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Investigating the Asymmetric Effect of Economic Growth on Environmental Quality in the Next 11 Countries

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Abstract: This study investigates the asymmetric cointegration and causal relationships between economic growth, carbon emissions, and energy consumption in the next eleven (11) countries over the period 1972–2013. The nonlinear autoregressive distributed lag (NARDL) bounds testing approach and nonpragmatic Granger causality tests are employed. This research's empirical results have entrenched vital relationships that have significant policy implications. We affirm nonlinear cointegration among the variables in Bangladesh, Iran, Turkey, and Vietnam. The long-run asymmetric effect outcomes indicate a definite boom in economic growth, significantly increases carbon emission in Turkey, and a decline in Vietnam. Additionally, a positive shock to energy consumption significantly increases the carbon emission in Bangladesh, Iran, and Turkey, but a decrease in emissions in Vietnam. Findings from the Wald test reveal a long-run asymmetric effect between carbon emission and economic growth in Bangladesh, Iran, and Vietnam, and for Iran, an asymmetric short-run impact. Long-run and short-run asymmetric effects between carbon emission and energy consumption in Bangladesh and Iran. In terms of asymmetric causality results, bidirectional causality between carbon emission and economic growth was noted in Bangladesh and Turkey, and a unidirectional causality from economic growth to carbon emission in Egypt and South Korea. Energy consumption causes carbon emission in Bangladesh, Egypt, Pakistan, South Korea, and not vice versa. We determined a bidirectional asymmetric causality relationship between carbon emission and energy consumption in Vietnam and a unidirectional causality link from carbon emissions to Turkey's energy consumption.

Keywords: economic growth; energy consumption; carbon emission; asymmetric relationship; next 11 countries

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1. Introduction

Globalization, which has been the hallmark of this current era, has had an unprecedented political, social, cultural, and economic impact on the world. It has led to some form of competition among developed and developing countries alike as they try to economically outperform each other since economic growth is deemed the penultimate goal by policymakers for sustainable development. Moreover, third world economies are frantically trying to induce human capital formation and economic activities while maintaining their comparative advantage in the globalized world. According to [1], the combination of labor, capital resources, other production inputs, and mainly human activities are responsible for growth globally. However, it is prudent to add that greenhouse gas (GHG) emissions have been on the ascending as a result of industrial growth in both first and third world countries. Notably, carbon emissions contribute to a more significant portion of GHG's, which are more probably linked to climate change [2–4]. Moreover, the concentration of CO_2 emission has increased by 45% in the past 130 years [5].

It is widely known in economic circles that sustainable development is a prerequisite to liberate an economy from backwardness, reducing poverty and instigating growth and development. Therefore, developing countries in the 21st century are embarking on aggressive economic growth and urbanization. The surge in their demand for energy and its consumption in recent years, however, can never go unnoticed. If the role machines played in the transition to new manufacturing processes in Europe and the United States was considered the game-changer during the industrial revolution, then energy was its driving force. Energy is an indispensable factor of production [6]. In this perspective, it is essential to note that, despite economic growth in developing countries is on the ascendance, its toll on natural resources and contribution to greenhouse gasses is alarming. All production categorically involves the conversion or metamorphosis of matter in some way using energy. Energy as a factor of production must be integrated into materials, machines, and the people who work them to be made useful; this provides the biophysical justification for treating capital, labor, and others as factors of production [7]. This proposes the efficient use of energy (i.e., the renewable or nonrenewable form). It is essential in the sense that carbon dioxide (CO_2) emission, which goes hand in hand with increasing energy consumption, has an irreversible adverse impact on the environment if allowed to go unchecked. Furthermore, the Intergovernmental Panel on Climate Change [8] anticipated that GHG emissions would increase from 25% to 90% increased and energy-related CO_2 emissions by 40–110% by the year 2030. The intricacies surrounding energy use and economic growth and their effects on carbon emissions have been unfolding into a severe topic among researchers [9,10].

To some extent, economic growth exerts pressure on environmental quality as boosting economic growth sabotage efforts aimed at either maintaining or improving environmental quality. The connection between economic growth, environmental quality, and energy consumption and how these entities affect one another has presented a challenging but intriguing topic of extensive academic research in energy economics literature [11] and [12]. As economies worldwide continue to strive to greater heights to the detriment of environmental quality, its impact on human life is alarming. For instance, an estimated 7,000,000 carbon emissions related deaths are recorded worldwide [13]. Interestingly, it has been uncovered that as much energy creation is imperative for industrialization in rising economies, for example, Africa; it has, however, shown many difficulties like air pollution [14]. The Intergovernmental Panel on Climate Change [15] asserted that, out of the numerous contributors to GHG, CO_2 accounts for an estimated 76.7%, signaling the immense devastation effect CO_2 will have on human life if allowed to go on unchecked. According to the International Energy Agency [16], to guard human life and wellbeing against profound climate change, an objective was developed under the Kyoto protocol in 1997. This was to lessen greenhouse gas emissions in advanced nations to 5.2% at some stage between 2008 and 2012. Nevertheless, the Kyoto Protocol was revised at the 2012 United Nations' Climate Change Conference to be prolonged to the year 2020 [17,18].

Under the weight of directing environmental change, developing countries are confronted with an impasse of reducing GHG emissions and energy consumption or boosting economic growth [19–22] have indicated that if actions to resolve the issue of environmental change as a result of global warming are not taken, the consequences thereof will be an economic loss and environmental catastrophe. Therefore, introducing a consistent policy to sustain economic growth while addressing issues concerning CO_2 emissions is paramount to economic development.

The next 11 countries, also known as N11 countries, include Egypt, Mexico, Bangladesh, Indonesia, Nigeria, Iran, Pakistan, Turkey, Vietnam, South Korea, and the Philippines: have developing markets that could turn out to be the world's major economies [23]. According to [24], these countries account for around 8% of the overall gross domestic product (G.D.P.), justifying their growth potential. With the growth in N-11 economies comes increased energy consumption. As economies become more industry-intensive and less energy-efficient to enhance growth, environmental problems begin to arise J.M.K.C.

Donev et al. (2020). N-11 countries, therefore, generate about 10% of the global CO_2 emissions [25].

Several researchers have reviewed the nexus between economic growth, environmental pollution, energy consumption, and findings have been inconclusive. Although most macroeconomic variables constitute nonlinear characteristics, a substantial part of the existing research on modeling the economic growth-carbon emission nexus was executed in a linear structure that assumed a symmetric relationship using different time-series methods. The mixed results that were arrived at concerning the economic growth–carbon emission relationship could be due to the linearity assumptions. Using linear models may not be a suitable approach to exploring the link between economic growth and carbon emissions since it may offer misleading suggestions on such a relationship.

As shown in a recent study by [26,27], carbon emission response will differ depending on the level of economic growth. Our study adds to the current literature in numerous forms. This study also aims to buttress the potential asymmetric relationship between economic growth and carbon emission for the next 11 countries. To the best of the authors' knowledge, this is the first study that examines the asymmetric relationship between economic growth and carbon emission in the next 11 countries using the nonlinear autoregressive distributed lag (NARDL) model.

Second, to study the possible nonlinear relation between economic growth, energy consumption, and carbon emission, we employ the nonlinear autoregressive distributed lag (N.A.R.D.L.) model proposed by [28] for the individual countries. We decompose the growth per capita into positive and negative changes. We also examine the asymmetric causality using the [29] nonlinear Granger causality in place of the extensively used [30] nonlinear causality test to assess the causal link between carbon emission and economic growth. Our decision to employ the [29] nonlinear Granger causality is because of the limitations pointed out by [29] in the [30] test that the null hypothesis of non-causality may be over rejected.

The remainder of this study is in the following format. Section 2 highlights the literature review focusing on previous related studies on energy consumption, economic growth, and carbon emission nexus. In Section 3, the sources of data and methodology employed are presented. Empirical results are shown in Section 4. Whiles Section 5 reports the conclusions drawn from the study with the main findings and corresponding policy recommendations.

2. Literature Review

Ever since the pioneering work of [31] on the EKC concept, which was named after [32] numerous empirical studies such [33–36] have examined the validity of an inverted "U" correlation between growth per capita and environmental contamination. With reference to the IEA 2016 report, human activities have increased greenhouse gas leading to global warming. An increase in greenhouse gas concentrations by 90% in 2014 originated from carbon dioxide emissions, and 68% of carbon dioxide emissions emanated from the energy sector. Therefore, in the energy sector, carbon dioxide emissions are generally produced by carbon oxidation in fuels, references [37,38] asserted that the consumption of energy critically affects the environment, and for that matter, these environmental issues impede economic growth.

Halicioglu, F. (2009) [17], who conducted his studies in Turkey found out that economic growth had a compelling impact in explaining the country's carbon emission than energy consumption. Pao, H.-T and Tsai, C.-M (2011) [39] found a similar in Brazil. As mentioned earlier, a year before just this work, [40] in conducting studies about this phenomenon in the BRIC (Brazil, Russia, India and China) countries found that a short-run and long-run causal relationship exists between carbon emission, energy consumption, and economic growth. In the same year, [18] came out with similar results for Turkey. Mendum, R. and Njenga, M. (2018) [41] reiterated that there is a considerable usage of fossil fuel energy, contributing to environmental degradation. On the other hand, reference [42] acknowledged the existence of a significant correlation between energy economic growth and consumption.

Similarly, [37] advocated that South Africa has to lessen energy consumption to fewer carbon emissions. In Saudi Arabia, [43] found that huge energy consumption volatility negatively impacts oil G.D.P. and CO_2 emission. IEA (2016) states that in 2014, electricity and heating had a combined carbon emission of 42.2%, with another 19% coming from construction and manufacturing. Paramati, S.R., Sinha A. and Dogan, E. [44] examined the impact of renewable energy and nonrenewable energy consumption on carbon emissions and economic growth in the next-11 countries. They reported that renewable energy consumption had reduced carbon emission significantly, but the same cannot be said about nonrenewable energy. Reference [45] disclosed that natural gas consumption had a positive knock-on effect on China and India's carbon emission from 1952 to 2012. Table 1 presents a summary of recent related literature on empirical studies that examined the EKC hypothesis.

Table 1. Summary of related studies and results.

