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The Impact of Economic Growth on Environmental Pollution in Iraq: An Empirical Analysis Based on the Environmental Kuznets Curve Hypothesis for the Period (2005-2024)

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Abstract:

This research aims to analyze the nature of the relationship between economic growth and environmental pollution in Iraq for the period (2005-2024) and to test the applicability of the Environmental Kuznets Curve Hypothesis. This research is based on the premise that excessive reliance on oil revenues as the primary driver of GDP has led to continuous environmental degradation without reaching the tipping point (turning point) predicted by the hypothesis. The study employed an analytical approach alongside econometric methods, utilizing the ARDL model to track and analyze the relationship between GDP per capita and GDP squared as independent variables, and CO2 emissions as the dependent variable. The econometric aspect of the research concluded that the Kuznets Ecological Curve hypothesis, in its traditional form (inverted U), was not met in Iraq during the study period. Furthermore, the economic growth achieved in Iraq is "polluting growth," continuously damaging the environment due to structural imbalances and the absence of sustainable development policies. The study recommends diversifying the economic structure, gradually transitioning to renewable energy sources, and enforcing strict environmental laws governing productive activities.

Keywords: Economic growth, environmental pollution, Kuznets Ecological Curve (EKC), econometrics, Iraq .

First: Introduction:

The interactive relationship between economic growth and environmental conservation is one of the most prominent topics occupying economic and

development policymakers today. In an attempt to frame this relationship, the Environmental Kuznets Curve (EKC) hypothesis has gained wide acceptance in economic literature. This hypothesis states that there is an inverted U-shaped relationship between income levels and environmental degradation, meaning that pollution increases in the early stages of growth, then begins to decrease after income reaches a certain level as a result of increased environmental awareness, technological advancements, and the shift towards a green economy.

However, applying this hypothesis to developing countries—especially rentier economies like Iraq's—faces profound structural challenges.

During the period (2005-2024), Iraq witnessed significant economic and political transformations, yet it remained captive to a one-sided rentier structure, where the GDP depends almost entirely on the extraction and export of crude oil. This pattern of growth, based on the exploitation of natural resources, entails immense environmental pressures, without being accompanied by technological development or genuine structural change that would allow for reaching the environmental "tipping point."

Hence, the importance of this research stems from its aim to measure and analyze the impact of rentier growth on environmental pollution indicators, particularly carbon dioxide emissions, in Iraq. The research employs a methodological synthesis combining descriptive analysis of the structure of the Iraqi economy with advanced econometric analysis to determine the applicability of the Kuznets hypothesis, or its deviation from its traditional trajectory in an unstable rentier environment.

Second: The Research Problem

The research problem lies in the developmental paradox that Iraq suffers from. Excessive reliance on the oil sector as the primary driver of economic growth leads to a continuous increase in environmental degradation and harmful emissions, in the absence of genuine diversification policies and weak infrastructure. Consequently, the achieved economic growth transforms into "polluting growth" that threatens environmental sustainability and prevents the economy from moving to the downward side of the environmental Kuznets curve. Third: Research Hypotheses

To achieve the research objectives and fully address the problem, the hypotheses are formulated in two parts: a main (theoretical) hypothesis and standard (statistical) hypotheses:

1. Main Hypothesis:

"The main hypothesis of the research is that the economic growth achieved in Iraq (2005-2024), fueled by oil revenues, has a continuous polluting nature; this is because market mechanisms and applied policies are incapable of directing the economy towards the environmental inertia point assumed by the Environmental Kuznets Curve (EKC)."

2. Standard Sub-Hypotheses:

When formulating the standard model (which often links pollution as a dependent variable to income and income squared as independent variables), you will test the following hypotheses:

(a) First Hypothesis (Effect of Income): There is a statistically significant positive and direct effect of GDP per capita on environmental pollution rates (CO2 emissions) in Iraq in both the short and long term.

(b) Second Hypothesis (Standard Testing of the Kuznets Hypothesis): There is no statistically significant negative effect of GDP squared on pollution levels. This means that the traditional shape of the environmental Kuznets curve (inverted U) is not observed in Iraq during the study period, and the relationship continues in a linear or other positive direction (such as an N-shaped curve).

