IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

EJ EconJournals

International Journal of Energy Economics and Policy, 2025, 15(5), 127-135.

Dynamic Analysis of the Relationship between Economic Growth and Carbon Emissions: A Nonlinear and Asymmetric Approach

Marwa Mohammed Ali Moustafa*, Sara Omran Alomran

Department of Economics, College of Business, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh, Saudi Arabia.
*Email: mmoustafa@imam.edu.sa

Received: 23 March 2025 **Accepted:** 11 July 2025 **DOI:** https://doi.org/10.32479/ijeep.19903

ABSTRACT

The main objective of this study is to investigate the non-linear relationship between economic growth and carbon emissions. To examine the validity of the Environmental Kuznets Curve (EKC) hypothesis for the Kingdom of Saudi Arabia during the period 1970-2022 based on a bound test for cointegration using Nonlinear Auto Regressive Distributed Lag model NARDL to examine the existence of asymmetric effect between carbon emission as a proxy for environmental degradation and gross domestic product per capita as a proxy for economic growth. Our empirical results confirm the presence of cointegration among the variables. Furthermore, the EKC hypothesis is invalid for the Kingdom of Saudi Arabia in the long run. While positive shocks in economic growth cause a reduction in CO_2 emission, adverse shocks in economic growth cause a decrease in CO_2 emission. This does not imply an inverted U-shaped link between economic growth and CO_2 emissions. Energy consumption, inflation, and trade openness significantly increase CO_2 emissions. Our results also revealed that foreign direct investment substantially decreases carbon emissions. It is clear from the results that Saudi Arabia is actively embracing green technologies as part of Vision 2030. This vision involves decreasing energy-intensive industries, turning to renewable energy sources, and expanding the services sector.

Keywords: Environmental Kuznets Curve, Nonlinear Auto Regressive Distributed Lag Model, Energy Consumption
JEL Classifications: Q53, Q56, O44, C32, C51

1. INTRODUCTION

Global economies face significant environmental challenges such as averting danger and climate change. Climate change is a problem facing all societies, both developed and developing. Addressing this problem is the responsibility of all countries (Intergovernmental Panel on Climate Change, 2023) Regarding this, the Kingdom of Saudi Arabia joined the United Nations Framework Convention on Climate Change (UNFCCC) in 1994, and in 2016 ratified the Paris Climate Agreement, which it adopted in 2015 (United Nations Framework Convention on Climate Change, 2015). Further according to Vision 2030 in 2016, the Kingdom of Saudi Arabia has taken rapid steps to build a more sustainable future. Since its launch in 2021, the Saudi Green Initiative has continued to enhance environmental protection efforts, accelerate the energy transition, and implement sustainability programs to achieve its comprehensive goals of offsetting and reducing carbon emissions, increasing afforestation and land reclamation, and protecting the Kingdom's land and marine areas (Saudi Green Initiative, n.d.).

The relationship between growth and the environment concerns all countries. This relationship is based on Kuznets' theory, which investigates the association between income levels and equitable distribution. Kuznets (2019) proposed a hypothesis suggesting that income inequality initially rises and declines as an economy develops. This relationship is often depicted as an inverted U-shaped curve between income inequality and per capita income. This association is now widely recognized as the Kuznets curve. The relationship between economic growth and environmental quality is complex and multifaceted, the EKC hypothesis offers a framework to understand the relationship between economic growth and environmental quality, which is often characterized by the Environmental Kuznets Curve (EKC) hypothesis, which suggests an inverted U-shaped relationship (Sarkodie and Strezov, 2019). This indicates that while economic growth initially leads to environmental degradation, it may eventually improve environmental quality as income rises and societies adopt cleaner technologies (Koilo, 2019; Yasinm et al., 2021).

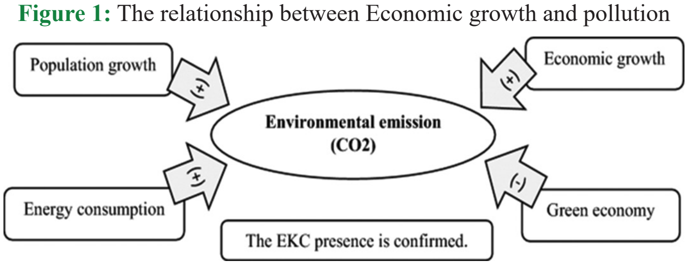
Growth theory has been biased, regarding this theory energy consumption is associated with increased economic growth. while fossil fuel energy consumption promotes economic growth, it harms the environment (Alaganthiran and Anaba, 2022). Therefore human activities increase greenhouse gas emissions, which in turn cause environmental pollution and climate change. This theory often overlooks the environmental costs associated with economic development. Most economists have focused on capital accumulation (Rising et al., 2022). Not much attention has been given to the relationship between economic growth and the environment until recent decades. Recently, interest has emerged in studying the compatibility between the environment and economic growth (Panayotou, 2003; Xepapadeas, 2005).

Sustainable growth is achieved through traditional and modern production factors. The traditional channels affect total factor productivity, such as the efficient distribution of resources and increasing the productivity of production factors through education and training, as well as in accumulating local savings and reducing the cost of capital. The modern channels represent technical progress and investments in clean technology that consider the environment (Wang & Kim 2024; Huang and Quadria, 2013).

This Figure 1 depicts the dynamic connection between population growth, energy consumption, environmental emissions, and economic growth, regarding Environmental Kuznets Curve (EKC). As populations expand, the demand for energy rises, driving increased CO_2 emissions and environmental degradation. In the early stages of economic growth, industrialization, and urbanization often lead to higher emissions. However, the EKC hypothesis posits that once a certain income threshold is reached, emissions begin to decline as economies shift toward cleaner technologies and sustainable practices.

Everett et al. (2010) address the vital role of the environment in supporting economic growth for current and future generations, by Providing resources and raw materials such as water, timber, and minerals which are required as inputs to produce goods and services. In addition to services provided by ecosystems including carbon sequestration, water purification, managing flood risks, and nutrient cycling. How can we continue to achieve economic growth constantly without considering the environment? Via checking the validation of EKC in Saudi Arabia the study can answer this question. Therefore, the Research question is does an increase in GDP growth affect carbon emissions differently from a decrease in Saudi Arabia?