Authors	Relationship	Region	Methodology	Period	Findings
[46]	CO_2-GDP	Spain	Threshold cointegration	From 1857 to 2007	Existence of EKC
[47]	CO_2-GDP	Spain	EKC analysis	From 1857 to 2007	Existence of EKC
[48]	CO_2-GDP	UK	Nonlinear threshold cointegration and error correction method	From 1830 to 2003	Existence of EKC
[49]	CO_2-Energy-GDP	Pakistan	Cointegration, Granger and EKC analysis	From 1971 to 2009	Existence of EKC
[50]	CO_2-Energy-GDP	Romania	Cointegration and EKC analysis	From 1980 to 2010	Existence of EKC
[51]	CO_2-Energy-GDP	Turkey	Cointegration and EKC analysis	From 1970 to 2010	Existence of EKC
[52]	CO_2-Energy-GDP	Ecuador	System dynamics modeling and EKC analysis	From 1980 to 2025	Existence of EKC
[53]	CO_2-GDP	Spain	Multivariate adaptive regression splines	From 1857 to 2007	Existence of EKC
[54]	CO_2-Energy-GDP	India	Bound testing cointegration.	From 1966 to 2009	Existence of EKC
[55]	CO_2-GDP	EU	Indicator analysis	From 1990 to 2008	Mixed Results
[56]	CO_2-Energy-GDP	BRICS Members	Granger causality analysis	From 1990 to 2010	Existence of EKC
[57]	CO_2-GDP	69 countries	Generalized method of moment estimators	From 2000 to 2008	Mixed results
[58]	CO_2-Energy-GDP	Ecuador	System dynamics modeling and scenario analysis	From 1980 to 2025	Existence of EKC
[59]	CO_2-Energy-GDP	Tunisia	A.R.D.L. cointegration and EKC analysis	From 1971 to 2010	Existence of EKC
[60]	CO_2-Industrial-GDP	Bangladesh	Bounds Testing cointegration	From 1975 to 2010	Existence of EKC
[61]	CO_2-Energy-GDP	G7 countries	Time-varying Granger causality analysis	From 1960 to 2010	EKC non-existence.
[52]	CO_2-GDP	Venezuela	Cointegration Technique	From 1980 to 2025	EKC non-existence.
[62]	CO_2-GDP	Korea	Bounds Testing cointegration	From 1978 to 2007	Existence of EKC
[63]	GDP–Energy–CO_2	Egypt	Johansen Cointegration	From 1977 to 2014	Existence of EKC

Table 1. *Cont.*

Authors	Relationship	Region	Methodology	Period	Findings
[64]	GDP–Energy–CO_2	50 Developing countries	Fully-modified OLS (FMOLS)	From 1995 to 2017	EKC exists in Mexico, Croatia, Kazakhstan, Iran, Algeria, Indonesia, and Thailand
[65]	CO_2-Energy-GDP	E7 countries	OLS, FMOLS, and DOLS	From 1990 to 2014	Existence of EKC
[66]	GDP–CO_2	Twelve (12) East African countries	Pooled Mean Group (PMG)	From 1990 to 2013	EKC non-existence.
[67]	GDP–CO_2	G-7 countries	Time-varying cointegration and bootstrap-rolling window	From the 1800s to 2010	EKC pre-existed in Italy, France, and the USA in the 1973 period
[68]	GDP–CO_2	34 Annex I countries	Panel cointegration test	From 1990 to 2016	EKC exists in 5 out of 34 countries
[69]	GDP–CO_2	United States of America	ARDL/NARDL	1990M1 and 2019M7	EKC exists in the NARDL approach
[70]	Energy–CO_2	50 US states and a Federal District (Washington, D.C.)	(CCE) and the augmented mean group (AMG) estimation	From 1980 to 2015	EKC exists in 14 states
[71]	CO_2–Energy-GDP	A panel of 65 countries	(VAR) model, Granger causality, and Toda–Yamamoto tests	From 1980 to 2014	Existence of EKC
[72]	GDP–CO_2	Different Income Group Countries	Panel FMOLS	From 1980 to 2013	EKC hypothesis is validated for lower middle income and also for upper-middle-income country panel
[73]	GDP–Energy–CO_2	Greece	Granger Causality	From 1960–2014	EKC non-existence.
[74]	GDP–Energy–CO_2	Korea	ARDL	From 1971 to 2017	EKC non-existence.

3. Material and Methods

3.1. Data Sources

This research investigated the influence of economic development and energy consumption on CO_2 emissions in the next 11 countries by utilizing annual time series data from 1972 to 2013 obtained from the World Development Indicator (WDI, 2019-CD-ROM). The variables employed include economic growth (proxied by GDP per capita (constant 2010 US$), energy consumption (measured in kilogram (kg) of oil equivalent per capita), and carbon emissions (measured in metric tons per capita). The countries used for the study are the next 11 countries, and the timeframe was dictated by data availability. They include; Egypt, Bangladesh, South Korea, Mexico, Iran, Nigeria, Vietnam, Indonesia, Turkey, Pakistan, and the Philippines. To eliminate heteroscedasticity, energy consumption and GDP per capita series were transformed to logarithmic form.

3.2. Theoretical Framework and Methodology

This section presents a theoretical framework via which economic growth may affect a country's carbon emission. Several studies have investigated this phenomenon known as the environmental Kuznets curve (EKC), which hypothesizes that countries experience an increase in environmental degradation during their early stages of development and a subsequent decline when economic growth at a certain threshold is attained.

Although there are differences in environmental quality relations, most researchers adopt standard endogenous variables and exogenous explanatory variables based on the stud's focus. It is important to note that several possible factors influence carbon emission apart from economic growth and energy consumption. For instance [75–79] included trade openness in their model. Other empirical studies also included financial development to investigate its impact on environment quality ([19,76,78,80–82], population density is another factor that has been identified to influence carbon emission as reported by [77,83,84], in their studies). Furthermore, [85,86] added technology and capital y to their explanatory variables whiles analyzing the link between carbon emission and economic growth. The impact of globalization and oil prices on carbon emission was also investigated in studies conducted by [51,75]. Some recent studies also included resource rents in their model to define the correlation between resource extraction, revenue, and carbon emissions. Our choice of variables is partly influenced by availability of a complete time data series in all the next-11 countries. We decided not to include other demographic variables, which in some previous studies are normally included as weak regressors because they are of little interest concerning the objectives of our research.

Some previous studies have established that a capital increase positively affects environmental quality in the long-run [86]. In terms of trade openness, [79] reported from a panel analysis that, trade openness hinders environmental quality for low income and middle, high income and global panels but noted that the effect is not the same in the various groups of countries investigated. Mrabet, Z., AlSamara, M. and Jarallah, S.H. (2017) [75] also noted that trade openness negatively impacts ecological footprint in the long-run. Jalil, A. and Feridun, M (2011) [76] revealed that financial development leads to a decline in China's environmental pollution, and similar findings were made by [82]. In contrast, [87] in their study, posited financial development takes place at the expense of environmental quality, consistent with findings of [88]; reference [81] who reported that an increase in financial development leads to a rise in carbon emission and so does not mitigate it. Onafowora, O.A. and Owoye, O. (2014) [77] found no unique relationship between population density and the environment. However, [83] found out that as Taiwan's population grows, there is an upsurge in carbon emission consistent with what has been reported by [89] in another study. A major driving force behind an increase in carbon emission globally in the last two decades is population [84]. The type of technology used also determines the level of environmental degradation [85].

This study adopts the multivariate framework, which controls for energy consumption since economic growth and carbon emission depend on the degree of energy consumption; thus, energy consumption has a significant effect on these variables and consistently included in models of most previous studies (see [26,34,90,91]). Similar studies conducted using a trivariate framework from which inspiration was drawn for this study are captured in the literature review.

Following the recent empirical work by [26], it is possible to test the long-run nexus between carbon emission, economic growth, and energy consumption. The primary, extended model, therefore, takes the following functional form with all variables converted into logarithms:

$$logCO_{i,t} = \alpha + \alpha_1 logEG_{i,t} + \alpha_{i,t}\, logEC_{i,t} + \mu_{i,t} \quad (1)$$

where i and t indicate countries and years, while log represents the natural logarithm. CO represents the carbon emission, EG denotes G.D.P. per capita, which we used as a measure of economic growth, and EC is energy consumption.

The nonlinear cointegration regression proposed by [28] specified as:

$$y_t = \beta^+ x_t^+ + \beta^- x_t^- + \mu_+ \quad (2)$$

where β^+ and β^- are long term parameters of $kx1$ vector of regressors x_t, decomposed as:

$$x_t = x_0 + x_t^+ + x_t^- \quad (3)$$

where $x_t^+\left(x_t^-\right)$ are the partial sums of positive (negative) change in x_t as follows:

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} \max(\Delta x_j, 0) \tag{4}$$

$$x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j=1}^{t} \min(\Delta x_j, 0) \tag{5}$$

The N.A.R.D.L. (p, q) form of Equation (3), in the form of asymmetric error correction model (A.E.C.M.), can be specified as:

$$\begin{aligned}\Delta CO_t = \alpha_0 + pCO_{t-1} + \theta_1^+ EG_{t-1}^+ + \theta_2^- EG_{t-1}^- + \theta_3^+ EC_{t-1}^+ + \theta_4^- EC_{t-1}^- + \sum_{i=1}^{p} \alpha_1 \Delta CO_{t-1} \\ + \sum_{i=0}^{q} \alpha_2 \Delta EG_{t-1}^+ + \sum_{i=0}^{q} \alpha_3 \Delta EG_{t-1}^- + \sum_{i=0}^{q} \alpha_4 \Delta EC_{t-1}^+ + \sum_{i=0}^{q} \alpha_5 \Delta EC_{t-1}^- + \mu_t\end{aligned} \tag{6}$$

where i = 1, . . . , 5., α_i signifies the short-run coefficients, and θ_i represents the long-run coefficients. At this point, the short-run coefficients disclose the immediate impact of independent variables on dependent variables. On the other hand, long-run coefficients display the speed and reaction time of the adjustment towards an equilibrium level. The Wald test is applied to analyze the null hypothesis for short-run asymmetry ($\alpha = \alpha^+ = \alpha^-$) and long-run asymmetry ($\theta = \theta^+ = \theta^-$) for variables CO_t, EG_t, and EC_t, which represents carbon emission, energy consumption, and economic growth, respectively. The optimal lags p and q will be resolved by the Akaike information criterion (A.I.C.) for the dependent variable CO_t and independent variables EG_t and EC_t. To decompose, the positive and negative sum of all independent variables are given in the manner as follows.

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} \max\left(\Delta x_j, 0\right) \; and \; x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j-1}^{t} min\left(\Delta x_j, 0\right) \tag{7}$$

where x_t denotes the independent variables, EG_t and EC_t.

Where $\theta^+ = -\rho\beta^+$ and $\theta^- = -\rho\beta^-$. To establish cointegration in a nonlinear structure, the first two initial steps are similar to the A.R.D.L. bound testing technique, i.e., estimating Equation (6) using ordinary least square and conducting the joint null ($\rho = \theta^+ = \theta^- = 0$) hypothesis test. However, in nonlinear A.R.D.L., the Wald test is applied to examine the long-run ($\theta^+ = \theta^-$) and short-run ($\pi^+ = \pi^-$) asymmetries in the relationship.