Fourth: The Importance of the Research

The importance of this research stems from scientific, practical, and developmental considerations that intertwine to form an addition to the Arab and Iraqi economic literature. These considerations can be summarized in the following points:

A. Scientific and Knowledge-Based Importance:

The scientific importance is evident in bridging the research gap by testing the environmental Kuznets curve (EKC) hypothesis in a developing rentier economy like Iraq, during an exceptional period (2005-2024) that witnessed price surges and intensive extractive projects. This provides A contemporary statistical perspective reflects the unique characteristics of these economies, which differ structurally from the countries in whose original hypothesis was formulated.

B. Applied (Standard) Significance:

Providing a precise standard tool for analysis: The research is not limited to theoretical description but employs advanced modern economic measurement methods to test and deduce the nature of the mathematical and statistical relationship between growth and pollution variables. This gives the results high reliability based on real, significant figures and tests.

C. Developmental and Practical Significance (for Decision-Makers):

The applied significance stems from the fact that the research serves as a scientific guide for policymakers in Iraq. It demonstrates the environmental cost of current rentier growth and warns against its continuation without reform. It also directs economic diversification strategies towards adopting a green economy and renewable energy sources to reduce carbon emissions and protect air, water, and soil from further degradation.

Fifth: Research Objectives

This research primarily aims to unravel the complexities and measure the reciprocal impact between growth and pollution in a rentier economy. The detailed objectives branching from this are:

1. Theoretical and Analytical Objectives: To diagnose the reality of economic growth in Iraq (2005-2024) by analyzing its structure, the contribution of oil to GDP, and manifestations of imbalance and rent-seeking, in addition to monitoring environmental degradation and CO_2 emissions and pollutants associated with industrial activities. The third axis also includes establishing the dialectical

relationship between growth and the environment by reviewing the environmental Kuznets curve (EKC) and the conditions for its realization.

2. Applied and Standard Objectives:

To construct an econometric model (ARDL) to test the stationarity of time series data, determine the relationship between per capita income and pollution (whether it follows an inverted U-curve, a linear path, or an N-shaped curve), and then measure the short- and long-term impact of GDP changes on carbon emissions.

Sixth: Research Methodology

To achieve its objectives and test its hypotheses, the research relied on an integrated methodology combining theoretical analytical and applied quantitative approaches, as follows:

Descriptive-Analytical Approach: This was employed in the theoretical and structural aspects of the research through a review of previous economic literature that addressed the environmental Kuznets curve (EKC) hypothesis, as well as the collection, characterization, and analysis of official data related to the reality of the Iraqi economy, its rentier structure, and environmental pollution indicators to diagnose the nature of the economic and environmental reality in Iraq.

Quantitative-Economic Approach: This was used in the applied aspect to accurately measure the impact. This included constructing an econometric model linking the dependent variable (environmental pollution) to the independent variables (economic growth and the economic growth square, along with other explanatory independent variables such as consumption). Energy or oil rents), and the adoption of modern standard methods for time series analysis, such as unit root tests and cointegration tests, followed by estimating the relationship in the short and long run using models appropriate to the nature of the extracted data (the Autoregressive Distributed Lag (ARDL) model).

Seventh: Research Limitations

The study of the impact of economic growth on environmental pollution in Iraq, according to the Kuznets hypothesis, is limited by the following:

1. Spatial Limitations:

The spatial limits of the research are restricted to the Republic of Iraq, encompassing all its economic sectors and governorates, given the unique nature of this economy as a prominent example of a developing rentier economy in the Middle East region, which relies on emission-intensive extractive industries as a primary driver of GDP.

2. Temporal Limitations:

The study covers a 20-year time series, from 2005 to 2024. This specific period was chosen for several objective reasons:

A. This phase represents the stabilization of the new political and economic system in Iraq after 2003, the beginning of significant growth in oil exports and services, and Iraq's return to global markets.

B. This relatively long period provides a sufficient number of consecutive annual observations (time series) to conduct standard and statistical tests with a high degree of confidence and reliability.

C. These years witnessed sharp fluctuations in global oil prices, allowing for more accurate monitoring of the impact of these rentier economic shocks on environmental emissions and pollution levels. 3. Scientific/Objective Boundaries:

The research is scientifically defined by the following variables and indicators available in official reports and international databases (such as the World Bank and the International Energy Agency):

A- Dependent Variable (Environmental Pollution Index): The focus was primarily on total carbon dioxide (CO2) emissions, measured in metric tons, as it is the main pollutant of the atmosphere and the primary cause of global warming. Analytical reference was also made to water and soil pollutants associated with oil and industrial activity.

