ENVIRONMENTAL DYNAMICS IN THE CASE OF SAUDI ARABIA: IS THERE A TRADE-OFF BETWEEN GROWTH CONSTRAINTS AND ECOLOGICAL DIMENSIONS?

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Introduction

It is widely recognized that the Kingdom of Saudi Arabia (KSA) has undergone unprecedented economic growth over the past two decades, leading to significant

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human and social development that the Kingdom aims to further strengthen in the coming decades. This progress, *ceteris paribus*, would not have been possible without the country's abundant reserves of oil and natural gas. In the context of evaluating the trade-offs between economic development and environmental quality, researchers have turned to the Environmental Kuznets Curve (EKC) hypothesis, which postulates that there is a relationship between environmental degradation and economic development. According to the EKC, as an economy grows, environmental degradation increases up to a certain point. However, once a country reaches a higher level of income and development, further economic growth leads to environmental improvement rather than further degradation. The curve is typically illustrated as an inverted U-shape with the implication that the behavior of countries toward environmental quality reflects a multiphase relationship between per capita income and the ecological dimension.

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According to this curve, the first phase of development of a country is often accompanied by the deterioration in environmental quality which is accompanied by increased industrialization and the extraction of resources. However, beyond a certain income threshold, environmental degradation begins to decline as societies become wealthier, leading to the adoption of cleaner technologies and the implementation of more stringent environmental regulations.

The validity and applicability of the EKC hypothesis have been extensively debated and tested in various national and regional contexts worldwide. However, its relevance to the case of the KSA remains relatively unexplored. Given the unique characteristics of the Saudi Arabian economy, including its heavy reliance on fossil fuels and the government's commitment to economic diversification and sustainability, it is crucial to examine whether the EKC framework holds true in this specific context.

In the case of Saudi Arabia, the relationship between economic development and environmental degradation can be explained by many factors, mainly industrialization and rapid growth resulting from a sustainable increase in production. As a result, the economic development of this country is primarily driven by industrialization and the expansion of production activities, both of which demand substantial investment in the extraction, production, and extensive use of natural resources. Over time, this process, *ceteris paribus*, leads to gradual environmental degradation, including deforestation, habitat destruction, and the depletion of nonrenewable resources.

The increased production of goods and services may also result in higher levels of pollution and waste generation. Another factor that can explain this relationship is energy consumption. In fact, economic development in this country is closely linked to increased energy consumption. As economies grow, there is a rising demand for energy, often met by burning fossil fuels.

It is also recognized that the combustion of fossil fuels releases greenhouse gases (GHGs), primarily carbon dioxide (CO_2) along with others, which contribute to global warming. This, in turn, has a detrimental impact on all aspects of life, including agriculture, drought, and devastating floods. The extraction, transportation, and combustion of fossil fuels also cause localized environmental impacts, such as air pollution, water contamination, and ecosystem disruption. Additionally, population growth and urbanization contribute to this dynamic in KSA. Indeed, it is often observed that any process of economic development generates an improvement in the quality of life which manifests itself, among other things, in expanded urbanization. Consequently, as soon as cities expand, the need for infrastructure and primary goods (health, education, social stability, etc.) and natural and processed resources (energy and others) increase in the same proportions.

These processes can contribute to deforestation, land degradation, and the conversion of natural habitats into urban areas, resulting in biodiversity loss and ecological imbalances. Another factor that influences the relationship between economic growth and the environment is the role of technology and industrial practices. In this context, economic development often involves the adoption of industrial technologies and practices that may not prioritize environmental sustainability. In the pursuit of economic growth, industries may prioritize productivity and cost-efficiency over environmental considerations. Outdated technologies and inadequate environmental regulations can lead to inefficient resource use, excessive waste generation, and higher pollution levels. Finally, this relationship can also be explained and justified by consumption patterns and lifestyle changes in KSA.

Thus, as in almost all countries, economic development in KSA is often associated with changes in consumption patterns and lifestyles. As people's incomes increase, there is a greater demand for consumer goods, including products with higher environmental footprints such as energy-intensive appliances, vehicles, and luxury items. Increased consumption can lead to increased waste generation and resource depletion.