In the framework of the asymmetric error correction model presented above, [28] proposed two test statistics, namely the t-BDM and F-PSS, for testing the existence or absence of a cointegration relationship. While the t-BDM tests the null of no cointegration $H0: \rho = 0$ against the alternative hypothesis of cointegration $H1: \rho < 0$, the F-PSS tests the joint null of no cointegration $H0: \rho = \theta^+ = \theta^- = 0$ against the alternative joint hypothesis of cointegration $H1: \rho = \theta^+ = \theta^- < 0$. As the asymptotic distribution of the t-BDM and F-PSS statistics is non-standard regardless of whether the variables are at a level I(0) or first difference I(1), the conclusion for cointegration is taken by assessing two groups of critical values, one of which assumes that all variables are I(1). It provides a bound covering with all possible categorizations of the variables. If the computed test statistics fall above the upper level of the bound, the null hypothesis ($H0$) is rejected, supporting cointegration. If the computed test statistics fall below the lower level of the bound, the null hypothesis ($H0$) cannot be rejected, which indicates that cointegration does not exist.

The equation below used to determine the asymmetric dynamic multiplier effects:

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial CO_{t+j}}{\partial EG_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial CO_{t+j}}{\partial EG_t^-}, m_h^+ = \sum_{j=0}^{h} \frac{\partial CO_{t+j}}{\partial EC_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial CO_{t+j}}{\partial EC_t^-}, m_h^+ \tag{8}$$

If $h \to \infty$, $m_h^+ \to Lm^+$and $m_h^- \to Lm^-$. It indicates the asymmetric reaction of the exogenous variable to both positive and negative changes in endogenous variables. The dynamic modification from the initial equilibrium to the new equilibrium in system variables can be observed.

The nonparametric Diks–Panchenko causality test:

In 1969, Granger proposed a causality test to define 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 or current values of X contain additional information on future values of Y.

Suppose that $\boldsymbol{X}_t^{lx} = (X_{t-1\ X+1}, \ldots, X_t)$ and $\boldsymbol{Y}_t^{ly} = (Y_{t-1\ y+1}, \ldots, Y_t)$ are the delay vectors, where l_X,$l_Y \geq 1$.

Diks, C.; Panchenko (2006) [29] examine the null hypothesis that past observations of X_t^{lx} contain any additional information about Y_{t+1} (beyond that in $\boldsymbol{Y}_t^{ly}$):

$$H_0: Y_{t+1} \left| \left(\boldsymbol{X}_t^{lX}; \boldsymbol{Y}_t^{lY} \right) \sim Y_{t+1} \right| \boldsymbol{Y}_t^{lY} \tag{9}$$

The equation below represents the test statistic:

$$T_n(\varepsilon_n) = \frac{n-1}{n(n-2)} \cdot \sum_i (\hat{f}_{\cdot X,Z,Y}(X_i, Z_i, Y_i)\hat{f}_{\cdot Y}(Y_i) - \hat{f}_{\cdot X,Y}(X_i, Y_i)\hat{f}_{\cdot Y,Z}(Y_i, Z_i)) \tag{10}$$

where $f_{X,Y,Z(x,y,z)}$ is the joint probability density function. For $l_X = l_Y = 1$ and if $\varepsilon_n = Cn^{-\beta}(C > 0, \frac{1}{4} < \beta < \frac{1}{3})$, [29] prove that the test statistic in Equation (2) satisfies the following:

$$\sqrt{n}\frac{(T_n(\varepsilon_n) - q)}{S_n} \xrightarrow{D} N(0,1) \tag{11}$$

where $\xrightarrow{D}$ denotes convergence in distribution and S_n is an estimator of the asymptotic variance of $T_n(.)$ [29,92].

4. Main Results and Discussions

Table 2 presents the main descriptive statistics of 41-year carbon emission, energy consumption, and growth values for each country. As can be observed, the highest amount of carbon emission was 11.803 recorded in South Korea. In terms of energy consumption, South Korea and Egypt recorded the highest value, 8.566, while the maximum growth value of 10.073 was reported in South Korea.

Table 2. Descriptive statistics.

Countries	Variable	Mean	Median	Max.	Min.	Std. Dev.	Skewness	Kurtosis	JB	Prob.
Bangladesh	CO	0.188	0.156	0.442	0.052	0.110	0.842	2.696	5.126	0.077
	EC	4.854	4.800	5.372	4.465	0.254	0.518	2.208	2.973	0.226
	EG	6.130	6.043	6.779	5.761	0.289	0.750	2.426	4.511	0.105
Egypt	CO	1.561	1.427	2.528	0.635	0.563	0.250	1.992	2.217	0.330
	EC	7.689	7.890	8.566	6.312	0.718	−0.393	1.715	3.969	0.137
	EG	7.329	7.342	7.864	6.602	0.375	−0.387	2.248	2.038	0.361
Indonesia	CO	1.097	1.060	2.560	0.358	0.543	0.798	3.169	4.503	0.105
	EC	6.298	6.385	6.774	5.708	0.361	−0.226	1.515	4.214	0.122
	EG	7.486	7.562	8.178	6.732	0.406	−0.178	1.966	2.095	0.351

Table 2. *Cont.*

Countries	Variable	Mean	Median	Max.	Min.	Std. Dev.	Skewness	Kurtosis	JB	Prob.
Iran	CO	4.967	4.494	8.004	2.807	1.607	0.596	2.034	4.116	0.128
	EC	7.291	7.267	7.956	6.294	0.449	−0.075	2.047	1.630	0.443
	EG	8.624	8.552	9.237	8.200	0.274	0.749	2.646	4.152	0.125
Mexico	CO	3.746	3.819	4.353	2.388	0.497	−1.309	4.058	13.950	0.001
	EC	7.227	7.286	7.414	6.753	0.166	−1.511	4.273	18.810	0.000
	EG	8.978	8.980	9.149	8.658	0.133	−0.665	2.655	3.305	0.192
Nigeria	CO	0.652	0.688	1.010	0.325	0.193	−0.215	2.024	1.990	0.370
	EC	6.542	6.542	6.682	6.372	0.074	−0.401	2.839	1.171	0.557
	EG	7.436	7.404	7.814	7.188	0.203	0.250	1.571	4.015	0.134
Pakistan	CO	0.643	0.654	0.991	0.309	0.218	−0.032	1.711	2.912	0.233
	EC	5.989	6.033	6.261	5.653	0.193	−0.310	1.659	3.819	0.148
	EG	6.604	6.674	6.988	6.118	0.267	−0.315	1.937	2.673	0.263
Philippines	CO	0.793	0.818	0.996	0.516	0.119	−0.602	2.691	2.706	0.258
	EC	6.122	6.117	6.240	6.008	0.054	0.271	2.672	0.701	0.705
	EG	7.402	7.370	7.783	7.185	0.145	0.951	3.200	6.400	0.041
S. Korea	CO	7.699	8.444	11.803	2.603	3.111	−0.206	1.575	3.850	0.146
	EC	7.689	7.890	8.566	6.312	0.718	−0.393	1.715	3.969	0.137
	EG	9.068	9.210	10.073	7.634	0.759	−0.336	1.765	3.461	0.177
Turkey	CO	2.797	2.736	4.419	1.472	0.879	0.223	1.919	2.391	0.302
	EC	6.892	6.885	7.369	6.402	0.276	0.036	1.852	2.316	0.314
	EG	8.866	8.841	9.462	8.426	0.292	0.299	2.010	2.341	0.310
Vietnam	CO	0.663	0.427	1.701	0.262	0.456	1.078	2.702	8.294	0.016
	EC	5.830	5.664	6.501	5.524	0.327	0.973	2.454	7.146	0.028
	EG	6.236	6.072	7.234	5.557	0.532	0.417	1.856	3.511	0.173

4.1. Unit Root Test

We began by testing the stationary properties of energy consumption, carbon emission, and economic growth. We applied the Phillips–Perron (PP) test and the augmented Dickey–Fuller (ADF) test to approve that the variables are not integrated at the second level difference since the NARDL test disallows the use of I(2) variables. The augmented Dickey–Fuller (A.D.F.) [93] and Phillips–Perron (P.P.) [94] test results shown in Table 3 indicate that all the variables are stationary at the first difference and level, respectively. This indicates that the variables are not integrated at the second level difference.

Table 3. Results for the unit root test.

Country	Variable	ADF	P.P.
		1st Diff.	Level
Bangladesh	CO	−4.958053 ***	−5.095271 ***
	EC	−8.105175 ***	−8.105175 ***
	EG	−9.388714 ***	−6.578150 ***
Egypt	CO	−8.060522 ***	−5.095271 ***
	EC	−5.466056 ***	−5.529220 ***
	EG	−9.388714 ***	−3.840639 ***
Iran	CO	−5.534588 ***	−5.533646 ***
	EC	−8.056607 ***	−8.302803 ***
	EG	−4.343252 ***	−4.323196 ***

Table 3. *Cont.*

Country	Variable	ADF	P.P.
Indonesia	CO	−7.351991 ***	−5.113169 ***
	EC	−6.408486 ***	−6.416679 ***
	EG	−4.740846 ***	−4.711259 ***
Mexico	CO	−7.493528 ***	−7.424368 ***
	EC	−4.697482 ***	−4.767260 ***
	EG	−5.225727 ***	0.0001 ***
Nigeria	CO	−7.798879 ***	−7.850522 ***
	EC	−5.680019 ***	−5.716808 ***
	EG	−4.477894 ***	−4.678554 ***
Pakistan	CO	−6.569886 ***	−6.612215 ***
	EC	−5.081361 ***	−5.081473 ***
	EG	−4.927686 ***	−4.990064 ***
Philippines	CO	−6.003711 ***	−6.065572 ***
	EC	−8.881027 ***	−8.511704 ***
	EG	−3.471897 **	−3.527832 **
South Korea	CO	−6.740287 ***	−6.843895 ***
	EC	−5.466056 ***	−5.529220 ***
	EG	−4.913235 ***	−4.908296 ***
Turkey	CO	−6.418895 ***	−7.079606 ***
	EC	−6.434442 ***	−6.915337 ***
	EG	−5.979640 ***	−5.980426 ***
Vietnam	CO	−4.981646 ***	−5.104254 ***
	EC	−5.091775 ***	−5.385382 ***
	EG	−5.091775 ***	−5.385382 ***

Note: ** indicates 5% level of statistical significance, *** indicates 1% level of statistical significance.

4.2. Linear Cointegration Test

Table 4 presents the results of the maximum-likelihood Johansen's cointegration between economic growth, energy consumption, and carbon emission in the N-11 countries. Since none of the parameters were significant at 5%, in most countries except Bangladesh and Vietnam, we ruled out cointegration between economic growth, energy consumption, and carbon emission in those countries. Apart from Bangladesh, the null hypothesis of no cointegration was not rejected in other countries. This might have arisen due to the long-run nonlinear cointegration between energy consumption, carbon emission, and economic growth to be established by employing nonlinearity tests.