Figure 1: The relationship between Economic growth and pollution



Source: Subramaniam, 2024

This paper aims to investigate how economic growth affects environmental degradation in Saudi Arabia covering 1970 to 2022. Further, examine the nature of the relationship between the two variables is it linear or nonlinear**?**

The rest of the study **is** organized as follows: Section 2 theoretical perspective and literature review outlines the related empirical literature, and Section 3 discusses the relationship between economic growth and the environment in Saudi Arabia. Section 4 outlines model specification, econometric methodology, and Empirical results. Finally, the Conclusion and policy recommendations in section 5.

2. LITERATURE REVIEW

This study focuses on a selective literature review analyzing the impact of economic growth on carbon emissions. This impact has gained attention in the literature due to the significant effects of carbon emissions on the global economy. Researchers have employed various methodologies and frameworks to analyze this relationship and recognize the challenges and opportunities for sustainable development. The research findings on the relationship between economic growth and the environment remain inconclusive. While some studies support a positive correlation between growth and environmental sustainability, particularly in developing countries, others present differing perspectives.

Wajahat et al. (2024) conducted a time-series analysis over 41 years to examine the impact of economic growth on carbon emissions in Pakistan. Using the Engle and Granger cointegration approach, they investigated the long-run relationship between economic growth and CO_2 emissions. Additionally, the Error Correction Model was applied to assess short-term effects. The study's findings reveal a strong positive correlation between CO_2 emissions and per capita energy consumption in both the short and long term. In contrast, GDP exhibits a positive but weaker association with CO_2 emissions Li et al. (2024) also found a positive relationship between economic growth and CO_2 emissions in their study of G20 countries spanning the period from 1992 to 2014. Tokpah et al. (2023) examined the impact of economic growth on carbon emissions across 15 developed and developing countries from 1991 to 2019 using the PMG-ARDL model. The results indicate that quadratic GDP has a significant and inverse effect on carbon emissions in industrialized nations over the long run. These findings support the validity of the Kuznets Curve when analyzed in the context of both emerging and developed economies. Those studies reached a consensus on the importance of promoting clean energy sources such as solar, wind, biogas, biomass, and hydropower to mitigate carbon emissions.

Kerfal and El alaoui (2024) reviewed The Impact of Economic Growth, Energy, and Electricity Consumption Usage on CO_2 Emissions in Morocco using the ARDL model from 1990 to 2020. This study indicated a positive significant linkage between economic growth, energy consumption, and CO_2 emissions in the long term. Teklie and Doğan (2024) examined the interactions between economic growth, technological innovation, renewable energy consumption, and carbon emissions in Africa the findings reveal both symmetric and asymmetric impacts on carbon emissions, demonstrating how economic and technological factors shape environmental outcomes. Positive economic growth leads to higher emissions, while economic downturns significantly reduce them. Additionally, technological innovation has a notable adverse effect on carbon emissions, highlighting its effectiveness in mitigating environmental degradation. Furthermore, increased renewable energy consumption substantially lowers emissions, whereas a decline in renewables exacerbates them, underscoring their critical role in sustainability. Goswami et al. (2023) examine the short- and long-run causal relationships between carbon dioxide emissions, energy consumption, economic growth, and trade openness using the ARDL model. The findings indicate that, in the short run, CO_2 emissions from previous periods, economic growth, and trade openness are negatively correlated with CO_2 emissions, while energy consumption and urbanization show a positive correlation. In the long run, energy consumption, urbanization, and trade openness positively influence CO_2 emissions. Wang and Zhang (2020) using data of 182 countries from 1990 to 2015 using the ordinary least squares (OLS) method and fully modified ordinary least squares (FMOLS) concluded that trade openness reduces carbon emissions in high-income and upper-middle-income countries while having little effect on lower-middle-income countries, also trade openness has increased carbon emissions in low-income countries.

Ahmad and Zhao (2018) examined the relationships between industrialization, urbanization, energy consumption, CO_2 emissions, and economic growth across 30 Chinese provinces/cities and three regional panels from 2000 to 2016. Their findings indicate that the impact of urbanization on economic growth varies by development level, being negative in less developed regions and positive in more developed ones. Additionally, CO_2 emissions were found to hurt economic growth. Omri et al. (2015) concluded that energy consumption plays a crucial role in driving economic growth, particularly in Middle Eastern and North African countries. Their findings suggest that higher economic growth increases energy demand, while lower growth reduces it. Consequently, policies aimed at energy conservation may have adverse effects on economic growth. Zhang et al. (2012) examined the causal relationship between energy consumption and GDP in China through time series data during the period 1995-2006 and concluded that economic growth leads to more energy consumption in China, the study recommended the importance of reforming the energy pricing system in China. Further, using panel data for 18 Asian countries covering 1971-2005, Niu et al. (2011) confirmed that energy consumption leads to more carbon dioxide emissions. Using time series data in South Africa Menyah and Wolde-Rufael (2010) found one-way causality from emissions and energy consumption to economic growth.

The validity of the environmental Kuznets curve (EKC) has been empirically tested using different methodologies for many countries, the results of these studies were different where some of them found the existence of an EKC, while others found no existence of the EKC. Caporin et al. (2024) investigated the linear and non-linear EKC relation for Central Asia considering ecological footprint, climate change adaptation, and energy consumption. The result reveals evidence of a linear Kuznets relation between carbon dioxide emissions, and gross domestic product this reflects no evidence of a U-shaped or N-shaped Kuznets relation for Central Asia. Almeida et al. (2024) revisit the EKC hypothesis by investigating the relationship between GDP and CO_2 emissions per capita from 1990 to 2020 in 158 countries and 44 world regions, grouping countries by income levels. The study concludes that there are variations in the agreement with the EKC hypothesis based on income level, where the EKC hypothesis applies to some countries while others do not. Usama et al. (2020) addresses the role of renewable and non-renewable energy in affecting CO_2 emissions under an augmented EKC framework. To achieve this goal, the study exploits data spanning 1981-2015. The Autoregressive Distributed Lag (ARDL) model is employed and the results surprisingly revealed that both renewable and non-renewable energy use reduce Ethiopia's CO_2 emissions The outcome supports the existence of the EKC hypothesis as well as an N-shaped pattern of association between real GDP per capita and CO_2 emissions per capita, particularly in the long run. Saidi and Mbarek (2017) examine the impact of financial development, income, trade openness, and urbanization on carbon dioxide emissions for the panel of emerging economies using the time series data from 1990 to 2013. Results showed a positive monotonic relationship between income and CO_2 emissions. All models do not support the EKC hypothesis which assumes an inverted U-shaped relationship between income and environmental degradation. Shahbaz et al. (2017) investigate the validity of the Environmental Kuznets Curve (EKC) hypothesis for China. Using the ARDL bounds test approach to examine the long-run relationship between the variables. The study concluded that the EKC hypothesis is valid in China in the short and long run.