In this broader context, this article aims to conduct a focused study on Saudi Arabia and contribute to the existing literature by examining whether the country's economic development has been environmentally neutral or has come at a cost in terms of environmental degradation. Specifically, we aim to address the following research question: Does the Environmental Kuznets Curve (EKC) hypothesis apply to the case of the Kingdom of Saudi Arabia, or does it not hold at all? To answer this question, we will analyze the relevant economic and environmental indicators over a given period, taking into account factors such as GDP per capita, carbon emissions, air and water pollution levels, and environmental policy interventions.

The findings of this study will have significant implications for policymakers, environmental advocates, and researchers interested in sustainable development and environmental management in the KSA. By examining the potential existence or absence of an EKC in this unique socio-economic context, we hope to contribute to a deeper understanding of the complex relationship between economic growth and environmental sustainability in the country. Additionally, the insights gained from this research may inform evidence-based policy decisions aimed at achieving a more balanced and environmentally friendly development path for the KSA.

In the subsequent sections of this paper, we will provide an overview of existing literature. We will then describe the methodology employed for data collection and analysis, followed by the presentation and interpretation of our findings. Finally, we will discuss the implications of our research and propose recommendations for future studies and policy actions.

Literature Review

Although there is a wealth of studies on environmental issues, no consensus has been reached. The complexity of the subject deepens when examining the interplay between pollution, environmental quality, and economic growth. In fact, the divergent findings highlight the inherently skeptical nature of this problem. Two main schools of thought emerge in response to these challenges. The first suggests that both exogenous and endogenous neoclassical growth models contribute to environmental degradation, while the second contends that it is possible to reconcile economic growth with the preservation of environmental quality.

This long-standing debate is encapsulated in the theory behind the Environmental Kuznets Curve (EKC). The core idea of this theory suggests that, in the initial phase of economic development, growth comes at the cost of environmental quality. However, in a second phase, as the economy matures, environmental quality starts to improve. In other words, as countries become wealthier, they are able to allocate financial and monetary resources toward adopting growth models that utilize cleaner, more environmentally friendly technologies. In practice, empirical evidence has supported the existence of the EKC curve. For example, a study by G. Grossman and A. Krueger[1] found that air pollution levels in the United States declined after the country reached a certain level of economic development.

This result was supported by other research works such as those developed by S. Dasgupta et al.,[2] which aimed to test the nature of the causal relationships that could take place between the relational binary (quality environmental and economic growth). The authors concluded that the two variables are linked by such a strong relationship over time and that its dynamics are almost stable. The relational dynamic between economic development and environmental quality generally follows three distinct phases: the deterioration phase, the stabilization phase, and the improvement phase of environmental quality, as evidenced by the work of N. Shafiq and S. Bandyopadhyay.[3]

In contrast to the previous perspective, other studies have emphasized that the Kuznets Curve is not an inevitable outcome or a universal natural law. As T. Panayotou[4] demonstrated, there is no predetermined path for the relationship between economic growth and environmental quality, particularly in developing countries. This suggests that the dynamic between these factors can vary significantly based on context and policies.

A few years later, S. Dasgupta et al.[5] underscored the crucial role that institutional and political factors play in achieving the traditional form of the Environmental Kuznets Curve (EKC). They argued that the EKC does not naturally occur but requires political and regulatory intervention. In other words, environmental policies must include technological advancements that can decouple economic growth from environmental degradation. This calls for a deliberate effort to design a new growth model that prioritizes environmental sustainability, replacing the outdated approach that sacrifices environmental quality for economic progress.

One of the main factors determining the relationship between pollution and economic growth is technology. As countries develop, they tend to adopt cleaner technologies, which can lead to improvements in environmental quality. For example, a study by D. Stern[6] found that technological progress has been a major factor in the decline of air pollution in the United States.

It is important to note that the previous thesis is not absolute, as there are exceptions. Indeed, numerous studies have demonstrated that adopting cleaner technologies alone is not always sufficient to prevent environmental degradation. In a similar vein, S. Dinda[7] concluded that economic growth can still result in environmental harm, even when cleaner technologies are implemented. This effect occurs through increased consumption, as economic growth often drives higher consumption, which in turn places greater strain on the environment.

On the other hand, M. Cole and E. Neumayer[8] explored the relationship between demographic factors such as population density, urbanization, and air pollution. Their findings provide evidence that population growth and urbanization tend to increase pollution levels, highlighting the importance of sustainable urban planning and environmental policies.