Table 4. Linear cointegration results.

	Trace Test Statistics	*p*-Value	Max-Eign Test Statistics	*p*-Value
Hypothesis of no cointegration				
Bangladesh	42.4764	0.0011	28.5185	0.0038
Egypt	30.592	0.0404	18.4978	0.1123
Indonesia	23.8596	0.2064	18.7493	0.1043
Iran	29.0294	0.0611	17.1946	0.163
Mexico	26.7122	0.1089	17.8188	0.1368
Nigeria	12.5034	0.9129	7.0153	0.9533
Pakistan	18.1126	0.5577	11.3872	0.6087
Philipines	21.1684	0.3472	15.8066	0.2364
South Korea	23.7202	0.2125	14.0065	0.3645
Turkey	21.2214	0.344	14.6463	0.3144
Vietnam	32.2486	0.0256	20.0402	0.0705

Table 4. *Cont.*

	Trace Test Statistics	*p*-Value	Max-Eign Test Statistics	*p*-Value
Hypothesis of at most 1 cointegration relationship				
Bangladesh	13.9579	0.0841	9.784	0.2265
Egypt	12.0942	0.1525	7.8039	0.399
Indonesia	5.1103	0.797	4.3982	0.8151
Iran	11.8347	0.165	11.8176	0.1177
Mexico	8.8934	0.3753	7.9445	0.3844
Nigeria	5.488	0.755	5.4876	0.6794
Pakistan	6.7253	0.6098	6.4833	0.552
Philipines	5.3618	0.7692	4.7917	0.7679
South Korea	9.7137	0.3034	8.1115	0.3675
Turkey	6.575	0.6275	6.1597	0.5928
Vietnam	12.2084	0.1472	12.1733	0.1043

Note: This table reports the cointegration tests between economic growth, energy consumption, and carbon emission in each country.

4.3. Linear Granger Causality Results

We assessed the linear causality between carbon emission, energy consumption, and economic growth, using each country's conventional linear Granger causality test. The null hypothesis of the analysis states that there was no Granger causality. Thus, there was no linear causal relationship between carbon emissions and the two independent variables (economic growth and energy consumption). In contrast, there existed a linear Granger causality between the variables as proposed by the alternative hypothesis. Table 5 presents the results of maximum-likelihood Johansen cointegration between the variables.

Table 5. Linear Granger causality results.

Country	Null Hypothesis	F-Statistic	Prob	Country	Null Hypothesis	F-Statistic	Prob
Bangladesh	EC→CO	2.12742	0.1343	Pakistan	EC→CO	8.57022	0.0009 ***
	CO→EC	0.86825	0.4285		CO→EC	0.92026	0.4078
	EG→CO	7.66062	0.0017 ***		EG→CO	3.34227	0.0469 **
	CO→EG	0.31741	0.7301		CO→EG	0.04464	0.9564
Egypt	EC→CO	1.84401	0.1732	Philippines	EC→CO	1.63126	0.2102
	CO→EC	0.68438	0.511		CO→EC	0.70981	0.4987
	EG→CO	0.59250	0.5584		EG→CO	0.64014	0.5333
	CO→EG	2.71256	0.0803 *		CO→EG	1.30704	0.2835
Indonesia	EC→CO	3.66009	0.036 **	South Korea	EC→CO	2.84736	0.0715 *
	CO→EC	0.48001	0.6228		CO→EC	0.79682	0.4588
	EG→CO	2.90335	0.0681 *		EG→CO	7.35589	0.0022 ***
	CO→EG	0.46341	0.6329		CO→EG	0.06048	0.9414
Iran	EC→CO	2.09535	0.1382	Turkey	EC→CO	0.28988	0.7501
	CO→EC	0.75668	0.4767		CO→EC	0.42228	0.6588
	EG→CO	2.93896	0.0661 *		EG→CO	1.74327	0.1898
	CO→EG	0.41869	0.6612		CO→EG	0.35153	0.7061
Mexico	EC→CO	2.08351	0.1397	Vietnam	EC→CO	13.9725	0.00003 ***
	CO→EC	0.25710	0.7747		CO→EC	7.66099	0.0017 ***
	EG→CO	2.93266	0.0664 *		EG→CO	8.73214	0.0008 ***
	CO→EG	0.07895	0.9242		CO→EG	1.76289	0.1864
Nigeria	EC→CO	1.33657	0.2758				
	CO→EC	0.01847	0.9817				
	EG→CO	1.19780	0.3139				
	CO→EG	0.76583	0.4726				

Note: E.C. denotes Energy Consumption. CO means Carbon Emissions, and E.G., represents Economic Growth. * indicates statistical significance at 10%, ** signifies significance at 5%, and *** represents a 1% statistical significance level.

In Bangladesh's case, we found no bidirectional causality betwixt carbon emissions and energy consumption; instead, we observed economic growth Granger, causing carbon emission. Furthermore, energy consumption and economic growth were found to Granger cause carbon emissions in Pakistan. In Egypt, a unidirectional causality was seen running from carbon emission to economic growth. Concerning the Philippines, we failed to reject the null hypothesis of no Granger causality between our variables at all levels of significance. We confirmed a unidirectional Granger causality linkage running from energy consumption and economic growth to carbon emissions in Indonesia and South Korea. For Iran, we mentioned that economic growth Granger causes carbon emissions at a 5% level of significance. However, there was no significant causality that existed from energy consumption to carbon emissions. For Turkey, we failed to reject the null hypothesis of no Granger causality between our variables at all levels of significance. We rejected the null hypothesis of economic growth, not Granger causing carbon emission at a 5% significance level for Mexico. Results for Vietnam show a bidirectional Granger causality betwixt carbon emission and energy consumption and a unidirectional causality running from economic growth to carbon emission. The results also point out that there was no causal relationship between the variables for Nigeria.

4.4. B.D.S. Test

In examining the likelihood of nonlinear dependence between energy consumption and G.D.P. per capita, we utilized the Brock, Dechert and Scheinkman (B.D.S.) test [95]. The test's null hypothesis states that the data were identically and independently distributed (i.i.d). As displayed in Table 6, we rejected the null hypothesis of i.i.d residuals at all the embedding dimensions (m). As strong evidence existed at the highest level of significance against linearity in various variables, it implies, the time series used for this particular study was nonlinear dependent.

Table 6. B.D.S. test results.

Countries	**Dimension**	**EC**	**EG**	**Countries**	**Dimension**	**EC**	**EG**
		B.D.S. Statistic (***)	**B.D.S. Statistic (***)**			**B.D.S. Statistics (***)**	**B.D.S. Statistics (***)**
Bangladesh	2	0.177024 ***	0.174039 ***	Pakistan	2	0.199488 ***	0.199703 ***
	3	0.285864 ***	0.278125 ***		3	0.334663 ***	0.337807 ***
	4	0.350735 ***	0.339179 ***		4	0.428513 ***	0.434716 ***
	5	0.389067 ***	0.37318 ***		5	0.495292 ***	0.502299 ***
	6	0.411109 ***	0.380987 ***		6	0.544884 ***	0.551332 ***
Egypt	2	0.201463 ***	0.198172 ***	Philippines	2	0.10975 ***	0.158969 ***
	3	0.341714 ***	0.337625 ***		3	0.175152 ***	0.244498 ***
	4	0.438403 ***	0.436021 ***		4	0.193586 ***	0.283601 ***
	5	0.506641 ***	0.506077 ***		5	0.187322 ***	0.283893 ***
	6	0.556544 ***	0.557602 ***		6	0.147491 ***	0.27089 ***
Indonesia	2	0.194317 ***	0.197835 ***	South Korea	2	0.201463 ***	0.20414 ***
	3	0.325502 ***	0.333295 ***		3	0.341714 ***	0.344286 ***
	4	0.417838 ***	0.427217 ***		4	0.438403 ***	0.443357 ***
	5	0.483318 ***	0.495225 ***		5	0.506641 ***	0.513784 ***
	6	0.531504 ***	0.546404 ***		6	0.556544 ***	0.565905 ***
Iran	2	0.187381 ***	0.171945 ***	Turkey	2	0.177244 ***	0.160076 ***
	3	0.312782 ***	0.289979 ***		3	0.295023 ***	0.265773 ***
	4	0.399411 ***	0.368851 ***		4	0.376469 ***	0.330013 ***
	5	0.458589 ***	0.419481 ***		5	0.435256 ***	0.380511 ***
	6	0.499275 ***	0.449397 ***		6	0.483341 ***	0.422466 ***

Table 6. *Cont.*

Countries	Dimension	EC	EG	Countries	Dimension	EC	EG
		B.D.S. Statistic (***)	B.D.S. Statistic (***)			B.D.S. Statistics (***)	B.D.S. Statistics (***)
Mexico	2	0.201463 ***	0.166562 ***	Vietnam	2	0.172391 ***	0.189636 ***
	3	0.341406 ***	0.271809 ***		3	0.270012 ***	0.309999 ***
	4	0.436461 ***	0.343492 ***		4	0.324388 ***	0.386616 ***
	5	0.498828 ***	0.391855 ***		5	0.343519 ***	0.438129 ***
	6	0.538705 ***	0.433351 ***		6	0.337443 ***	0.470514 ***
Nigeria	2	0.172747 ***	0.134242 ***				
	3	0.276635 ***	0.21865 ***				
	4	0.343756 ***	0.264458 ***				
	5	0.410921 ***	0.281335 ***				
	6	0.472064 ***	0.28456 ***				

Note: *** signifies statistical significance at 1%.

4.5. Diagnostic Test Results

We conducted robustness checks through the post-estimation technique of the NARDL model. As shown in Table 7, results indicate that the model did not suffer from serial correlation. Additionally, the Breusch and Pagan heteroscedasticity test results infer a rejection of the chances of homoscedasticity and heteroscedasticity, which demonstrates that variance was constant in the data variables. Furthermore, the Ramsey RESET test was employed, and the results presented confirmed models were stable and did not have misspecification errors or bias.

Table 7. Diagnostic results.