Climate change and environmental pollution are among the biggest challenges facing all nations, as carbon dioxide (CO_2) emissions are closely linked to economic activity and industrial growth. There is a significant long-run relationship between economic growth and carbon emissions. Many studies depend on linear or symmetric models of the relationship between economic growth and carbon emissions. This underscores the need for further investigation to validate the hypothesis, particularly in the Kingdom of Saudi Arabia. This study addresses these limitations by employing Nonlinear Autoregressive Distributed Lag (NARDL) models to capture the positive and negative effects using Nonlinear Auto Regressive Distributed Lag models NARDL to better capture the complex dynamics in different economic phases to assess the alignment of the results with the objectives of Vision 2030. This study also explores the macroeconomic determinants of CO_2 emissions in the Kingdom of Saudi Arabia providing a more nuanced understanding of the factors influencing environmental outcomes.

This study investigates the long-run relationship between CO_2 emissions and economic growth and explores whether this relationship is asymmetric using the NARDL model. In this context, the following hypotheses can be formulated building on the insights derived from the literature review:

1. There is a long-term relationship between carbon emissions and economic growth
2. Positive and negative changes in GDP have asymmetric effects on CO_2 emissions in Saudi Arabia.

3. ECONOMIC GROWTH AND ENVIRONMENT IN THE KINGDOM OF SAUDI ARABIA

The Kingdom of Saudi Arabia is an oil producer and is constantly striving to raise the well-being of citizens and achieve high rates of economic growth, for this the Kingdom has paid great attention to reducing carbon emissions as it is a signatory to the 2015 Paris Agreement on Climate Change. Saudi Arabia has committed to contributions that aim to reduce the carbon emissions to 278 million tons annually by 2030, also the Kingdom committed to generating 50% of electrical energy from renewable sources by 2030. Saudi Arabia has pledged to reach zero net carbon emissions by 2060 it is a challenging endeavor and it requires significant efforts from all economic sectors.

Saudi Arabia's Vision 2030 has taken important steps to reduce carbon missions through reforms energy prices and investment in renewable energy sources. In 2016 and 2018, electricity, petrol and diesel prices were raised to reflect its actual costs and to promote more efficient energy use. Also, Saudi Arabia has introduced policies that reduce energy consumption, enhance energy efficiency, and reduce waste production (Alshehri et al., 2021).

Vision 2030 also aims to reduce dependence on oil exports and increase interest in non-oil exports to rise from 10% to 50% of total exports by 2030 (Mukhtarov et al., 2024). The Kingdom's vision focuses on the growth of renewable energy such as solar and wind energy, as it is a key aspect of Saudi Arabia's environmental sustainability in order to diversify its economy and reduce carbon emissions, and Saudi Arabia's renewable energy market expected to reach 29.27 gigawatt by 2030 (Mordor Intelligence, 2023).

In addition, in 2021 Saudi Arabia adopted the Saudi and Middle East green initiative, this initiative promotes environmental protection, energy transition and sustainability programs with the overarching aims of offsetting and reducing emissions, increasing afforestation and land restoration, and protecting the Kingdom's and middle East land and sea (Kingdom's vision, 2030).

As observed in the Figure 2 The progression of GDP per capita and carbon emissions in Saudi Arabia for the period from 1970 to 2022, it shows that GDP per capita was 79334.69 thousand in 1970 and continued to rise, but in the eighties, it starts to decline to reach 62322.37 thousand in 1989 due to the economic and political conditions in this period, after that it continued to fluctuate during the remainder of the study to reach 81975.63 thousand in 2022. Also figure shows that Carbon emissions reached 45 tons in 1970 and continued to rise to reach 663 tons in 2022.

Figure 3 depicts the progression of GDP per capita and energy consumption in Saudi Arabia for the period from 1970 to 2022, We observe that energy consumption rises in most periods of study, reaching 30,876,234 in 1970, reaching the 293885696 in 2022, which is normal as a result of rising in population numbers.

4. DATA AND METHODOLOGY

4.1. Data

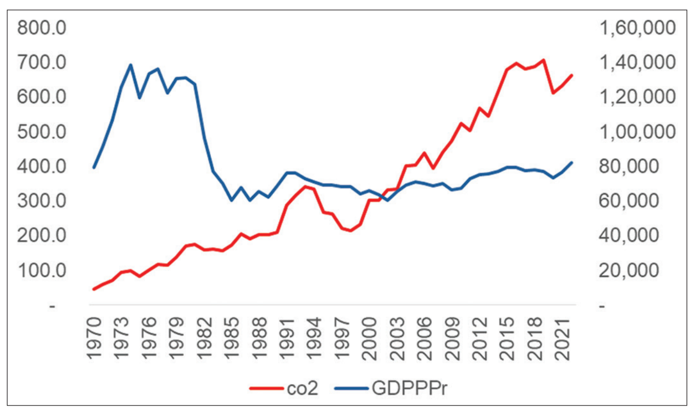
Data was collected from several sources as shown in Table 1 from the Global Carbon Budget (2023), the global material flows database, and World Development Indicators by the World Bank.

4.2. Methodology

Literature proposed numerous econometric approaches to address the complexities of time series data. Ramadanti et al. (2024) employed the simultaneous equation model using Two Stage Least Squares (2SLS). Xu et al. (2018) employed the ARDL and VECM model. This study utilizes the Nonlinear autoregressive distributed lag (NARDL) bound-testing approach suggested by Shin et al. (2014).