Some research has taken a different approach by examining the role public authorities can play in improving environmental quality. Many scholars emphasize the crucial role governments can play in reducing polluting emissions, whether through regulating polluting activities—such as imposing bans or taxes—or by subsidizing industries that invest in or adopt clean technologies. For instance, A. Jaffe et al.[9] found that government policies can be effective in reducing pollution. However, it is important to recognize that, despite their success in lowering pollutants, such policies may also have negative economic impacts. P. Fredriksson et al.[10] highlighted this by showing that certain environmental regulations can lead to job losses.

N. Jalloul[11] sought to determine the extent to which non-renewable energy consumption affects ecological and environmental quality in Saudi Arabia. To achieve this, the author used oil consumption as an indirect indicator of non-renewable energy and measured environmental degradation through CO_2 emissions. Employing the ARDL econometric approach on data spanning from 1971 to 2014, the study produced three key findings. First, a long-term causal relationship exists between environmental quality and polluting emissions, demonstrating that increased use of non-renewable energy leads to greater environmental degradation. Second, the author confirmed that Saudi Arabia follows the Environmental Kuznets Curve (EKC) logic, suggesting the country is beginning to address ecological concerns by using a portion of its oil revenues to improve environmental quality and promote human and sustainable development.

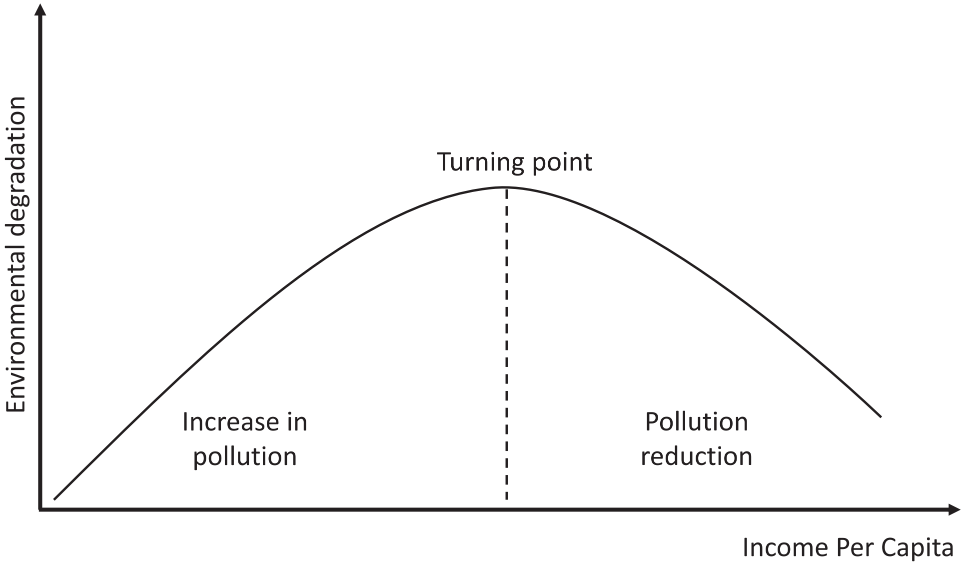
Secondly, the author confirmed that the case of Saudi Arabia conforms to the logic of the EKC. Consequently, it seems that this country is currently looking at the ecological question to internalize it by trying to transfer a good part of its oil revenues to improve the environment and for human and sustainable development.

The Dynamics of the Long-Run Relationship Between CO_2 Emissions and Economic Growth in the Case of KSA

Building on the work of R. Berahab,[12] it can be observed that the dual relationship between economic growth and environmental quality has intrigued researchers, particularly regarding how growth impacts environmental conditions and contributes to environmental improvement once achieved. This dynamic is captured by the Environmental Kuznets Curve (EKC), which describes a relationship where, initially, economic growth negatively affects the environment. However, beyond a certain maximum point (qi), as a country becomes wealthier, environmental quality improves due to a shift in societal priorities toward a cleaner environment, as demonstrated by G. Grossman and A. Krueger and T. Selden and D. Song.[13] This inverted U-shape of the EKC is illustrated in figure 1.

The lesson inherent in the logic of the Kuznets curve (CEK) is that economic growth contributes in the long run to the improvement of the quality of the environment and this is the effect of technological improvements and the transition to models of cleaner growth. But what should be noted is that the curve is conditioned by the fact that growth generates a real increase in per capita income. This wealth effect will encourage public authorities to invest in environmental research and in technologies that can contribute to improving the environment. When cleaner technologies are socially demanded, then companies will have more interest in investing in this type of technology and encouraging the community to do so as part of its social responsibility.