Countries	Diagnostics	t-Statistics	Countries	Diagnostics	t-Statistics
Bangladesh	SC	21.89 (0.2369)	Pakistan	SC	18.78 (0.2803)
	HT	0.01553 (0.9008)		HT	1.56 (0.2116)
	FF	0.3552 (0.7859)		FF	0.5388 (0.6706)
Egypt	SC	15.62 (0.5507)	Philippines	SC	14.68 (0.6186)
	HT	1.029 (0.3103)		HT	0.1156 (0.7338)
	FF	0.2407 (0.8663)		FF	0.6411 (0.5990)
Indonesia	SC	22.09 (0.1403)	South Korea	SC	17.18 (0.3738)
	HT	0.5262 (0.4682)		HT	0.9664 (0.3256)
	FF	4.383 (0.1914)		FF	1.11 (0.4070)
Iran	SC	14.48 (0.5628)	Turkey	SC	18.38 (0.3651)
	HT	0.2562 (0.6127)		HT	0.2189 (0.6399)
	FF	0.9677 (0.4597)		FF	2.302 (0.1137)
Mexico	SC	15.33 (0.5005)	Vietnam	SC	24.75 (0.1004)
	HT	5.007 (0.0252)		HT	0.07845 (0.7794)
	FF	1.66 (0.3974)		FF	1.095 (0.3780)
Nigeria	SC	26.1 (0.0974)			
	HT	0.01154 (0.9144)			
	FF	0.5819 (0.6331)			

Notes: (SC) denotes the Portmanteau test for serial correlation, (HT) signifies the Breusch–Pagan test for heteroscedasticity, and (FF) represents the Ramsey RESET test for functional misspecification, respectively. Numbers in brackets ( ) are *p*-values.

4.6. Nonlinear Cointegration Results

The NARDL bounds cointegration results are illustrated in Table 8. The t-statistic (T_{BDM}) developed by [96] confirms cointegration among variables in Bangladesh, Iran, Turkey, and Vietnam at various levels of statistical significance. The NARDL F-statistic (F_{PSS}) from [28] validates the presence of asymmetric cointegration amongst the variables, which shows that carbon emission, economic growth, and energy consumption have a long run asymmetric nexus in Bangladesh, Iran, and Vietnamese economies.

Table 8. Nonlinear cointegration results.

Countries	T_{BDM}	F_{PSS}
Bangladesh	−4.8587 ***	6.2568 **
Egypt	−2.2745	2.1176
Indonesia	−0.9489	2.7873
Iran	−3.7883 **	16.9986 ***
Mexico	−1.1636	1.3792
Nigeria	−1.6423	1.7724
Pakistan	−2.0074	2.3549
Philippines	0.1254	1.9312
South Korea	−3.177	2.7674
Turkey	−3.6632 *	3.5945
Vietnam	−5.2785 ***	5.9065 **

Note: * indicates statistical significance at 10%, ** signifies significance at 5%, and *** represents 1% statistical significance level.

4.7. Long-Run Nonlinear Effect Results

Table 9 and Appendix A presents the projected long-run coefficients related to the negative and positive changes in energy consumption and economic growth.

Table 9. Results of long-run asymmetric effects.

Countries	Long-Run Effect	EG	EC
Bangladesh	LR-P	−0.056 (0.508)	0.604 (0.000) ***
	LR-N	−0.379 (0.031) **	−0.964 (0.000) ***
Iran	LR-P	−3.579 (0.279)	7.161 (0.006) ***
	LR-N	−5.924 (0.000) ***	1.493 (0.738)
Turkey	LR-P	1.766 (0.003) ***	1.517 (0.007) ***
	LR-N	−2.555 (0.077) *	−0.794 (0.555)
Vietnam	LR-P	−0.365 (0.003) ***	1.901 (0.0000) ***
	LR-N	1.168 (0.012) **	−1.665 (0.0000) ***

Note: LR-P indicates long-run positive, and LR-N signifies long-run negative effects. * indicates statistical significance at 10%, ** signifies significance at 5%, and *** represents a 1% statistical significance level.

Concerning the long-run link betwixt carbon emission and economic growth, a boost in Bangladesh's economic growth leads to a negative but not statistically significant consequence on carbon emission (a coefficient −0.056) at all levels of significance. A decline in economic growth reduces carbon emission (with a coefficient of −0.379) and statistically significant. This result opposes the findings of [60], who found the existence of the conventional EKC hypothesis in Bangladesh based on bounds testing cointegration. However, the study results of [53] using the cointegration technique concluded that EKC does not exist in Venezuela, which is consistent with our findings with regards to Bangladesh. In the case of energy consumption, an increase in energy consumption not only has a positive but statistically significant effect on carbon emission (a coefficient of 0.604). However, a decrease in energy consumption has a negative and statically significant consequence (a coefficient of −0.964) on carbon emission in Bangladesh. It means that an upsurge in Bangladesh's energy consumption contributes to a significant increase in carbon emission by 0.604%. In comparison, a down string in energy consumption will significantly cause a decline in carbon emission by 0.964%. This outcome is consistent with [97] findings of an upsurge in the consumption of energy, which contributed to environmental pollution when the author examined the relationship between energy use and economic growth employing panel estimation systems in sub-Sahara African countries.

Concerning Iran, a boom in economic growth has a negative relationship with carbon emission (a coefficient of −3.579) but statistically insignificant. While a decrease in economic growth also negatively affects carbon emissions (a coefficient of −5.924) and statistically significant. This means that a drop in economic growth will account for a 5.924% reduction in carbon emission in Iran. This outcome is also in harmony with findings from [61]. They found no presence of the EKC hypothesis when the author used time-varying Granger causality analysis to test for G7 countries. A rise in energy consumption accounts for a positive and statistically significant effect (with a coefficient of 7.161) on carbon emission. While a negative shock to energy consumption has a positive (with a coefficient of 1.493) impact on economic carbon emission but not statistically significant. Therefore, it implies that an increase in energy consumption in Iran increases carbon emission by 7.161%. This result confirms the findings of [98], who asserted that the use of energy critically affects the environment.

For Turkey, an increase in economic growth has a statistically significant positive relationship with carbon emission (a coefficient of 1.766). Additionally, a downswing in economic growth leads to a statistically significant carbon emission reduction (a coefficient of −2.555). This implies that Turkey's economic boom increases carbon emission by 1.766%, while a decline in economic growth reduces the country's carbon emission by 2.555%. Findings for Turkey are contrary to [51] results that found the conventional EKC hypothesis based on cointegration analysis. Moreover, the results are also in line with [17], who found out that economic growth had a compelling impact in explaining the CO_2 emission in Turkey.

Nevertheless, an upsurge in energy consumption resulted in a statistically significant increase (a coefficient of 1.517) in carbon emissions. In contrast, a decrease in energy consumption led to a statistically insignificant reduction (a coefficient of −0.794) in carbon emission. In Turkey, when there was an increase in energy consumption by 1%, it led to a 1.517% rise in carbon emission in the long-run. The result of a significant increase in Turkey's carbon emission caused by an increase in the country's energy consumption is in line with the findings of [37,99] about the rise in carbon emissions as a result of energy consumption.

Results for Vietnam indicate that a boom in economic growth results in a statistically significant negative effect on carbon emission (a coefficient of −0.365). However, a negative shock to economic growth results in a statistically significant rise in carbon emission (a coefficient of 1.168). It implies that in Vietnam, an upsurge in economic growth lessens carbon emissions by 0.365%, while a reduction in economic growth increases carbon emissions by 1.168%. With this, an observation of the existence of the conventional EKC hypothesis is made and is contrary to findings from the works of [52,61]. Concerning energy consumption, an increase is associated with a statistically significant increase in carbon emissions (a coefficient of 1.901), while a decline in energy consumption is associated with a statistically significant reduction in carbon emissions (a coefficient of −1.665). Thus, in Vietnam, an upsurge in energy consumption consequently increased carbon emissions by 1.901%, and a reduction in energy consumption decreases carbon emissions by 1.665%. The attribution of an upsurge in carbon emissions to an upsurge in energy consumption is in line with results published from the work of [38].

4.8. Results for Nonlinear Restrictions

The Wald test results for economic growth validate the presence of long-run asymmetric effects for Bangladesh, Iran, and Vietnam. Wald test outcomes in the short-run show asymmetric effects for only Iran. We found both the long-run and the short-run asymmetric effects in Bangladesh and Iran concerning energy consumption. These results are displayed in Table 10. This asymmetric effect implies that carbon emissions reacted differently to an increase and decrease in energy consumption and economic growth in these countries.

Table 10. Wald test result.

Countries	Wald Statistics	EG	EC
Bangladesh	WLR-E WSR-E	7.812(0.010) ** 0.2544(0.618)	20.13(0.000) *** 8.27(0.008) ***
Iran	WLR-E WSR-E	9.393(0.012) ** 7.367(0.022) **	7.678(0.020) ** 21.28(0.001) ***
Turkey	WLR-E WSR-E	0.5065(0.485) 0.3356(0.569)	0.4219(0.523) 0.4007(0.534)
Vietnam	WLR-E WSR-E	5.031(0.036) ** 2.447(0.133)	0.7198(0.406) 0.36(0.555)

Note: WLR-E represents Wald statistics estimate for long-run symmetry, and WSR-E shows Wald statistics for short-run symmetry, which tests the null hypothesis long-run ($\theta^{+} = \theta^{-}$) and short-run ($\pi^{+} = \pi^{-}$). ** signifies significance at 5%, and *** represents a 1% statistical significance level.

4.9. Model Stability Tests

We then present the dynamic asymmetric nexus between economic growth and carbon emissions by graphing the multipliers effects. These dynamic multipliers (see Figures 1–4) display carbon emission adjustments to a unit change in economic growth to its new long-run equilibrium following a negative or positive single shock in the 42 years. The positive change depicted by a continuous black line and negative change indicated by dashed black line curves describes the adjustment of carbon emission to a positive and negative effect of multipliers to shocks in the 42-year economic growth at a given forecast horizon. The asymmetry line (continuous red line) indicates the variance between the negative and positive effects multipliers to shocks in the 42-year economic growth. The empirical findings affirm the presence of a nonlinear connection between carbon emission and economic growth. The occurrence of a long-run nonlinear relationship between changes in 42-year carbon emission and economic growth shows the essence to consider nonlinearity when studying the relationship among the variables.

Figures 5–12 display the CUSUM and CUSUMSQ tests graphs. CUSUM and CUSUM of squares are utilized to explore if the coefficients are stable or not. Therefore, the two graphs validate that the model was reliable and stable since they both fell within the critical bounds at a 5% significance level.

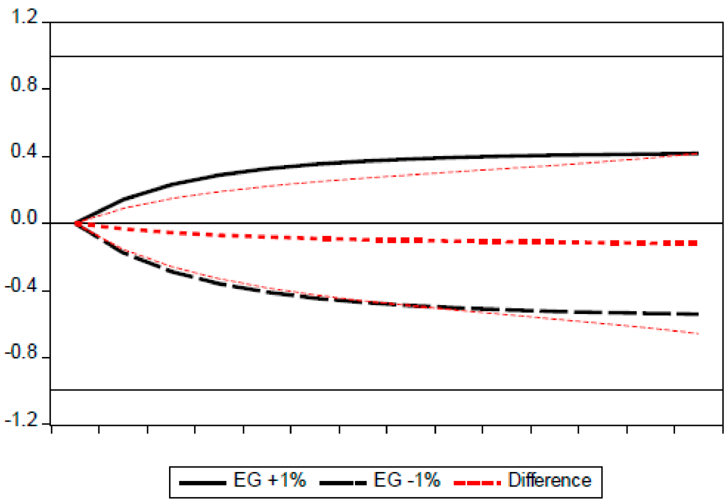

Figure 1. Dynamic multiple adjustments of carbon emission to a unitary change of economic growth in Bangladesh.