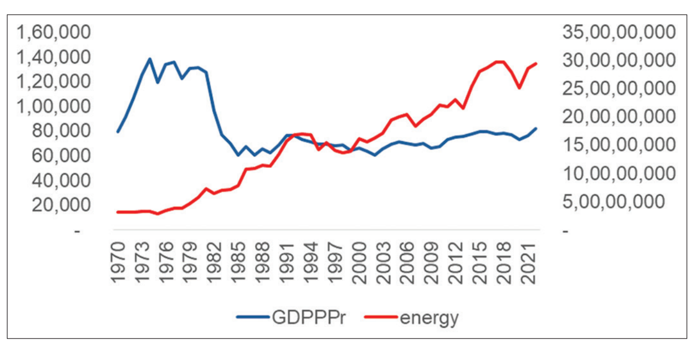
Based on the theoretical and empirical evidence and following similar studies conducted by Shittu et al. (2018), Azam and Khan (2016), and Musibau et al. (2021), this paper examines the nonlinear impact of economic growth on carbon emissions in the Kingdom of Saudi Arabia, considering energy consumption,

Figure 2: The relationship (between CO_2 emissions and GDP per capita in Saudi Arabia)



Source: Compiled by the author based on World Bank Data (2024)

Figure 3: The relationship between energy and GDP per capita in Saudi Arabia



Source: Compiled by the author based on World Bank Data (2024)

Table 1: Data description

Variables	Abbreviation	Definition	Source
Carbon emissions	CO_2	territorial CO_2 emissions	globalcarbonatlas.org
Economic growth	GDPP	GDP per capita (constant LCU)	WDI
Trade openness	TRADE	The total volume of exports and imports of goods and services % of GDP	WDI
foreign direct investment	FDI	Net inflows of foreign direct investment % of GDP	WDI
Gross fixed capital formation	GCF	Gross fixed capital formation (% of GDP)	WDI
Inflation	CPI	Consumer price index (2010=100)	WDI
Energy consumption	Energy	Fossil fuels; Domestic Material Consumption in tons.	www.resourcepanel.org/global-material-flows-database

foreign direct investment, real GDP per capita, trade, inflation, and gross capital formation. Equation (1) depicts the functional relationship between carbon emissions and explanatory variables:

$$CO_2 = f\,(GDP,\ energy,\ CPI,\ FDI,\ GCF,\ trade) \quad (1)$$

This relationship can be specified formally after tacking the natural logarithm in linear form as follows in equation (2):

$$lnCO2_t = \beta_1\ lnGDP + \beta_2\ lnenergy + \beta_3\ lnCPI + \beta_4\ lnFDI + \beta_5\ lnGCF + \beta_6\ lntrade + U_t \quad (2)$$

To estimate the asymmetric relationship in equation (2) a time series nonlinear autoregressive distributed lag model NARDL was used to describe the relationship between variables in the long run. The NARDL unrestricted error correction model was presented by Shin et al. (2014). In the NARDL model, we should separate the partial sum of positive and negative changes of the independent variable (Ghazouani, 2021), and the nonlinear effect on the dependent variable is measured.

Use the partial sum decomposition to separate the positive and negative changes in the independent variable GDP:

- Positive change: $GDP^{+} = \sum_{j=1}^{t} \max(\Delta GDP_t, 0)$
- Negative change: $GDP^{-} = \sum_{j=1}^{t} \min(\Delta GDP_t, 0)$

A positive change may have a different effect than a negative change. By splitting the GDP variable into two components one that expresses positive changes and the other that shows negative changes the previous connection can be represented in its non-linear form as shown in equation (3) (Ghazouani, 2021):

$$\begin{aligned}\Delta LnCO2_t = C_0 &+ \sum_{i=1}^{p}\gamma_{1i}\ \Delta LnCO2_{t-i} + \sum_{i=1}^{q1}\gamma_{2i}\ \Delta\ Lnenergy_{t-i} + \\ &\sum_{i=1}^{q2}\gamma_{3i}\Delta\ LnGCF_{t-i} + \sum_{i=1}^{q3}\gamma_{4i}\ \Delta\ LnFDI_{t-i} + \\ &\sum_{i=1}^{q4}\gamma_{5i}\ \Delta\ Lntrade_{t-i} + \sum_{i=1}^{q5}\gamma_{6i}\ \Delta\ LnCPi_{t-i} + \\ &\sum_{i=1}^{q6}\gamma_{7i}\ \Delta\ LnGDP^{+}_{t-i} + \sum_{i=1}^{q7}\gamma_{8i}\ \Delta\ LnGDP^{-}_{t-i} + \beta_1 Lnenergy_{t-i} \\ &+\beta_2 LnGCF_{t-i} + \beta_3 LnFDI_{t-i} + \beta_4 Lntrade_{t-i} + \\ &\beta_5 LnCPi_{t-i} + \beta_6^{+} LnGDP^{+}_{t-i} + \beta_7^{-} LnGDP^{-}_{t-i} + U \end{aligned} \quad (3)$$

The NARDL model extends the traditional ARDL model to capture both short- and long-run asymmetric relationships between carbon emissions and economic growth. It allows for decomposing the explanatory variable (economic growth) into positive and negative partial sums to explain how increases and decreases affect the dependent variable (carbon emissions) differently.