Figure 1
THE ENVIRONMENTAL KUZNETS CURVE



Studies Carried Out on Time Series: According to R. Berahab,[14] who we previously cited, studies on time series are relatively fewer compared to those on panel series; however, they still yield significant conclusions. Among the various works on this subject, the author highlights three studies as examples, without excluding others. The first notable study is that of J. Roca and V. Alcantara,[15] which aimed to assess whether the EKC hypothesis holds true for Spain during the period 1972-1997. The two researchers sought to determine how much current energy consumption contributes to pollution emissions. Their findings revealed that the Kuznets Curve no longer applies in this case, indicating that the use of polluting energy sources will likely persist into the future.

The second study, conducted by U. Soytas et al.,[16] sought to replicate the methodology of J. Roca and V. Alcantara in the context of the United States. Their objective was to explore the tripartite relationship between income, energy consumption, and CO_2 emissions over the period from 1960 to 2004. The results confirmed that, in the case of the United States, the EKC holds true. Additionally, the authors identified a unidirectional causal relationship, indicating that energy consumption in the United States directly leads to increased CO_2 emissions.

The third study, following a similar approach, was conducted by A. Jalil and S. F. Mahmud[17] who investigated the long-term relationship between environmental quality (measured by CO_2 emissions and energy consumption), economic growth, and international trade in the case of China. Their findings align with those of U. Soytas et al.,[18] confirming the validity of the EKC in the Chinese context. The study also established a unidirectional relationship, where economic growth leads to increased carbon emissions.

Econometric Specification

As previously mentioned, the primary goal of this article is to examine whether a long-term relationship exists between economic growth, on the one hand, and environmental quality, on the other hand. Additionally, the model includes other control variables to enhance the estimation and provide a more comprehensive analysis.

To test the long-term relationship between CO_2 emissions and the specified variables, we employed an ad hoc model, with environmental quality—measured by carbon emissions (CO2)—as the dependent variable. The model includes five explanatory variables: Gross Domestic Product (GDP), measuring wealth and economic growth; energy consumption (EC); agricultural production (AGR); life expectancy (LE); and population density (PD). This relationship is formalized in equation (1).

$$CO2_t = \alpha_0 + \alpha_1 GDP_t + \alpha_2 GDP2_t + \alpha_3 EC_t + \alpha_4 AGR_t + \alpha_5 LE_t + \alpha_6 PD_t + \varepsilon_t \tag{1}$$

For the econometric estimation to be conducted effectively, it is important to note that we will use the ARDL (Autoregressive Distributed Lag) method. This approach is advantageous because it accounts for the temporal dynamics of time series variables, making it well-suited to address issues related to forecasting, adjustments, and economic policies. But why choose this method? The decision is based on three key reasons. First, ARDL performs well with small sample sizes, which is relevant to our research. Second, unlike other methods, ARDL can be applied to time series without concerns about stationarity and does not require all variables to have the same order of integration. Finally, as Harris and Sollis[19] have pointed out, the ARDL method effectively avoids issues of endogeneity.

The ARDL approach goes through several stages. Equation (1) is transformed as follows:

$$\begin{aligned}\Delta CO2_t = \alpha_0 &+ \sum_{i=1}^{p} \beta_i \Delta GDP_{t-i} + \sum_{i=1}^{p} \gamma_i \Delta GDP2_{t-i} + \sum_{i=1}^{p} \delta_i \Delta EC_{t-i} \\ &+ \sum_{i=1}^{p} \theta_i \Delta \mathrm{AGR}_{t-i} + \sum_{i=1}^{p} \lambda_i \Delta \mathrm{LE}_{t-i} + \sum_{i=1}^{p} \kappa_i \Delta \mathrm{PD}_{t-i} + \sum_{i=1}^{p} \varphi_i \Delta \mathrm{CO2}_{t-i} \\ &+ \phi_1 CO2_{t-1} + \phi_2 GDP_{t-1} + \phi_3 GDP2_{t-1} + \phi_4 EC_{t-1} + \phi_5 AGR_{t-1} \\ &+ \phi_6 LE_{t-1} + \phi_7 PD_{t-1} + u_t.\end{aligned}$$

Before conducting the econometric analyses, it is important to highlight that the data for all the variables in our model were obtained from the World Bank database, covering the period from 1960 to 2021. However, prior to moving forward, it is methodologically essential to begin with a descriptive analysis of the statistical data for the various variables included in the model (Table 1).