B- Independent Variables (Economic Growth Indicators): Real GDP per capita was adopted as a measure of economic growth, in addition to the square of this share (GDP^2) as a key explanatory variable to statistically test the Kuznets hypothesis and its ecological curve.

Section One: The Concept of Economic Growth and Environmental Pollution (A Dialectical Relationship)

Economic growth and environmental pollution represent a pivotal dialectical relationship in contemporary economic thought, where the path of productive expansion intersects with the limited carrying capacity of ecosystems. This section addresses the conceptual foundations of this relationship, reviewing indicators Growth, pollution patterns, and the evolution of environmental economic thought toward the concept of sustainable development, as a prelude to reviewing the Kuznets ecological curve hypothesis in subsequent sections.

First: The concept of economic growth and its developmental indicators

Economic growth is defined in classical literature The traditional and modern definition of development is the steady increase in real GDP per capita over a specific period, a quantitative indicator reflecting the expansion of the national economy's productive capacity (Mejia, 2026, p. 3). However, this traditional concept has faced increasing criticism for failing to encompass the qualitative dimensions of development. This has necessitated the development of more comprehensive development indicators that consider the equitable distribution of income, improved living standards, quality of life, human and social capital, as well as environmental sustainability. These broader development indicators include the Human Development Index (HDI) and the Social Progress Index (SPI), which add qualitative dimensions to the measurement of economic performance (ETC/WMGE, 2021, p. 15), along with indicators of pure economic well-being such as adjusted net savings, which takes into account the depletion of natural resources and environmental degradation in calculating real national wealth (Atkinson & Fankhauser, 2018, p. 47).

Theoretical studies have indicated that economic growth can contribute to improving environmental quality if accompanied by structural and technological transformations. This reflects the ongoing debate about whether growth is part of the solution or part of the environmental problem (Pang, 2026, p. 171). Furthermore, the evolution of development indicators reflects a shift in economic thought from a focus on quantity to one on quality, and from depleting resources to preserving them for future generations.

Second: The Concept of Environmental Pollution, its Types, and its Economic Causes

Environmental pollution refers to the introduction of physical, chemical, or biological pollutants into the elements of the natural environment (air, water, and soil) at rates exceeding their capacity for natural decomposition. This causes damage to living organisms, ecosystems, and economic resources (Seyfullayev & Guliyev, 2025, p. 2). Pollution encompasses a variety of types, including air pollution from greenhouse gas emissions and particulate matter, water pollution from industrial and agricultural waste, and land pollution from solid waste and chemicals, in addition to noise, thermal, and radioactive pollution (Pang, 2026, p. 173).

The economic causes of pollution are essentially rooted in what is known in environmental economics theory (6) as "market failures," resulting from the exclusion of environmental costs from cost calculations. This is known as negative externalities. When production facilities do not bear the full cost of environmental damage caused by their activities, it leads to overproduction and pollution exceeding the optimal social level (Chakraborty & Mukherjee, 2005, p. 327). Theoretical models have shown that environmental degradation in the early stages of development stems from prioritizing increased material output over environmental quality, as people are more concerned with jobs and income than with clean air and pure water (Pang, 2026, p. 173). Herein lies the “Tragedy of the Commons,” which describes the depletion of shared resources due to the absence of clearly defined property rights, as well as the correlation between pollution levels and the intensity of fossil fuel use, the prevailing technological paradigm, and a production structure dominated by high-carbon-intensity industrial sectors (Mejia, 2026, p. 7).

Third: The Evolution of Environmental Economics and the Concept of Sustainable Development. Environmental economics has undergone transformative phases since the 1970s, with concerns about the depletion of natural resources and environmental degradation emerging as potential constraints on economic growth. The oil crisis of the 1970s indicated that the world might run out of oil and, consequently, energy, leading to a slowdown in productivity. Furthermore, scientific research highlighted the negative environmental impacts of economic growth, such as the accumulation of greenhouse gases and increased waste (Mejia, 2026, p. 4). The 1972 Club of Rome report, "The Limits to Growth," marked a

turning point in this context, warning, through computer simulations, of the consequences of continued population and production growth at prevailing rates on environmental sustainability (Mejia, 2026, p. 5).