Where Δ denotes the first difference operator, γ_{1i} to $\gamma 8_i$ represent the short-term dynamic coefficients of the corresponding variables with lag lengths p, q_1 q_4, respectively. The coefficients β_1 to $\beta 7$ capture the long-term relationship among the variables in the cointegrating set, while U denotes the error term. The short-run dynamics will be analyzed through the estimation of a restricted error correction model (ECM). The short-run dynamics will be examined by estimating a restricted error correction model (ECM) as shown in equation (4):

$$\begin{aligned}\Delta CO2_t = C_0 &+ \sum_{i=1}^{p}\gamma_{1i}\,\Delta \ln CO2_{t-i} + \sum_{i=1}^{p}\gamma_{1i}\ \Delta Lnenergy_{t-i} + \\ &\sum_{i=1}^{q1}\gamma_{2i}\ \Delta\ LnTRADE_{t-i} + \sum_{i=1}^{q2}\gamma_{3i}\Delta LnGCF_{t-i} + \\ &\sum_{i=1}^{q3}\gamma_{4i}\ \Delta\ LnFDI_{t-i} + \sum_{i=1}^{q4}\gamma_{5i}\ \Delta\ LnFCPi_{t-i} + \\ &\sum_{i=1}^{q5}\gamma_{6i}\ \Delta\ LnGDP^{+}_{t-i}\ +\ + \sum_{i=1}^{q6}\gamma_{7i}\ \Delta\ LnGDP^{-}_{t-i} + \psi\ EC_{t-1} + \mu_t \end{aligned} \quad (4)$$

Where ψ, the coefficient on the error-correction term, For the model to support convergence to the long-run equilibrium after a shock, the error-correction term must be negative, statistically significant, and falls between zero and 1.

Applying the NARDL model required several steps. Where the traditional cointegration tests only support the variable that integrates of the same order (Baz et al., 2020), whereas the NARDL is a more robust and popular approach due to its flexibility that it can be used irrespective of the nature of variables, i.e., I(0), I(1), or a mixture of both (Vasichenko et al., 2020). So, the first step is to check the degree of integration of each series through augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) stationary tests. Then ensured that the residuals of the estimated unrestricted equations must be white noise, which confirms the absence of serial correlation and heteroscedasticity problem in the model. When the residuals meet the white-noise assumption, the bounds test can be used to determine the presence of a long-term relationship. Once cointegration is established using the bounds test, the long-run equilibrium relationship can be estimated (Elroukh, 2024).

The other step is using a Wald test to check if the coefficients for B^+ and B^- are significantly different:

Null hypothesis: $B^+ = B^-$ (symmetry).

Alternative hypothesis: $B^+ \neq B^-$ (Asymmetry).

5. RESULTS

This section presents the results of the NARDL model starting with, descriptive statistics, results of the unit root test, bound test, Short and long-run relationship for the NARDL model, waled test for asymmetry, and concluding with diagnostic tests.

5.1. Descriptive Statistics

The descriptive statistics are summarized in Table 2. All variables show consistent mean, median, and standard deviation values. According to the Jarque-Bera test, all variables are normally distributed, Regarding the correlations, CO_2 emissions are positively linked to energy consumption, CPI, FDI, and GCF. On the other hand, CO_2 emissions have an inverse relationship with economic growth and trade openness.

5.2. Stationary Unit Root Test

Based on the results of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) stationary tests, as presented in Table 3 the empirical findings indicate that CO_2, TRADE, CPI, and Energy are integrated of order one, I(1), and become stationary after taking their first differences. In contrast, FDI and GCF are stationary at level, I(0). Some variables are stationary at level and others at first difference therefore the NARDL model Fits for implementation.

5.3. Short Run and Bound Test for Cointegration

Based on the results illustrated in Table 4 The coefficient of ECT is statistically significant and negative and lies between 0 and 1, indicating that around 71% of the short-term imbalance is rectified in the long term. Regarding the bound test for the long-run relationship, the values of the F statistic for the nonlinear bounds test are 19.57, which is significant at a 1% level, ensuring the presence of a long-run association among the variables.

5.4. Long-run Estimates for NARDL

The long-run results are reported in Table 5, The results do not support the presence of the EKC hypothesis, as the initial phase of the curve, where economic growth initially increases pollution, is not observed. The results suggest a significant inverse relationship between positive shocks in growth and emissions, consistent with the post-EKC phase. This could indicate the implementation of effective environmental policies, the adoption of more efficient technologies, or a shift towards a service-based economy rather than pollution-intensive industries. It also shows less dependence on carbon-intensive activities and a shift to renewable energy which leads to lower emissions. The findings confirm a negative relationship between CO_2 emissions and positive GDP shocks, while a decline in economic growth leads to a decrease in CO_2 emissions. The association between energy consumption and CO_2 emissions is positive and significant, this, result corroborates with the findings of (Ramadanti et al., 2024; Wajahat et al., 2024; Xu et al., 2018). The relationship between CO_2 emissions and FDI is negative and statistically significant, this means that foreign direct investment contributes to improving the quality of the environment in Saudi Arabia. Where foreign firms use environmental protection rules and standards in Saudi Arabia which can reduce CO_2 emissions, Our result is like Shahbaz et al. (2016). The correlation between Co2 emissions and CPI is significantly positive. Finally, the impact of trade openness on CO_2 emissions is positive and significant this result aligns with the result of (Goswami et al., 2023; Ghazouani et al., 2021).

5.5. Waled Test for Asymmetry

The long-run asymmetry between the decomposed variable (economic growth) and CO_2 emissions has been verified through the Wald test as shown in Table 6 These results strongly suggest the presence of asymmetry in the relationship between carbon emissions and economic growth in the long run. This means that positive and negative changes in economic growth have different effects on carbon emissions. Such findings support that the NARDL model is the appropriate model for capturing these nonlinear and asymmetric dynamics. The dynamic multipliers illustrated in Figure 5 provide evidence of a nonlinear relationship between the two variables.