Table 1
DESCRIPTIVE STATISTICS[a]

	CO2	**GDP**	**EC**	**LE**	**PD**	**AGR**
Mean	4.9961	26.3955	4.5267	4.1759	1.9259	1.1596
Median	5.3369	26.2608	4.5368	4.2364	2.0658	1.2463
Maximum	6.5204	28.1482	4.5369	4.3477	2.8181	1.8474
Minimum	0.9836	24.0544	4.4944	3.8273	0.6947	−0.2340
Std. Dev.	1.4564	1.2021	0.0123	0.1635	0.6704	0.5775
Skewness	−1.3445	−0.1317	−0.8253	−0.7998	−0.3485	−0.7835
Kurtosis	3.9464	2.0511	2.3548	2.2859	1.8279	2.6840
Jarque-Bera	20.9940	2.5052	8.1132	7.9269	4.8044	6.6005
Probability	0.0000	0.2858	0.0173	0.0190	0.0905	0.0369

[a] CO2 = carbon emissions; GDP = Gross Domestic Product; EC = energy consumption; AGR = agricultural production; LE = life expectancy; and PD = population density.

Stationarity Test: To assess the stationarity of the time series, it is essential to determine the order of integration for each one. This requires the application of standard stationarity tests, such as the Augmented Dickey-Fuller (ADF) and Philips-Perron (PP) tests. The results from these tests on our statistical data indicate that all series are integrated of order (1), meaning they are stationary after taking their first difference (Table 2).

Cointegration Test: Once the order of integration for all variables in the model has been established, we can proceed with the ARDL approach to determine whether the variables are cointegrated, which would indicate the presence of long-run equilibrium relationships between them. To achieve this, the Bound test is employed, which calculates an F-statistic (as shown in Table 3) to test the null hypothesis that the coefficients of the lagged variables are equal to zero. To assess the validity of this hypothesis, the critical values of the F-statistic are compared to the significance levels of 10%, 5%, and 1%. In our study, the F-statistic is 3.46, which exceeds the lower bounds (2.11, 2.46, 3.29) and is greater than the upper bound at the 5% significance level (3.24). Therefore, we reject the null hypothesis of no cointegration, meaning that the variables are indeed cointegrated, and there is a long-run relationship between the variables in the model.

Table 2

UNIT ROOT TEST[a]

	Augmented Dickey-Fuller Test			**Phillips Perron Test**		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
Panel A: Level series						
CO2	−3.6196	−2.7539	1.9280	−5.7322	−3.3621	1.6915
GDP	−1.5718	−2.9616	2.8002	−1.7776	−2.0668	5.1542
GDP2	−1.3738	−2.9896	2.7679	−1.4930	−2.0338	5.0490
EC	−1.2156	−1.3898	−0.5091	−1.4184	−1.9095	−0.5109
AGR	−1.9199	−1.9013	−1.1697	−1.7749	−1.7627	−1.1209
LE	−10.0131	1.1318	−1.1481	−5.4079	0.3154	3.9263
PD	−2.7302	0.6075	−0.7463	−4.0643	1.3687	4.1772
Panel B: First difference						
CO2	−6.3200	−6.7811	−5.7496	−6.2548	−6.7684	−6.7684
GDP	−4.1020	−4.3005	−4.97502	−4.0830	−4.3074	−8.5622
GDP2	−4.1698	−4.3023	−3.2031	−4.1614	−4.3106	−7.258
EC	−10.8315	−4.1184	−10.8886	−11.2078	−10.8785	−11.2502
AGR	−5.5078	−5.4604	−5.5366	−5.5078	−5.4604	−5.5366
LE	−6.2954	−5.1397	−4.0816	−5.2430	−4.3792	−4.58201
PD	−4.6323	−6.6173	−3.9937	−4.8713	−7.5420	−5.46203

[a] CO2 = carbon emissions; GDP = Gross Domestic Product; EC = energy consumption; AGR = agricultural production; LE = life expectancy; and PD = population density.

Table 3

ARDL BOUND TEST

F-statistic		**Critical values**		
3.4680	Level	10%	5%	1%
	I(0) bound	2.11	2.46	3.29
	I(1) bound	3.15	3.24	4.62

Estimation of Basic Model: ARDL Approach

To estimate the short- and long-run equilibrium of an ARDL model, CO_2 emissions per capita are considered as an endogenous variable, in order to know the main factors that adjust to the evolution of this variable assumed to be a source of environmental degradation (Table 4).