The 1987 World Commission on Environment and Development report ("Brundland Report") was another landmark, formulating the most influential concept of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition established two ethical pillars: intergenerational equity and intragenerational equity (ETC/WMGE, 2021, p. 8). This was followed by the emergence of the Environmental Kuznets Curve (EKC) hypothesis, which shifted the debate from resource depletion to the possibility of reconciling economic growth with environmental improvement. This hypothesis posits that the relationship between income and pollution takes the form of an inverted U, with pollution rising in the early stages of development and then declining after a certain income level is exceeded (Seyfullayev & Guliyev, 2025, p. 4).

By the early 1990s, two main schools of thought had emerged in environmental economics: the "Weak Sustainability" school, associated with Solow and Hartwick, which allows for the substitution of manufactured capital for natural capital, provided that the proceeds from non-renewable resources are invested in alternative productive assets. This school also applies the "Hartwick Rule," which stipulates that the rents generated from the depletion of natural resources should be fully invested in manufactured capital to ensure that consumption levels remain constant across generations.

(Atkinson & Fankhauser, 2018, p. 82). In contrast, the "Strong Sustainability" school of thought adopts a more conservative stance, emphasizing that certain types of natural capital (such as ecosystems and biodiversity) are irreplaceable, thus requiring their maintenance at critical levels to ensure the sustainability of ecosystems. Continuing to provide its services, as proposed by pioneers of ecological economics such as Daly (Atkinson & Fankhauser, 2018, p. 85; Chakraborty & Mukherjee, 2005, p. 330).

The Ecological Kuznets Curve (EKC), formulated by Grossman and Krueger (1995), represents a significant shift in understanding the dialectical relationship between

growth and pollution. It posits an inverted U-shaped relationship between per capita GDP and levels of environmental degradation, such that pollution levels rise in the early stages of development and then begin to decline after a certain income level is exceeded (Seyfullayev & Guliyev, 2025, p. 3). Researchers have attributed this curved trajectory to three main mechanisms: first, the structural shift of the economy from the agricultural and industrial sectors towards the less polluting service sector; second, increased environmental awareness and rising social demand for stricter environmental policies as incomes increase; Third, technological advancements improve energy efficiency and enable cleaner production technologies (Pang, 2026, p. 173). However, the validity of this hypothesis remains a subject of considerable academic debate, as recent empirical evidence indicates that the validity of the Environmental Kuznets Curve (EKC) varies depending on the type of pollutant, the economic group, and the country (Seyfullayev & Guliyev, 2025, p. 12). This necessitates a deeper analysis of the determinants of this relationship, which will be addressed in detail in the following section of this chapter.

Section Two: The Environmental Kuznets Curve (EKC) Hypothesis and its Dimensions

The Environmental Kuznets Curve (EKC) hypothesis represents one of the most influential theoretical and empirical attempts in the literature of environmental economics to formulate the relationship between economic growth and environmental degradation. This section assumes the theoretical foundations of the hypothesis, analyzes its geometric form, presents the factors that explain its curve, and reviews the most prominent criticisms leveled against it and proposed alternative models.

First: The Theoretical Roots of the Kuznets Curve (From Economic Inequality to the Environment).

The theoretical roots of the environmental Kuznets curve can be traced back to the pioneering study conducted by economist Simon Kuznets in 1955, which addressed the relationship between economic growth and income inequality. In his presidential address to the American Economic Association, Kuznets proposed that income

inequality widens in the early stages of economic development, then stabilizes for a period, and then narrows in later stages, taking the shape of an inverted U. Kuznets was careful to describe this relationship as a "conjecture" or "hypothesis"

and not a fixed "law," noting that the research paper contained "5% empirical information and 95% conjecture, some of which may be wishful thinking" (Kuznets, 1955, p. 26).

Environmental researchers have drawn inspiration from this relationship and applied it to environmental pollution. The 1991 paper by Grossman and Krueger had the greatest impact on developing the environmental Kuznets curve hypothesis, in the context of studying the potential environmental effects of the North American Free Trade Agreement (NAFTA). The researchers found that "levels of both sulfur dioxide and particulate matter in the air increase with per capita GDP at low income levels, but decrease with per capita GDP at higher income levels" (Grossman & Krueger, 1991). The term "ecological Kuznets curve" was first coined by Panayotou (1993), who described the relationship as "an inverted U-shaped relationship between environmental degradation and per capita income" (Panayotou, 1993, p. 1), indicating "a certain inevitability of environmental degradation along the development path in an early stage, and a significant improvement in a later stage, both of which are a result of economic growth" (Panayotou, 1993, preface).