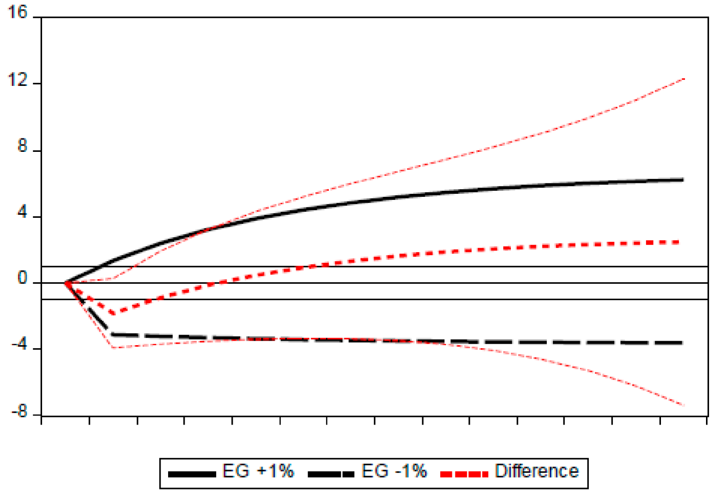

Figure 2. Dynamic multiple adjustments of carbon emission to a unit change in economic growth in Iran.

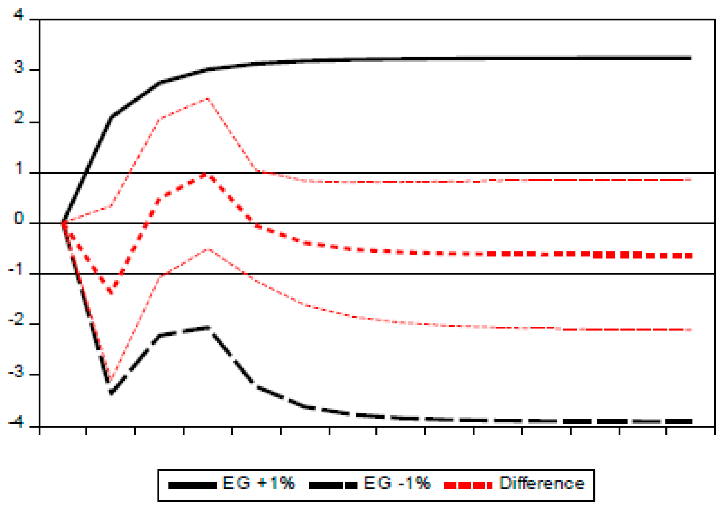

Figure 3. Dynamic multiple adjustments of carbon emission to a unit variation of economic growth in Turkey.

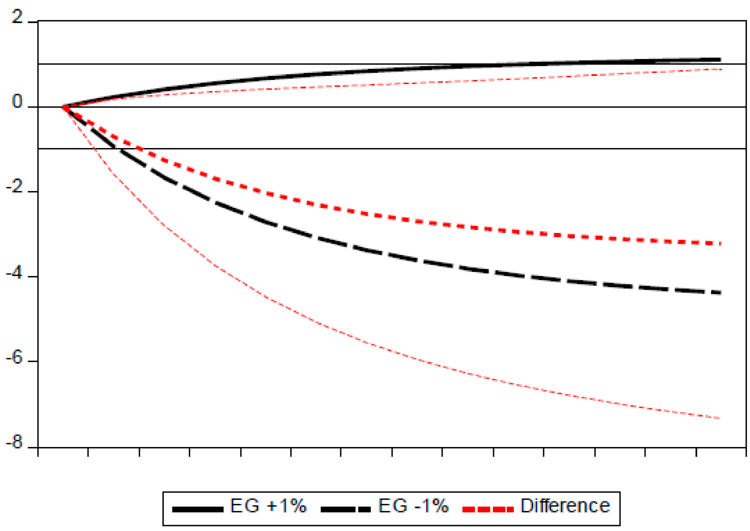

Figure 4. Dynamic multiple adjustments of carbon emission to a unitary variation of economic growth in Vietnam.

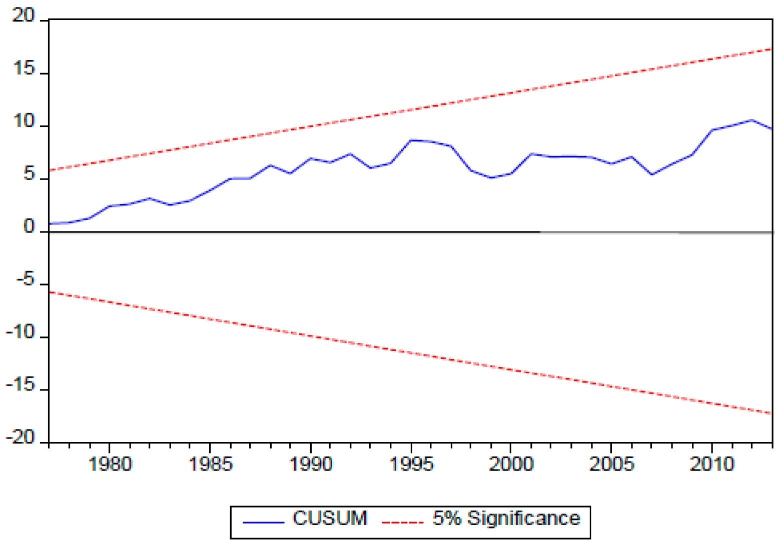

Figure 5. Plot of cumulative sum of recursive residuals for Bangladesh.

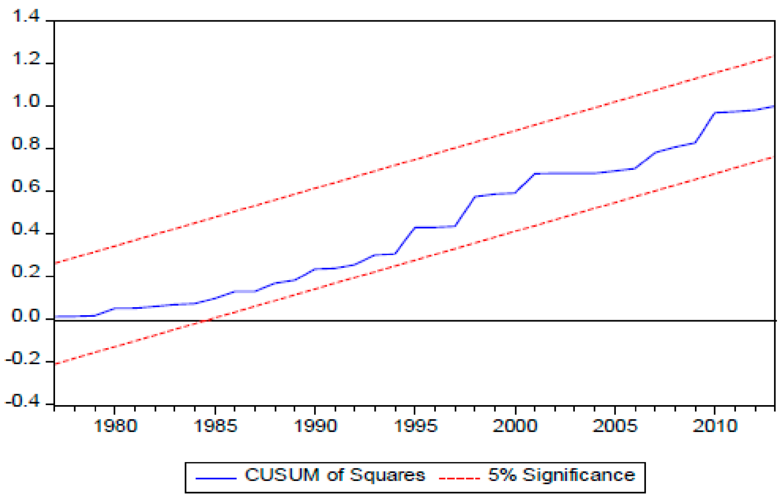

Figure 6. Plot of cumulative sum squares of recursive residuals for Bangladesh.

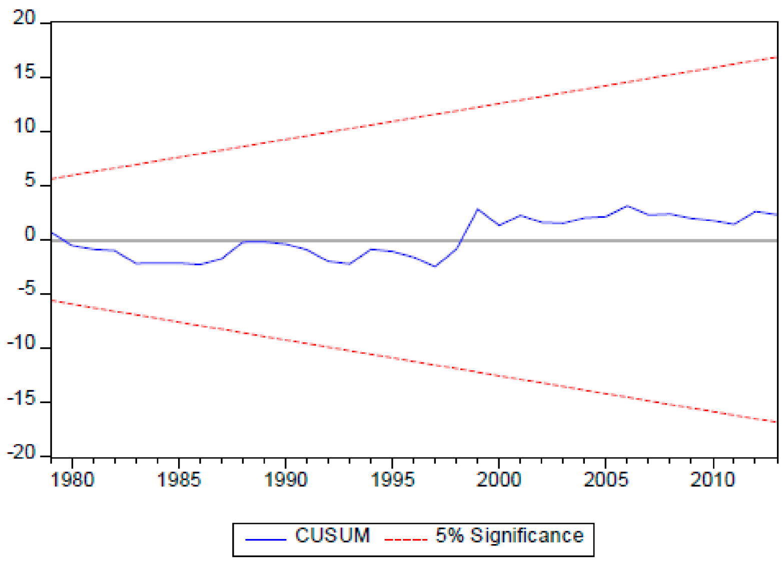

Figure 7. Plot of cumulative sum of recursive residuals for Iran.

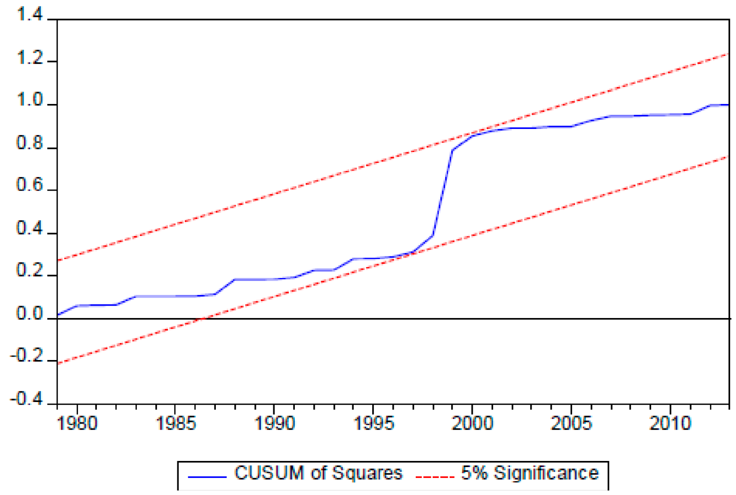

Figure 8. Plot of cumulative sum squares of recursive for residuals for Iran.

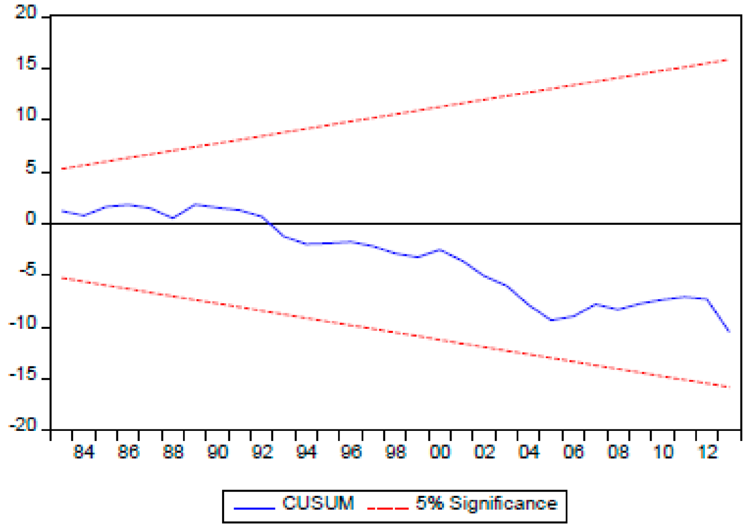

Figure 9. Plot of cumulative sum of recursive residuals for Turkey.