Table 4

ARDL MODEL AND ESTIMATED COEFFICIENTS OF VARIABLES (SHORT AND LONG RUN)[a]

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.***
Short-run coefficients				
C	−336.7417***	61.9587	−5.4349	0.0000
CO2(-1)	0.4632***	0.1239	3.7403	0.0006
CO2(-2)	−0.5376***	0.1360	−3.9542	0.0003
EC(-1)	2.320***	0.1226	−1.2326	0.0005
GDP(-1)	1.3640***	0.4976	2.7414	0.0092
AGR(-1)	0.4032**	0.1618	2.4914	0.0171
LE(-1)	16.3831	17.2785	0.9482	0.3489
LE(-2)	79.4258***	21.6057	3.6762	0.0007
GDP2 (-1)	−102.3538***	18.7780	−5.4507	0.0000
PD(-1)	−8.2588	20.5565	−0.4018	0.6901
PD(-2)	−8.9688	28.7677	−0.3118	0.7569
PD(-3)	41.6716	25.4528	1.6372	0.1096
PD(-4)	−28.9055***	10.2952	−2.8077	0.0078
Long-run coefficients				
GDP	17.5204***	4.5506	3.8501	0.0004
GDP2	−0.3330***	0.0878	−3.7924	0.0005
EC	20.4861***	3.9414	5.1977	0.0000
AGR	0.1369	0.1415	0.9674	0.3393
LE	0.8093	12.8141	0.0632	0.9500
PD	7.3832	8.5273	0.8658	0.3919
Diagnostic				
R-squared		0.9890		
F-statistic		194.25***		
Prob(F-statistic)		0.0000		

[a] CO2 = carbon emissions; GDP = Gross Domestic Product; EC = energy consumption; AGR = agricultural production; LE = life expectancy; and PD = population density.

Short-Run Analysis: A short-term analysis reveals that CO_2 emissions are influenced by their past values, showing a tendency to increase over time. The coefficient for GDP is positive and significant, at 1.364, indicating that a 1% increase in GDP results in a 1.364% rise in CO_2 emissions. Similarly, agricultural production (AGR) has a positive and significant coefficient of 0.4032, meaning a 1% increase in agricultural output leads to a 0.4032% increase in emissions. The positive and significant coefficient for life expectancy (LE) suggests that longer life expectancy contributes to higher CO_2 emissions, possibly linked to increased human capital formation.

Additionally, the negative and statistically significant coefficient for squared GDP (GDP^2) indicates that as the country becomes wealthier, its CO_2 emissions decrease, supporting the EKC hypothesis, which posits that pollution initially increases with economic growth but decreases after reaching a certain income level. Energy consumption (EC) plays a significant role in increasing emissions, with a 1% increase in energy use leading to a 2.32% rise in CO_2 emissions.

Interestingly, the negative and significant coefficient for population density suggests that a 1% increase in population density leads to a 28.90% reduction in CO_2 emissions. This may be due to the urbanization process, which often leads to stricter environmental regulations, adoption of cleaner technologies, and efforts to improve air quality. In Saudi Arabia, this reflects how population density contributes to reduced fuel consumption.

Long-Run Analysis: The long-term estimation results of the ARDL model show differences compared to the short-term analysis, attributed to the varying effects of certain exogenous variables on CO_2 emissions. For the GDP variable, its impact remains stable over the long term, with a positive and significant coefficient indicating that a 1% increase in GDP leads to a 17.52% rise in CO_2 emissions. Similarly, the positive and significant coefficient for energy consumption (EC) suggests that a 1% increase in EC results in a 20.48% increase in CO_2 emissions, highlighting energy consumption as a key factor in air pollution in Saudi Arabia.

Additionally, the negative effect of squared GDP (GDP^2) per capita on CO_2 emissions, as discussed in the short-term analysis, supports the notion that economic growth initially increases emissions but reduces them as wealth grows. However, the positive yet insignificant coefficients for agricultural production (AGR), life expectancy (LE), and population density (PD) suggest that these variables have a negligible impact on CO_2 emissions, indicating that they are not major contributors to air pollution in this context.