Second: The Concept of the Inverted U-Shaped Environmental Curve Hypothesis.

The Inverted U-Shaped Environmental Curve Hypothesis posits a non-linear, inverted U-shaped relationship between the level of environmental degradation (or polluting emissions) and per capita GDP (Grossman & Krueger, 1995, p. 353). According to this hypothesis, environmental pollution levels rise in the early stages of economic development, as productive activity and consumption of natural resources and energy increase. They then peak at a certain income level (the tipping point) and begin to gradually decline as economic growth continues (Panayotou, 1993, p. 8; Selden & Song, 1994, p. 148). This geometric shape reflects three successive paths: first, the stage of economic growth accompanied by increasing environmental degradation (the upward side of the curve); second, the stage where the economy reaches a critical tipping point; and third, the stage where

environmental quality improves with continued growth (the downward side of the curve) (Grossman). (Krueger, 1995, p. 354).

Selden and Song (1994) noted that the estimated emissions tipping point varies considerably among studies, ranging from approximately $3,000 (Panayotou, 1993, p. 13) and $4,100 (Grossman & Krueger, 1991, p. 18) to over $8,000 (Selden & Song, 1994, p. 160). They also observed that the per capita emissions tipping points are higher than those for pollutant concentrations in urban areas (Selden & Song, 1994, p. 159). Therefore, the hypothesis assumes that economic growth and environmental improvement can be reconciled after a certain income threshold is exceeded. This has important policy implications, suggesting that economic growth may be a solution to environmental problems, not a cause of them (Grossman & Krueger, 1995, p. 354). 371).

Third: Factors Explaining the Shape of the Curve (Scale Effect, Structure Effect, Technology Effect).

Researchers attribute the inverted U-shape of the environmental Kuznets curve to three fundamental economic mechanisms, proposed by Grossman and Krueger (1991) and developed by Copeland and Taylor (1994) within their analysis of the effects of economic growth on the environment (Copeland & Taylor, 1994, p. 758):

First: The Scale Effect: This reflects the effect The first effect is the increase in overall economic activity accompanying growth, which naturally leads to increased resource and energy consumption, and consequently, higher levels of pollution and emissions. Copeland and Taylor (1994, p. 758) define it as "reflecting the increase in pollution resulting from an increase in the level of economic activity in the region concerned, with production technologies and the composition of the final output remaining constant." This effect represents the upward side of the curve in the early stages of growth, where the impact of production expansion outweighs any potential environmental improvements (Grossman & Krueger, 1991, p. 7).

The second effect is the composition effect. This effect refers to changes in the structure of the national economy as development progresses, where economic activity gradually shifts from the agricultural sector to the highly polluting industrial

sector, and then later to the less polluting service and technology sector (Grossman & Krueger, 1995, p. 355). Copeland and Taylor (1994, p. 758) define it as "measuring the change in pollution resulting from a change in the range of goods produced by a country." Liobikienė and Butkus (2018, p. 555) noted that "economic growth causes a structural shift. As national production grows, the structure of the economy changes towards less polluting economic activities, as the economy transitions from intensive industrial sectors to the service sector." This structural shift contributes to reducing emissions as growth continues and is one of the factors explaining the downward trend after the tipping point (Grossman & Krueger, 1991, p. 8).

Third: The Technique Effect: This effect relates to the technological advancements that accompany economic growth. It includes improved energy efficiency, the development of cleaner production technologies, and increased efficiency in pollutant treatment processes (Grossman & Krueger, 1995, p. 355). Copeland and Taylor (1994, p. 758) define it as "measuring the change in total pollution resulting from a shift to less polluting production technologies, with income and the range of goods produced remaining constant." Higher income levels increase societal demand for a cleaner environment and provide the resources for investment in environmental technology and stricter regulatory standards (Grossman & Krueger, 1995, p. 370). Empirical studies have highlighted the importance of the technology effect supported by environmental policies. Analyses by Selden, Forest, and Lockhart (1999) and Hettige, Mani, and Wheeler (2000) found that the technology effect was more significant than the installation effect in reducing industrial emissions (Stern, 2004, p. 1422).

