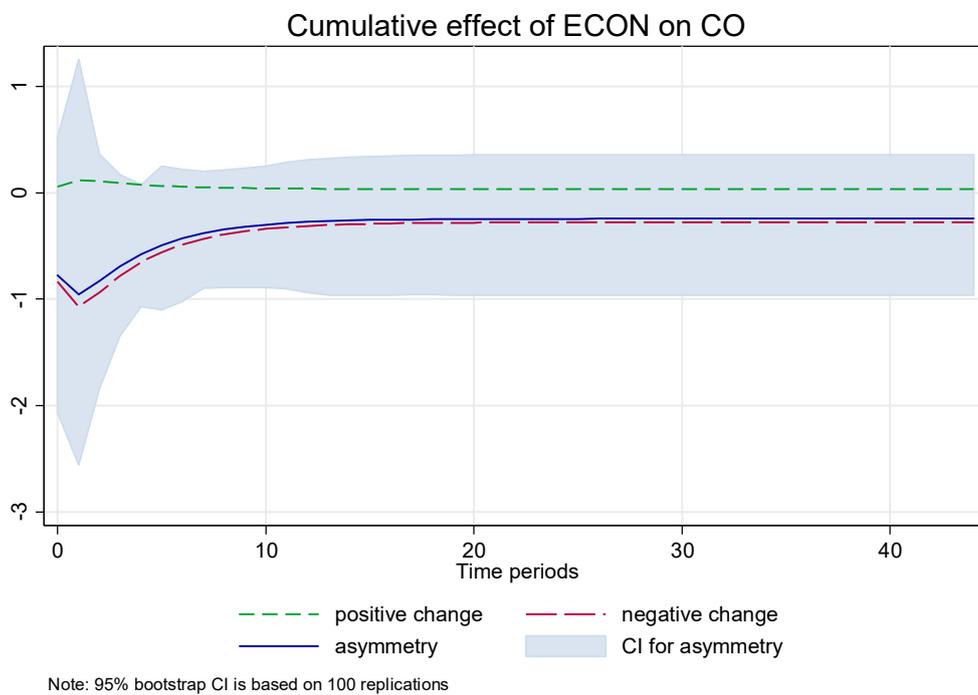
Figure A5. Cumulative effect of ECON on CO.
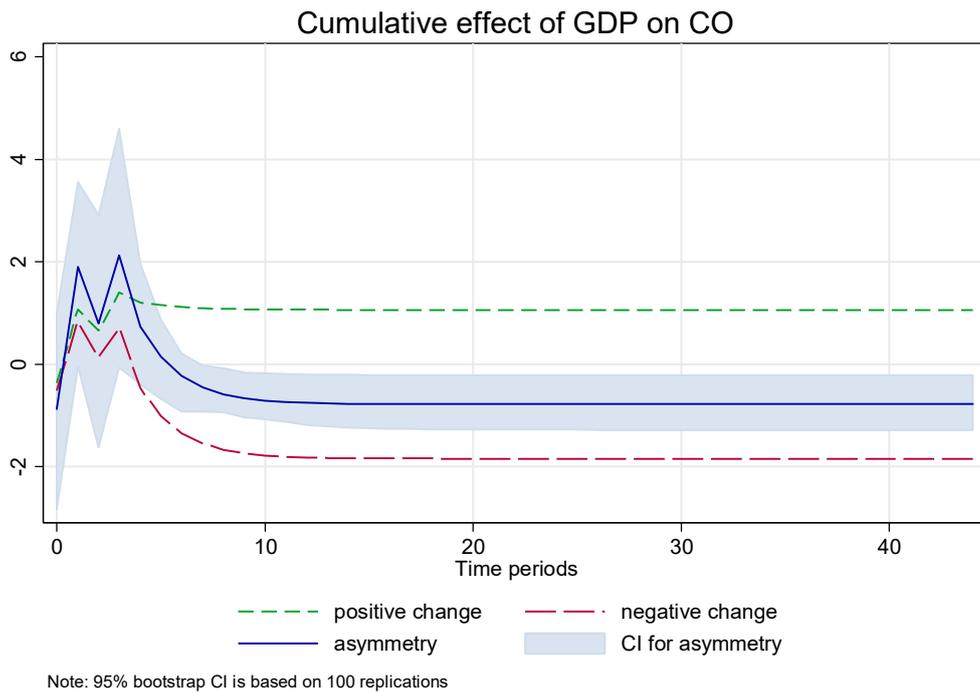
Figure A6. Cumulative effect of GDP on CO.