Finally, the adjusted parameter R^2 value of 0.9890 and the F-statistic of 194.25 demonstrate that the model is well-fitted and statistically significant overall. This suggests a strong explanatory power for the relationship between the variables and CO_2 emissions in the model.

Tests on the Residuals of the ARDL Regression: To ensure the validity of the model, it is essential to analyze the nature and distribution of the residuals from the ARDL regression. First, the Breusch-Godfrey Serial Correlation test was employed, confirming the absence of autocorrelation in the residuals. Second, the White test was used to check for homoskedasticity, and the results indicated no heteroskedasticity in the residuals. Third, the Jarque-Bera test confirmed that the residuals follow a normal distribution. To verify the proper specification of the linear regression model, the Ramsey Regression Equation Specification Error Test (RESET) was applied. The results, provided in Table 5, demonstrated that the model was correctly specified, with no evidence of omitted variables.

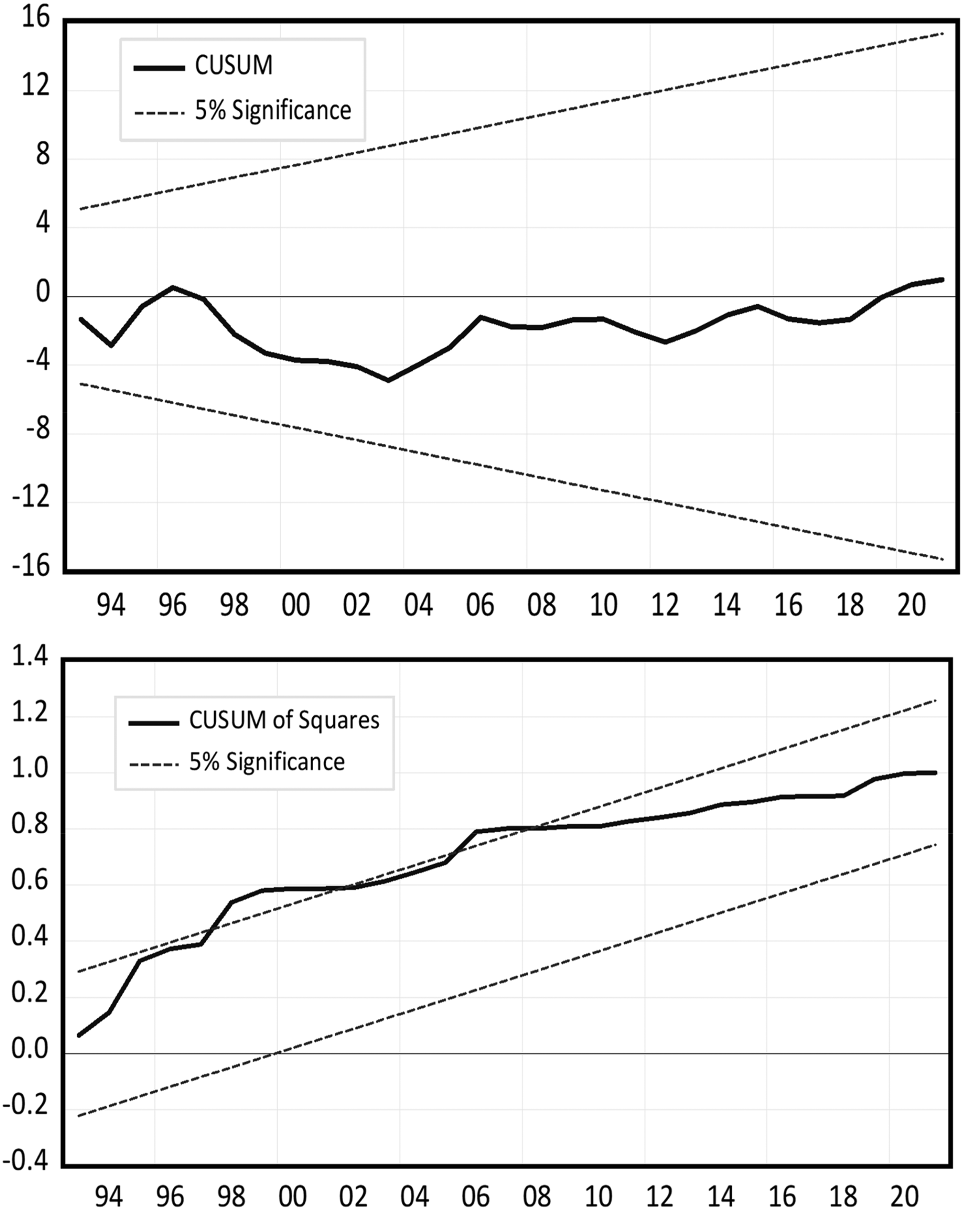
As seen in Table 5, the validation tests for the estimated ARDL model showed that the p-values for all four tests were greater than 0.05, allowing us to accept the null hypothesis (H0) for each test, confirming the robustness of the model.