5.6. Diagnostic and Stability Tests

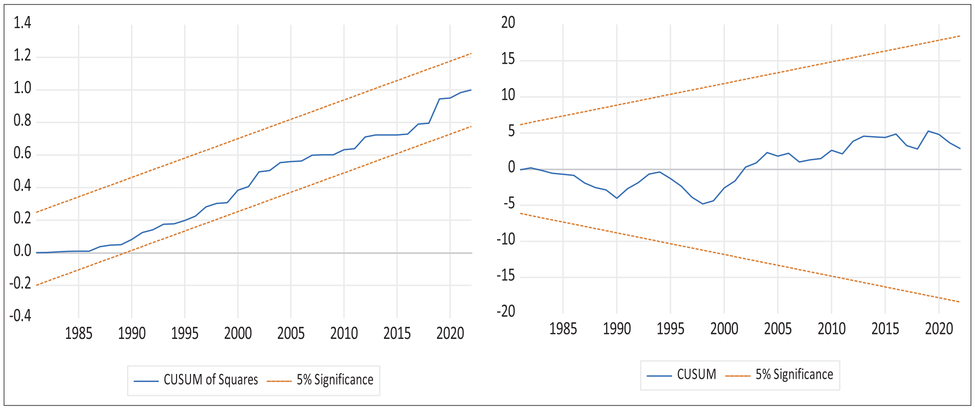
Diagnostic and stability tests determine the model's fit. Regarding Table 7 the Jarque-Bera test, the P-value (>0.05) indicates that the null hypothesis of normality cannot be rejected, and the residuals are normally distributed, satisfying the assumption of normality. The LM test for autocorrelation in the residuals ensured no evidence of serial correlation in the residuals, indicating this

Table 2: Descriptive statistics

Variables	ln CO_2	lnENERGY	lnGDP	Lnfdi	lnCPI	lnTRADE	lnGCF
Mean	326.9811	1.50E+08	1.554799	−0.123321	79.73094	75.27397	21.61842
Median	289.0000	1.56E+08	1.545464	0.057568	76.01867	72.36609	22.38601
Maximum	707.0000	2.97E+08	4.071542	1.260167	129.3542	120.6195	29.35602
Minimum	45.00000	28431460	−0.582106	−2.111903	22.47656	49.71347	12.21306
Std. Dev.	201.1195	84672234	1.070287	0.978308	26.27041	13.50979	3.823225
Skewness	0.532838	0.129678	0.189550	−0.511084	−0.093251	0.672481	−0.741398
Kurtosis	2.029716	1.937288	2.966944	2.309729	2.975894	3.688206	3.878807
Jarque-Bera	4.586966	2.642540	0.150843	1.584689	0.078096	5.040638	3.094775
Probability	0.100914	0.266796	0.927353	0.452782	0.961704	0.080434	0.212803
Correlation	-------------	0.88610	-0.206997	0.171677	0.91688	-0.346487	0.4618691

Source: Author's computation based on EViews results

Figure 4: CUSUM and of squares test CUSUM



Source: Author's estimation using NARDL model in EViews

Table 3: ADF and PP unit root test

Variables	ADF		PP	
Intercept	P-value (0) at level	P-value (I) at first difference	P-value (0) at level	P-value (I) at first difference
CO_2	0.9251	0.0000	0.9283	0.0000
GDPGR	0.0024	---------	0.4180	0.0000
TRADE	0.1116	0.0000	0.1354	0.0000
FDI	0.0001	--------	0.0001	-------
GCF	0.0000	--------	0.0000	--------
CPI	0.5235	0.0277	0.6815	0.0211
Energy	0.9345	0.0000	0.9691	0.0000
Trend and Intercept				
CO_2	0.5011	0.0000	0.5011	0.0000
GDPGR	0.4573	0.0004	0.4747	0.0003
TRADE	0.1417	0.0000	0.1632	0.0000
FDI	0.0002	-------	0.0002	--------
GCF	0.0397	--------	0.0001	---------
CPI	0.1347	0.0677	0.5574	0.0677
Energy	0.1412	0.0000	0.1146	0.0000
None				
CO_2	0.9881	0.0000	0.9871	0.0000
GDPGR	0.4554	0.0136	0.5323	0.0000
TRADE	0.5932	0.0000	0.5850	0.0000
FDI	0.0000	-------	0.0000	--------
GCF	0.7729	0.0000	0.3525	0.0000
CPI	0.9460	0.0134	0.9907	0.0098
Energy	0.9925	0.0000	0.9979	0.0000

Source: Author's computation based on EViews results

Table 4: Bound test for cointegration

I (1)	I (0)	Significant	F-statistic
3.181	2.099	10%	19.5751
3.65	2.457	5%	
4.73	3.282	1%	
(1, 0, 0, 0, 0,0,1, 0)		NARDL	
−0.714902		ECT	

Source: Author's estimation using NARDL model in EViews

assumption is met. According to the Breusch and ARCH test the variance of the residuals is constant (homoskedasticity) also the model does not suffer from ARCH effects, confirming homoskedasticity. For the Ramsey test, the model appears to be correctly specified, with no omitted variables or functional form errors. The diagnostic tests indicate that the model satisfies assumptions, including normality of residuals, absence of serial correlation, homoskedasticity, and correct model specification. These results strengthen the reliability and validity of the model's estimate.

Table 5: Long-run estimations for NARDL

Variable	Coefficient	Standard error	t-Statistic	Probability
Energy	0.0272	1.57E-07	17.37569	0.0000
GDP_POS	−0.01725	0.000557	−3.095161	0.0035
GDP_NEG	0. 0485	0.000253	1.916198	0.0622
FDI	−4.379092	2.004760	−2.184347	0.0346
CPI	1.942134	0.636709	3.050270	0.0040
TRADE	1.943185	0.393944	4.932647	0.0000
GCF	2.313030	1.634551	1.415086	0.1644
C	−196.7044	32.95853	−5.968238	0.0000

Source: Author's estimation using NARDL model in EViews

Table 6: Waled test for asymmetry

Test statistic	Value	df	Probability
F-statistic	21.42656	(2, 42)	0.0000
Chi-square	42.85312	2	0.0000

Source: Author's estimation using NARDL model in EViews

Table 7: Diagnostics tests for NARDL model

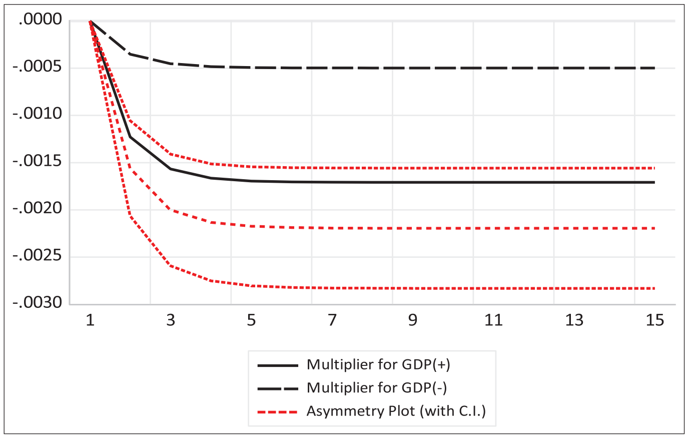
Test	Value	Probability
Test Jarque-Bera	0.487	0.783
LM Test	0.8078	0.7588
Heteroskedasticity test breusch	0.8932	0.5394
Heteroskedasticity Test ARCH	0.3092	0.5807
Ramsey reset test	0.7444	0.4609

Source: Author's estimation using NARDL model in EViews

The cumulative sum (CUSUM) and cumulative sum of squares (CUSUMS[2]) stability tests in Figure 4 confirmed the structural stability of the models. Where their statistics are significant at the 5% significance level.