Zambia
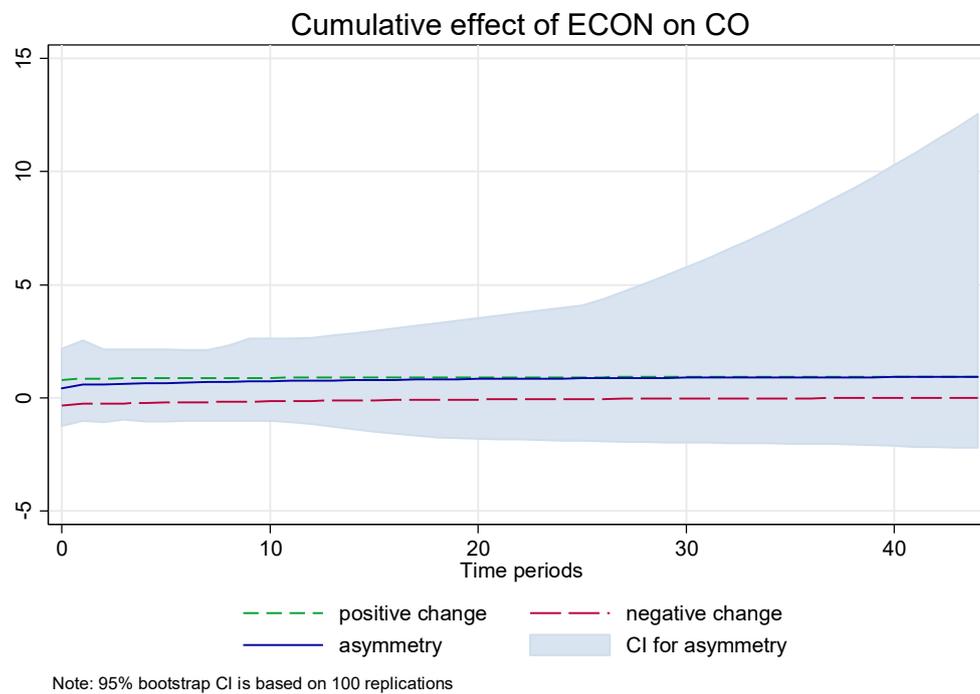
Figure A7. Cumulative effect of ECON on CO.
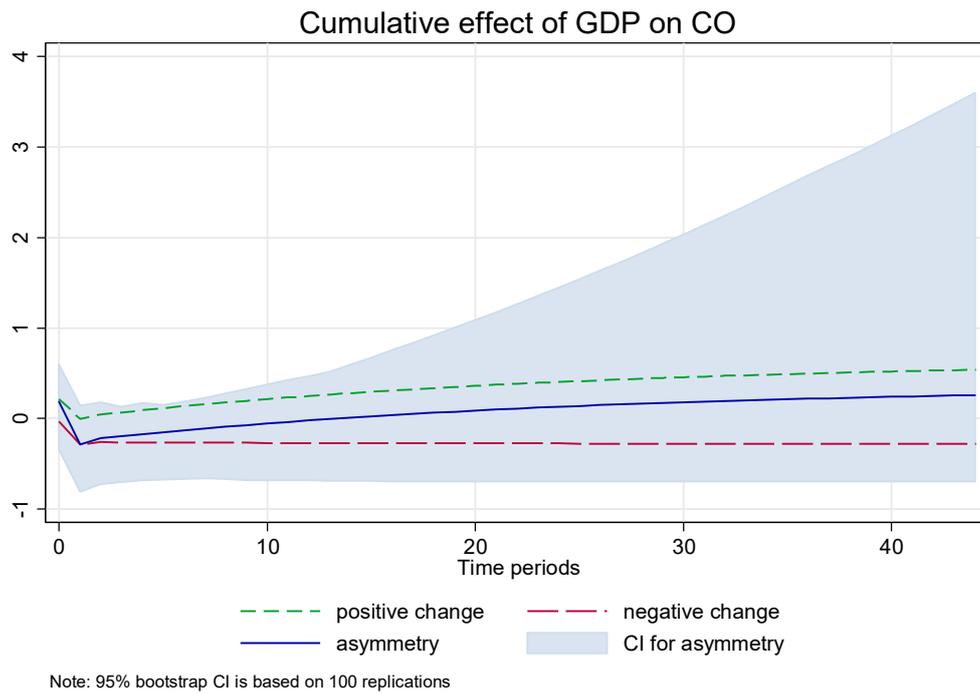
Figure A8. Cumulative effect of GDP on CO.