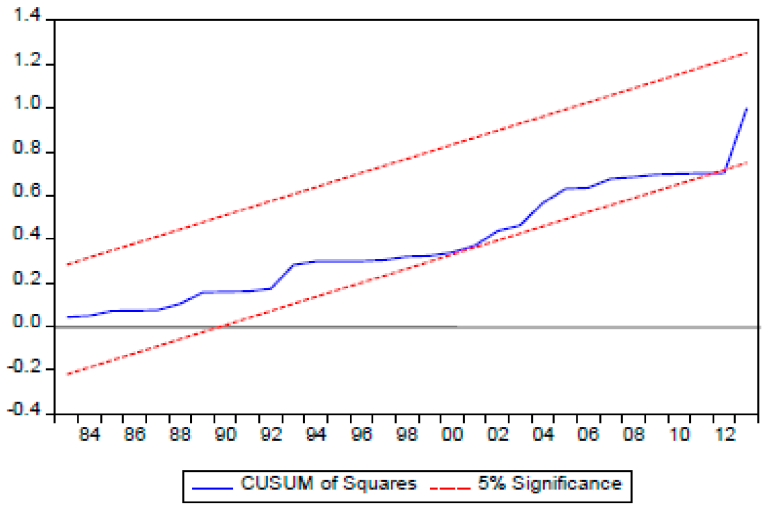

Figure 10. Plot of cumulative sum of squares recursive residuals for Turkey.

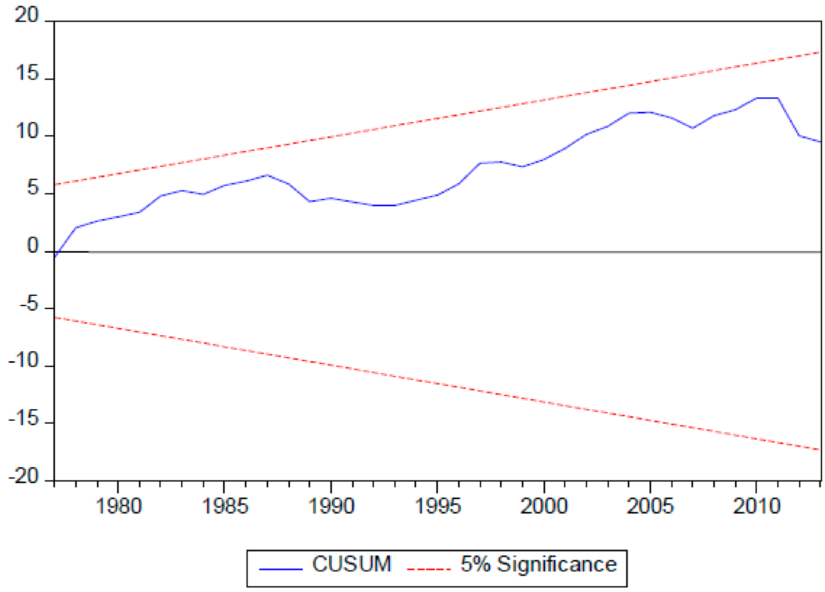

Figure 11. Plot of cumulative sum of recursive residuals for Vietnam.

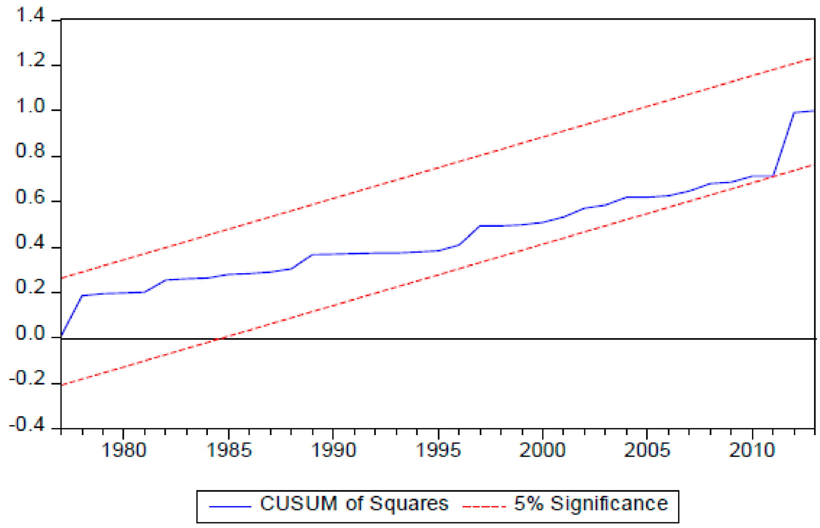

Figure 12. Plot of cumulative sum of squares recursive residuals for Vietnam.

4.10. Asymmetric Causality Results

The nonlinear Granger causality test outcomes presented in Table 11 for Bangladesh describe a feedback causality betwixt carbon emission and economic growth. It is contrary to no bidirectional causality reported from the linear Granger causality test. The outcome of [100], which is similar to ours, found a feedback causality in the long-run between carbon emission and economic growth in Bangladesh. Additionally, the unidirectional causality, which runs from energy consumption to carbon emissions as reported in the nonlinear framework, was consistent with findings presented in the linear framework in Table 5. Similar findings were made by [100] in Bangladesh and [101] in China's case.

In Egypt, we identified a unidirectional asymmetric Granger causality connection, which runs from economic growth to carbon emission in dimension four (4) at a 10% level of statistical significance. However, it contrasts with the linear Granger causality results for Egypt but consistent with results reported by [100] in Egypt. Contrary to no causality between energy consumption and carbon emission in Egypt, we identified a nonlinear unidirectional causality that runs from energy consumption to carbon emission. Chebbi, H.E. (2010) [102] also found that energy consumption Granger causes carbon emission in Tunisia, and in South Africa, [103] made similar findings.

Table 11. Diks and Pachenko asymmetric causality test.

Country	Null Hypothesis	m = 2		m = 3		m = 4	
		t-Stats	*p*-Value	t-Stats	*p*-Value	t-Stats	*p*-Value
Bangladesh	EG→CO	2.510	0.00604 ***	2.016	0.0219 **	2.014	0.02201 **
	CO→EG	1.645	0.05003 **	1.661	0.04832	1.687	0.0458 **
	EC→CO	1.804	0.03559 ***	1.877	0.03027 **	1.950	0.02556 **
	CO→EC	1.177	0.1196	1.191	0.11683	1.195	0.11601
Egypt	EG→CO	1.322	0.0931 *	1.262	0.10344	1.389	0.08237 *
	CO→EG	0.816	0.20736	0.830	0.20334	0.833	0.20233
	EC→CO	2.228	0.01295 ***	1.703	0.04424 **	1.600	0.05484 **
	CO→EC	1.112	0.86703	1.049	0.85295	−0.803	0.78904
Indonesia	EG→CO	1.244	0.10676	0.941	0.17332	0.851	0.19741
	CO→EG	−0.909	0.8182	0.663	0.25374	0.695	0.2434
	EC→CO	1.416	0.07839 *	1.021	0.15357	0.887	0.18749
	CO→EC	−0.727	0.76624	−0.729	0.76688	−0.731	0.76755
Iran	EG→CO	0.358	0.3603	0.650	0.25789	0.968	0.16644
	CO→EG	1.484	0.06887 *	1.440	0.07491 *	1.393	0.08187 *
	EC→CO	1.084	0.13912	1.041	0.14901	1.000	0.15864
	CO→EC	1.160	0.12296	1.102	0.13531	1.104	0.13487
Mexico	EG→CO	−1.174	0.87986	−0.952	0.82957	−0.964	0.8324
	CO→EG	0.733	0.23191	0.203	0.41954	−0.976	0.83539
	EC→CO	−0.926	0.82273	−0.865	0.80644	−0.963	0.83222
	CO→EC	0.799	0.21228	0.618	0.26813	0.626	0.26569
Nigeria	EG→CO	−1.565	0.94124	−1.218	0.88844	−1.095	0.86327
	CO→EG	0.494	0.31078	0.892	0.18615	0.905	0.18263
	EC→CO	0.574	0.28314	−0.253	0.59991	0.356	0.36099
	CO→EC	−0.933	0.82457	−1.363	0.91357	−0.938	0.8260
Pakistan	EG→CO	1.027	0.15227	0.959	0.16866	0.970	0.16611
	CO→EG	0.956	0.16946	0.733	0.23193	0.776	0.21884
	EC→CO	1.464	0.07155 *	1.364	0.08625 *	1.385	0.0831 *
	CO→EC	0.573	0.28326	−0.902	0.81635	−0.847	0.80154
Philippines	EG→CO	−0.589	0.72215	−0.427	0.66534	−0.308	0.621
	CO→EG	0.979	0.16372	1.005	0.15752	0.963	0.16775
	EC→CO	0.403	0.34354	0.483	0.31457	0.711	0.23842
	CO→EC	1.079	0.1404	0.941	0.17342	1.357	0.08734 *
South Korea	EG→CO	1.343	0.08962 *	0.764	0.22244	0.754	0.22543
	CO→EG	0.828	0.20372	0.831	0.20308	0.800	0.21197
	EC→CO	1.631	0.05144 *	0.764	0.22244	0.753	0.22558
	CO→EC	0.773	0.21962	0.797	0.2126	0.833	0.20232
Turkey	EG→CO	1.172	0.12055	1.198	0.11553	1.343	0.08962 *
	CO→EG	1.921	0.02739 **	1.525	0.06366 *	1.299	0.09692 *
	EC→CO	1.240	0.10752	0.901	0.1839	0.988	0.16167
	CO→EC	1.730	0.04185 **	1.390	0.08221 *	1.372	0.08496 *
Vietnam	EG→CO	1.220	0.11131	1.057	0.14523	1.063	0.14381
	CO→EG	0.794	0.21367	0.826	0.20426	0.895	0.18529
	EC→CO	1.345	0.08936 *	1.058	0.14497	1.059	0.14483
	CO→EC	0.923	0.17812	1.445	0.07429 *	1.454	0.07298 *

Note: This table reports the results of the [29] asymmetric Granger causality test for the variables in each country. m denotes dimension and * represents statistical level at 10%, ** at 5%, and *** at 1%, respectively.