As shown in Figure 4 the zero-line falls outside the two confidence bounds of the multiplier, it confirms that the relationship between economic growth and carbon emissions is statistically significant and nonlinear, indicating that positive and negative economic growth shocks affect carbon emissions differently. The figure also shows that the negative shocks of the decomposed variable

Figure 5: Dynamic multipliers of positive and negative changes of GDP on CO_2 emissions



Source: Author's estimation using NARDL model in EViews

(economic growth) affect more than the positive shocks in. positive economic growth shocks.

6. CONCLUSION

This study explored the asymmetric impact of economic growth on carbon emissions in the Kingdom of Saudi Arabia during the period 1970-2022 using a time series Nonlinear Autoregressive Distributed lag model to capture the asymmetry that arises from positive or negative components of economic growth. Various diagnostic tests were conducted to ensure the reliability of the results, along with CUSUM and CUSUM sq tests to assess the stability of the models. Our results indicate that the Environmental Kuznets Curve (EKC) hypothesis does not hold for Saudi Arabia. Saudi Arabia's effective measures to combat climate change contributed to results emphasizing the importance of attracting clean investments and promoting research and development in green technology. In conclusion, this study highlights the urgent need for sustainable development strategies to address environmental challenges, ensuring that economic growth aligns with long-term ecological stability.

Lastly, it is essential to acknowledge the limitations of this study, as they offer valuable insights for future research. Potential areas for further exploration include the long-term impact of technology and innovation on energy efficiency, the influence of globalization and international trade on the Environmental Kuznets Curve, and the role of institutional quality, governance, and transparency in reducing environmental degradation. Additionally, future studies could investigate the impact of urbanization on environmental sustainability and assess how the private sector can contribute to sustainable environmental practices.

7. FUNDING

This work was supported and funded by the Deanship of Scientific Research at Imam Mohammad Ibn Saud Islamic University (IMSIU) (grant number IMSIU-DDRSP2502).

REFERENCES

Ahmad, M., Zhao, Z.Y. (2018), Empirics on linkages among industrialization, urbanization, energy consumption, CO_2 emissions and economic growth: A heterogeneous panel study of China. Environmental Science and Pollution Research, 25(30), 30617-30632.

Alaganthiran, J.R., Anaba, M.I. (2022), The effects of economic growth on carbon dioxide emissions in selected Sub-Saharan African (SSA) countries. Heliyon, 8(11), e11193.

Almeida, D., Carvalho, L., Ferreira, P., Dionísio, A., Haq, I.U. (2024), Global dynamics of environmental Kuznets Curve: A cross-correlation analysis of income and CO_2 emissions. Sustainability, 16(20), 9089.

Alshehri, T., Braun, J., Gasim, A., Luomi, M. (2021), What Drove Saudi Arabia's 2020 Fall in CO_2 Emissions? Saudi Arabia: King Abdullah Petroleum Studies and Research Center.

Azam, M., Khan, A.Q. (2016), Testing the environmental Kuznets Curve hypothesis: A comparative empirical study for low, lower middle, upper middle and high income countries. Renewable and Sustainable Energy Reviews, 63, 556-567.

Baz, K., Xu, D., Ali, H., Ali, I., Khan, I., Khan, M.M., Cheng, J. (2020), Asymmetric impact of energy consumption and economic growth on ecological footprint: Using asymmetric and nonlinear approach. Science of the Total Environment, 718, 137364.

Caporin, M., Cooray, A., Kuziboev, B., Yusubov, I. (2024), New insights on the environmental Kuznets Curve (EKC) for central Asia. Empirical Economics, 66(5), 2335-2354.

Elroukh, A.W. (2024), What determines Egypt's demand for foreign reserves? Jordan Journal of Economic Sciences, 11(1), 1-15.

Everett, T., Ishwaran, M., Ansaloni, P., Rubin, A. (2010), Economic Growth and the Environment. London: Defra.

Ghazouani, T. (2021), Impact of FDI inflow, crude oil prices, and economic growth on CO_2 emission in Tunisia: Symmetric and asymmetric analysis through ARDL and NARDL approach. Environmental Economics, 12(1), 1-13.

Goswami, A., Kapoor, H.S., Jangir, R.K., Ngigi, C.N., Nowrouzi-Kia, B., Chattu, V.K. (2023), Impact of economic growth, trade openness, urbanization and energy consumption on carbon emissions: A study of India. Sustainability, 15(11), 9025.

Huang, Y., Quibria, M. (2013), Green Growth: Theory and Evidence (No. 2013/056). WIDER Working Paper.

Intergovernmental Panel on Climate Change. (2023), Climate change 2023: Synthesis Report. In: Lee, H., Romero, J., editors. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC. Available from: https://www.ipcc.ch/report/ar6/syr/

Kerfal, W., El Alaoui, A. (2024), The impact of economic growth, energy and electricity consumption usage on CO_2 emissions: A case study of morocco. European Scientific Journal, 20(22), 101.

Kingdom of Saudi Arabia. (2016), Vision 2030. Available from: https://www.vision2030.gov.sa

Koilo, V. (2019), Sustainability issues in maritime transport and main challenges of the shipping industry. Environmental Economics, 10(1), 48.

Kuznets, S. (2019), Economic growth and income inequality. In: The Gap between Rich and Poor. United Kingdom: Routledge. p25-37.