CUSUM and CUSUMQ Stability Tests: Finally, it is essential to verify the stability of the model parameters in both the short and long run based on the ARDL estimation. To do this, we employed the CUSUM (Cumulative Sum Control Chart) and CUSUMQ (Cumulative Sum of Squares of Recursive Residuals) techniques. As shown in Figure 2, the statistical graphs for both CUSUM and CUSUMQ remain within the critical value bounds at the 5% significance level. This indicates that the model's coefficients are stable over time in both the short and long run.

Table 5
TESTS ON THE RESIDUALS OF THE ARDL REGRESSION

Test/Statistics	**Stat**	**P-value**
Autocorrelation		
k=1	2.1774	0.1400
k=5	5.6539	0.3410
k=10	12.9960	0.2240
Normality		
Skewness	−0.0783	0.3299
Kurtosis	2.9653	0.3843
J-B	0.0622	0.9693
Heteroscedasticity		
F-statistic	1.8555	0.0529
Obs*R-squared	26.7567	0.0837
Scaled explained SS	11.8881	0.8530
RESET Ramsey test		
t-statistic	1.3156	0.1942
F-statistic	1.7308	0.1942
Likelihood ratio	2.0358	0.1536

Figure 2
STABILITY TESTS CUSUM AND CUSUMQ



Conclusion

The objective of this study was to examine the long-term relationship between economic growth and environmental pollution in Saudi Arabia from 1960 to 2021. The analysis incorporated several variables, including gross domestic product (GDP), energy consumption (EC), agricultural production (AGR), life expectancy (LE), and population density (PD). The study utilized the Autoregressive Distributed Lag (ARDL) model, which is well-suited for small sample sizes and non-stationary time series data.

The ARDL model estimation reveals both short-run and long-run effects of the explanatory variables on CO_2 emissions. In the short run, CO_2 emissions are affected by their lagged values, with a trend of increasing emissions over time. The GDP variable shows a positive and significant coefficient, indicating that a 1% increase in GDP results in a 1.364% rise in CO_2 emissions. Similarly, agricultural production (AGR) and life expectancy (LE) have positive and significant coefficients, demonstrating their contribution to higher CO_2 emissions.

On the other hand, the squared GDP (GDP^2) variable has a negative and significant coefficient, supporting the EKC hypothesis, which suggests that while CO_2 emissions initially rise with income, they eventually decline as the economy develops. Energy consumption (EC) also has a positive and significant coefficient, highlighting its multiplier effect on CO_2 emissions. Interestingly, population density (PD) has a negative coefficient, suggesting that a 1% increase in population density leads to a 28.90% reduction in CO_2 emissions, likely due to factors such as urbanization and improved regulatory measures.

In the long run, the variable effects differ slightly. Both GDP and energy consumption (EC) continue to show positive and significant coefficients, reaffirming their sustained impact on CO_2 emissions over time. The negative coefficient of GDP^2 also remains, further validating the EKC hypothesis that emissions initially rise with economic growth but decline as income levels increase. However, the coefficients for agricultural production (AGR), life expectancy (LE), and population density (PD) become non-significant, indicating that these factors have a negligible effect on CO_2 emissions in the long run.

In conclusion, this study provides strong evidence of a long-term relationship between economic growth and CO_2 emissions in Saudi Arabia. The results indicate that GDP, energy consumption, and population density significantly influence CO_2 emissions, while agricultural production and life expectancy have minimal effects.

This research offers valuable insights for policymakers, helping them better understand the environmental challenges facing the Saudi government, particularly in light of the country's Vision 2020/2030 goals. The use of time series data has enabled more reliable and robust findings, which can be considered with greater confidence. Furthermore, the choice of the ARDL method as an econometric approach proves to be effective, especially given the non-stationary nature of the data and the focus on a single country. Notably, the study's conclusions align with the broader body of research and the prevailing paradigm in environmental economics.

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