Our findings regarding Indonesia revealed no causality running between carbon emission and economic growth consistent with [104] in India's study. However, [105] revealed that economic growth Granger causes carbon emission in Indonesia. Tiwari, A.K., Shahbaz, M. and Hye, Q.M.A (2013) [54] also discovered a feedback effect between carbon emission and economic growth in India. In terms of nonlinear causality, a unidirectional causality that runs from energy consumption to carbon emission is confirmed with similar findings reported in the traditional Granger causality results. Soytas, U., Sari, R. and Ewing, B.T (2007) [4] also made similar findings in the U.S. reporting that causality exists between carbon emission and energy consumption.

We discovered a unidirectional linear causality that runs from economic growth to Iran's carbon emission. However, a unidirectional nonlinear causality was found to run from carbon emission to economic growth. No feedback causality was found between energy consumption and carbon emission in both the linear and nonlinear framework.

The nonlinear Granger causality results revealed no causality between economic growth, energy consumption, and carbon emission in Nigeria and Mexico. These results are comparable to the findings reported by [105] in the two countries using time-varying and time constant Granger causality tests.

Asymmetric causality results from Pakistan show no causality between carbon emission and economic growth, but a unidirectional causality is confirmed, running from energy consumption to carbon emission. Compared with the linear Granger causality was found running from energy consumption and economic growth to carbon emission.

In the Philippines' economy, we found that economic growth did not Granger cause carbon emission in the symmetric framework, similar to a finding from the symmetric Granger causality results. The result is similar to [52,106] in the case of Ecuador and Venezuela, where the existence of the EKC hypothesis could not be found. However, a unidirectional causality that runs from carbon emission to energy consumption was found from the asymmetric results contrary to no causality between the variables in the symmetric results. Using a dynamic Granger causality test [103] also found that carbon emission and economic growth in the Philippines led to energy consumption.

Regarding South Korea, our results indicate a significant asymmetric Granger causality that runs from economic growth to carbon emission, which implies that economic growth causes carbon emission, which confirms the existence of the EKC hypothesis. Baek (2015) and [105] also confirmed the existence of EKC in South Korea in their studies. It is comparable to the results of symmetric Granger causality, which indicates that the economic growth Granger causes carbon emission in South Korea. Additionally, in both the linear and nonlinear causality framework, energy consumption leads to carbon emission. In a similar study, [26] also found asymmetric causality that runs from energy consumption to carbon emission in Italy and France.

In Turkey's economy, the null hypothesis of no asymmetric Granger causality that runs from economic growth to carbon emission and vice versa was rejected. It means that an asymmetric Granger causality relation exists from carbon emission to economic growth vice versa. This finding is divergent to results reported in the linear Granger causality structure, signifying no bidirectional causality between the variables in Turkey. However, the asymmetric causality results are similar to findings made by [51] in Turkey, where they affirmed the existence of the EKC hypothesis. We identified a unidirectional asymmetric causality that runs from carbon emission to energy consumption whiles no linear causality was reported. Lean, H.H. and Smyth, R (2010) [107] also reported a causal relationship that runs from electricity consumption to carbon emission in Asian Nations.

Asymmetric Granger causality results from Vietnam also show no feedback causality betwixt carbon emission and economic growth in contrast to bidirectional linear Granger causality result reported earlier. However, linear Granger causality outcomes reported earlier shows a unidirectional causality from economic growth to carbon emission in the case of Vietnam. The asymmetric Granger causality results are in contrast with findings made by [105], who also found a linear relationship from economic growth to carbon emission in Vietnam. However, it is consistent with [52,61]. We found bidirectional asymmetric causality between energy consumption and carbon emission consistent with [60] in the case of Bangladesh.

5. Conclusions and Recommendations

This research contributes to the significant debate on the nexus between carbon emission, energy consumption, and economic growth. Our analysis was based on the 42 years (1972–2013) data on carbon emission, energy consumption, and economic growth for the next 11 (N-11) countries globally. Nonlinear A.R.D.L. and linear Granger causality tests were applied to investigate the cointegration and causality link among the variables. The empirical findings show a significant rejection of a significant feedback causality connection between the dependent variable (carbon emission) and the two independent variables (economic growth and energy consumption) in all of the N11 countries excluding Vietnam. Vietnam shows a bidirectional Granger causality betwixt carbon emission and energy consumption and unidirectional causality that runs from economic growth to carbon emission. Economic growth granger causing carbon emissions were observed in South Korea, Bangladesh, Mexico, Iran, Indonesia, and Pakistan.

Meanwhile, in Egypt, a unidirectional causality nexus running from carbon emission to economic growth was observed. Furthermore, Indonesia, Pakistan, and South Korea displayed a unidirectional Granger causality running from energy consumption to carbon emission. Interestingly, no Granger causality relationship was found to exist between carbon emission, energy consumption, and economic growth in both Nigeria and Turkey.

Various vital findings were attained from the N.A.R.D.L. bounds testing analysis outcomes. The nonlinear cointegration outcomes show four significant long-run links between economic growth, carbon emissions, and energy consumption at usual significance levels for Bangladesh, Iran, Turkey, and Vietnam. Substantial evidence was also obtained from our long-run asymmetric effect results. Concerning the linkage between economic growth and carbon emission, we obtained evidence that showed the EKC hypothesis exists in Vietnam but does not exist in Bangladesh, Iran, and Turkey. For Bangladesh and Iran, an upsurge in economic growth has a statistically insignificant negative consequence on carbon emission, while a decrease in economic growth has a statistically significant negative consequence on carbon emissions.

On the other hand, results for Vietnam show that a boost to economic development leads to a statistically significant negative consequence on carbon emission, confirming the EKC hypothesis. In contrast, a reduction in economic growth results in a statistically significant upsurge in carbon emissions. No evidence of the existence of the EKC hypothesis was established for Turkey because an expansion in economic growth has a statistically significant positive relationship with carbon emission. In contrast, a downswing in economic growth leads to a statistically significant reduction in carbon emissions. Concerning the EKC hypothesis, the mixed results obtained were consistent with findings from [56,58]. In the case of the relationship between carbon emission and energy consumption, we found evidence of a positive shock to energy consumption, leading to a statistically significant increase in carbon emissions in Bangladesh, Iran, Turkey, and Vietnam. In contrast, a negative shock in energy consumption leads to a statistically significant decrease in carbon emissions in Bangladesh and Vietnam. Moreover, negative shocks in energy consumption for Iran and Turkey both obtained statistically insignificant effects, with Iran and Turkey having a statistically insignificant increase in carbon emissions and a statistically insignificant decrease in carbon emissions, respectively.

According to the Wald test results, with regards to nonlinear associations, long-run results show evidence of an asymmetric relationship between carbon emissions and economic growth in Bangladesh, Iran, and Vietnam. For carbon consumption and energy emission, long-run asymmetries were found in Bangladesh and Iran. Short-run asymmetries between carbon emissions and energy consumption were observed for both Bangladesh and Iran. In contrast, short-run asymmetries between carbon emissions and economic growth were only observed for Iran.

Based on these findings, Bangladeshi policymakers can tackle the problem of carbon emissions by controlling energy consumption. From our analysis, changes in economic growth do not have a significant increasing influence on carbon emissions. Instead, changes in energy consumption have huge impacts on carbon emissions. Hence, new alternative sources of energy must be explored by Bangladesh's government by implementing energy exploring policies and investing in renewable energy systems, which will help reduce cumulative amounts of carbon emissions without affecting its economic growth.

Iranian policymakers should also focus on the energy consumption of the country. From our analysis, a decline in economic growth significantly reduces Iran's carbon emission, but this will not be the path the Iranian government would want to pursue. Thus, without affecting the country's economic growth, the Iranian government can also explore new energy sources and switch to renewable energy to reduce carbon emissions. Expediently, the government can encourage both local and foreign investors to adopt energy sufficient technologies without reducing their productivity level.

Economic growth can play a significant role in reducing energy consumption; consequently, it has an insignificant effect on carbon emissions. The Turkish government should improve its environmental quality by introducing carbon emission trading and tax schemes. The government can also initiate educational programs about the dangers associated with carbon emissions to help create awareness. The government should make sure that those responsible do implement these recommended policies, and those who fail to adhere should face the full force of the law. Policymakers in Turkey can also embrace forceful investment in developing energy expertise and elevating energy exploration to accomplish technological breakthroughs that will possibly empower the nation to deliver more output with lesser emissions. Investment can also be made into green energy technologies such as e-transport. The usage of e-bikes, e-cars, e-trains, and e-buses like what is being implemented in China can go a long way to help drastically reduce the carbon emissions in Turkey.

Interestingly, findings for Vietnam enable the issue of carbon emissions to be tackled from both the economic growth aspect and the energy consumption aspect. From our results for Vietnam, a boost in economic growth reduced carbon emissions significantly, and a reduction in economic growth boosts the carbon emissions. With the expansion of the Vietnamese economy, carbon emissions reduced significantly. Policymakers have put in place tight regulations to lessen the level of carbon emissions of the country. Additionally, the adoption of improved technological equipment and investment into renewable energy has helped the country decrease carbon emissions level without affecting its economic growth. The Vietnamese government can still explore new energy sources from the energy consumption aspect by investing in other untapped renewable energy available.

Finally, empirical results from the entire sample of the next 11 countries indicate a significant increase in carbon emission linked to economic growth. A corresponding increase in energy consumption in some countries should be a global concern. Therefore market-based policy options such as "polluter pay", which require the imposition of fees and taxes such as carbon taxes on industries associated with high carbon emissions in their operations. Additionally, public policies aimed at moving to the use of environmentally friendly energy production projects should be aggressively rolled out and implemented.

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Appendix A

Table A1. Summary of the long-run asymmetric effects of economic growth and energy consumption on carbon emission.

Countries	Positive and Negative Changes in Economic Growth and Energy Consumption (Independent Variables)	The outcome of Changes in Independent Variables (Economic Growth and Energy Consumption) on the Dependent Variable (Carbon Emission)
Bangladesh	Increase in economic growth	Reduces carbon emission but not significant
	A decrease in economic growth	A significant decline in carbon emission
	Increase in energy consumption	Significantly increases carbon emission
	A decrease in energy consumption	Leads to a significant reduction in carbon emission
Iran	Increase in economic growth	Decreases carbon emission but not significant
	A decrease in economic growth	Carbon emission decreases significantly
	Increase in energy consumption	A significant rise in carbon emissions
	A decrease in energy consumption	Carbon emission increases but not significant
Turkey	Increase in economic growth	A significant upsurge in carbon emissions
	A decrease in economic growth	Carbon emission declines significantly
	Increase in energy consumption	A significant rise in carbon emission
	A decrease in energy consumption	A nonsignificant reduction in carbon emissions
Vietnam	Increase in economic growth	Significantly decreases carbon emission
	A decrease in economic growth	Increases carbon emissions significantly
	Increase in energy consumption	Carbon emissions significantly rise
	A decrease in energy consumption	A significant decline in carbon emissions

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