Li, K., Hu, E., Xu, C., Musah, M., Kong, Y., Mensah, I.A., Zu, J., Kong, Y., Mensah, I.A., Su, Y. (2021), RETRACTED: A heterogeneous analysis of the nexus between energy consumption, economic growth and carbon emissions: Evidence from the group of twenty (G20) countries. Energy Exploration and Exploitation, 39(3), 815-837.

Menyah, K., Wolde-Rufael, Y. (2010), Energy consumption, pollutant emissions and economic growth in South Africa. Energy Economics, 32(6), 1374-1382.

Mordor Intelligence. (2023), Saudi Arabia Renewable Energy Market Size and Share Analysis-Growth Trends and Forecasts (2023-2028). Available from: https://www.mordorintelligence.com/industry-reports/saudi-arabia-renewableenergy-market [Last accessed on 15 Oct 2023].

Mukhtarov, S., Azizov, M., Kartal, M.T., Eynalov, H. (2024), Catalyzing green transformation: Mitigating oil price impact on CO_2 emissions in Saudi Arabia via renewable energy transition. Environmental Economics and Policy Studies, 2024, 1-23.

Musibau, H.O., Shittu, W.O., Ogunlana, F.O. (2021), The relationship between environmental degradation, energy use and economic growth in Nigeria: New evidence from non-linear ARDL. International Journal of Energy Sector Management, 15(1), 81-100.

Niu, S., Ding, Y., Niu, Y., Li, Y., Luo, G. (2011), Economic growth, energy conservation and emissions reduction: A comparative analysis based on panel data for 8 Asian-Pacific countries. Energy Policy, 39(4), 2121-2131.

Omri, A., Shahbaz, M., Chaibi, A., Rault, C. (2015), A Panel Analysis of the Effects of Oil Consumption, International Tourism, Environmental Quality and Political Instability on Economic Growth in MENA Region. Working Papers Ipag Business School, 613.

Panayotou, T. (2003), Economic growth and the environment. Economic Survey of Europe, 2003, 45-72.

Ramadanti, S.S., Azwardi, A., Subardin, M. (2024), Economic growth and environmental quality: A study on mineral-rich provinces in Indonesia. Signifikan: Jurnal Ilmu Ekonomi, 13(1), 85-96.

Rising, J., Dietz, S., Dumas, M., Khurana, R., Kikstra, J., Lenton, T., ... & Ward, B. (2022), What will climate change cost the UK? Risks, impacts and mitigation for the net-zero transition.

Saidi, K., Mbarek, M.B. (2017), The impact of income, trade, urbanization, and financial development on CO_2 emissions in 19 emerging economies. Environmental Science and Pollution Research, 24, 12748-12757.

Sarkodie, S.A., Strezov, V. (2019), A review on environmental Kuznets curve hypothesis using bibliometric and meta-analysis. Science of the Total Environment, 649, 128-145.

Shahbaz, M., Khan, S., Ali, A., Bhattacharya, M. (2017), The impact of globalization on CO_2 emissions in China. The Singapore Economic Review, 62(4), 929-957.

Shahbaz, M., Shahzad, S.J.H., Ahmad, N., Alam, S. (2016), Financial development and environmental quality: The way forward. Energy policy, 98, 353-364.

Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014), Modeling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In: Festschrift in Honor of Peter Schmidt: Econometric Methods and Applications. Germany: Springer Science. p281-314.

Shittu, W.O., Musibau, H., Hassan, S. (2018), Revisiting the environmental Kuznets curve in Malaysia: The interactive roles of deforestation and urbanization. International Journal of Green Economics, 12(3-4), 272-293.

Subramaniam, Y. (2024), Investigating the impact of a green economy on the EKC hypothesis: Evidence from European countries. Environment, Development and Sustainability, 26(8), 21689-21708.

Teklie, D.K., Doğan, B. (2024), Analyzing the dynamics: Asymmetric effects of economic growth, technological innovation, and renewable energy on carbon emissions in Africa. International Journal of Energy Economics and Policy, 14(5), 509-519.

Tokpah, J.T., Seraj, M., Ozdeser, H. (2023), Panel examination of the impact of economic growth on carbon emissions-case of 15 emerging and advanced economies. Universal Journal of Carbon Research, 1, 43-55.

United Nations Framework Convention on Climate Change. (2015), Paris Agreement. United Nations. Available from: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

Usama, A.M., Solarin, S.A., Salahuddin, M. (2020), The prominence of renewable and non-renewable electricity generation on the environmental Kuznets Curve: A case study of Ethiopia. Energy, 211, 118665.

Vasichenko, K., Khan, I., Wang, Z. (2020), Symmetric and asymmetric effect of energy consumption and CO_2 intensity on environmental quality: Using nonlinear and asymmetric approach. Environmental Science and Pollution Research International, 27, 32809-32819.

Wajahat, M.N., Iqbal, T., Ali, S. (2024), Impact of economic growth on carbon emissions in Pakistan. Bahria University Journal of Management and Technology, 7(1), 144.

Wang, Z., Kim, M.K. (2024), Decoupling of CO_2 emissions and income in the US: A new look from EKC. Climatic Change, 177(3), 52.

Wang, Q., Zhang, F. (2021), The effects of trade openness on decoupling carbon emissions from economic growth-evidence from 182 countries. Journal of Cleaner Production, 279, 123838.

Xepapadeas, A. (2005), Economic growth and the environment. Handbook of Environmental Economics, 3, 1219-1271.

Xu, Z., Baloch, M.A., Danish, K., Meng, F., Zhang, J., Mahmood, Z. (2018), Nexus between financial development and CO_2 emissions in Saudi Arabia: analyzing the role of globalization. Environmental Science and Pollution Research International, 25, 28378-28390.

Yasin, I., Ahmad, N., Chaudhary, M.A. (2021), The impact of financial development, political institutions, and urbanization on environmental degradation: Evidence from 59 less-developed economies. Environment, Development and Sustainability, 23(5), 6698-6721.

Zhang, N., Zhang, Y., Xu, Y.J. (2012), Recent progress on graphene-based photocatalysts: Current status and future perspectives. Nanoscale, 4(19), 5792-5813.