UK
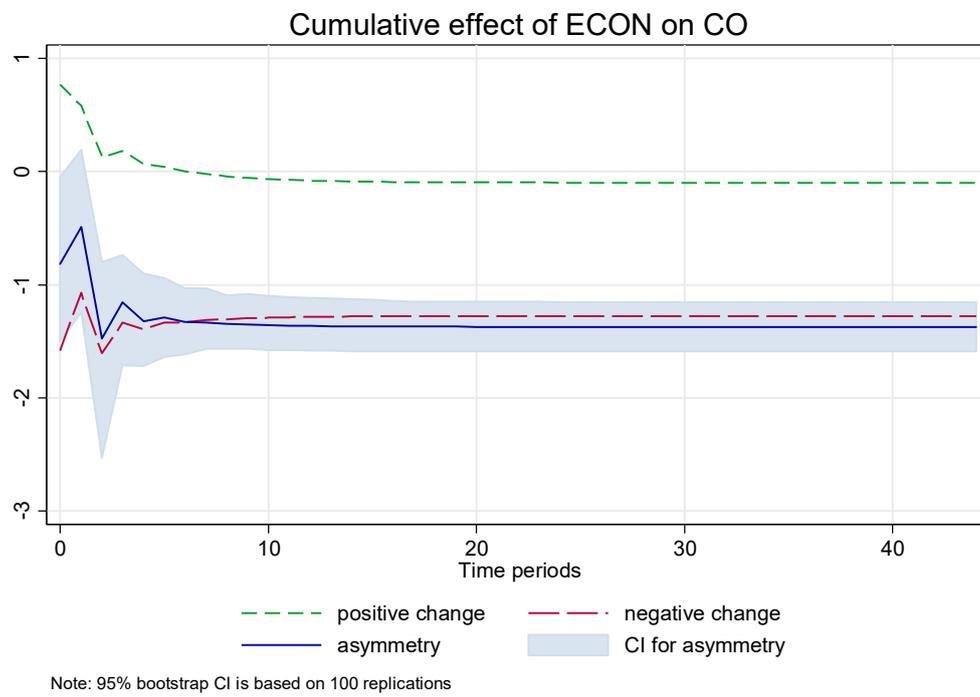
Figure A9. Cumulative effect of ECON on CO.
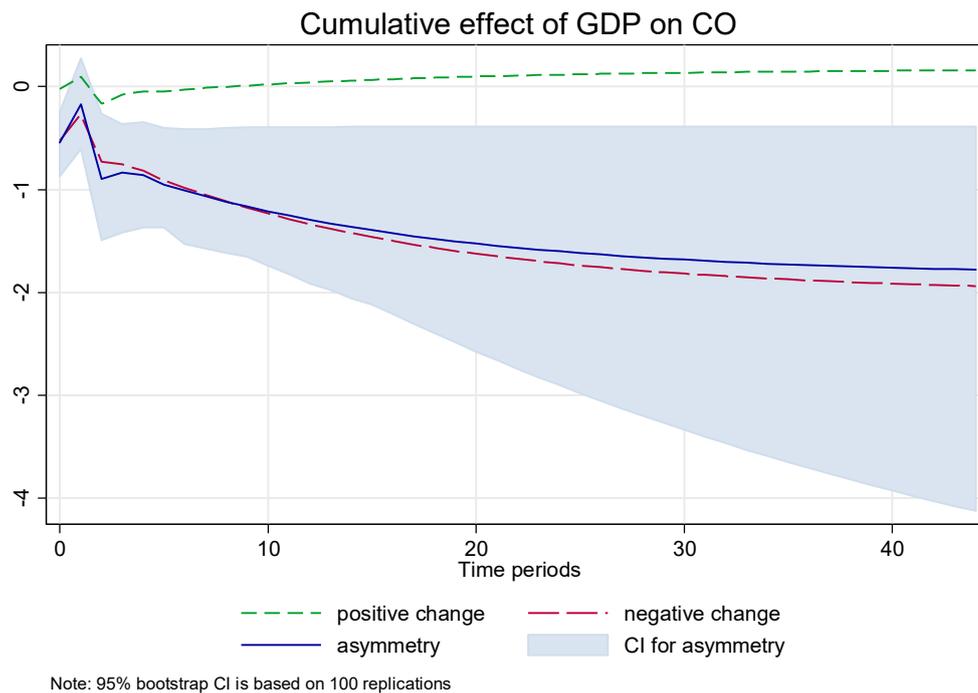
Figure A10. Cumulative effect of GDP on CO.

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