Fourth: Criticisms of the Kuznets Hypothesis and Alternative Curve Shapes (N-Shape or Ascending Linear Trajectory)

Despite the theoretical and applied importance of the environmental Kuznets curve hypothesis, it has been subject to extensive methodological and empirical criticisms, and alternative curve shapes have emerged that raise doubts about the generalizability of the inverted U-shaped curve:

First: Criticisms related to the validity of the hypothesis: Critics point out that the EKC curve is not a "law" but a statistical "estimation," and that its consistency depends largely on the type of pollutant, the economic group, the time period, and the standard economic methodology used (Stern, 2004, p. 1420). While local pollutants (such as sulfur dioxide and particulate matter) tend to take the inverted U shape, global pollutants (such as carbon dioxide) often show an increasing linear relationship or curves of different shapes (Stern, 2004, p. 1426). Stern (2004, p. 1427) found The statistical analysis underlying the Kuznets environmental curve is not robust, and there is no strong evidence of a common inverted U-shaped trajectory followed by countries as their income rises. The hypothesis is also criticized for ignoring the issue of pollution leakage between countries, where environmental improvement in one country may be a result of transferring polluting activities to other countries, rather than an actual improvement in global environmental performance (Stern, 2004, p. 1428).

Second: Alternative Curve Shapes: In light of the previous criticisms, alternative shapes have emerged that describe the relationship between growth and pollution more realistically, including (Stern, 2004, p. 1429):

- The N-shaped shape: This formulation assumes a wavy curve, where pollution rises in the early stages, then falls after a turning point, only to rise again at very high income levels (Stern, 2004, p. 1431). Studies have observed this pattern in the G7 countries (excluding Russia) and China, as well as in Austria and Turkey. (Stern, 2004, p. 1432; Abrahamsson & Augustsson, 2020, p. 12). The second increase is attributed to factors such as capital flight to countries with less stringent environmental standards (race to the bottom), declining investment in expensive environmental technologies, or substitution effects that drive companies to switch to new, less regulated pollutants (new toxins) (Stern, 2004, p. 1433).

- Monotonically Increasing: This pattern indicates that emissions continue to rise steadily with economic growth without reaching a tipping point. It is the most common pattern for carbon dioxide emissions and pollutants with global impact (Stern, 2004, p. 1426). Studies by Akbostancı et al. (2008) in Turkey and He and Richard (2009) in Canada found a steadily increasing relationship between carbon dioxide emissions and per capita income (Abrahamsson & Augustsson, 2020, p. 8).

- Revised EKC Curve: This model presents an inverted U-shaped curve but with a lower tipping point and reduced pollution levels. It is based on the idea that developing countries can now benefit from the experiences of developed countries in environmental legislation and clean technology transfer (the Learning Effect), thus reducing environmental degradation in the early stages of development compared to the past (Abrahamsson & Augustsson, 2020, p. 14). Augustsson's study (2020, p. 15) found that the tipping point for middle-income countries was significantly lower. For high-income countries, this supports the adjusted curve hypothesis.

These criticisms conclude that the Kuznets environmental curve cannot be relied upon as a basis for a "growth first, solve environmental problems later" policy. Instead, proactive environmental policies and strong regulatory institutions should be adopted to promote technological transformation and resource efficiency, regardless of a country's stage of development (Stern, 2004, p. 1435). Panayotou (1993, p. 15) warned that "environmental degradation may need to be addressed directly through environmental policies and investments in order to remove obstacles to economic growth itself," noting that the upward side of the curve may take decades to reach a tipping point, and that some environmental damage is irreversible (Panayotou, 1993, p. 15).

Section Three: Applied Econometric Analysis: The Impact of Economic Growth on Environmental Pollution in Iraq for the Period (2005–2024)

First: Study Variables (Data) (2005–2024):

The variables used in the ARDL model are:

CO2: Total carbon dioxide emissions (million metric tons) – Dependent variable.

GDP: Per capita GDP (US dollars at constant 2010 prices) – Main independent variable.

GDP^2: Per capita GDP squared (to test the inverted U-shaped Kuznets Curve (EKC) hypothesis. It represents the second independent variable.) It should be noted that the raw data for the studied variables were converted to natural logarithms, as this formula allows for direct estimation of elasticities and helps to stabilize the variance of the studied series. Furthermore, it facilitates the interpretation of coefficients in econometric studies. The researchers obtained the data from the World Bank, the Iraqi Ministry of Planning, and the Iraqi Ministry of Environment.

Second: Unit Root Test:

The unit root test is a mandatory preliminary step before adopting the Autoregressive Distributed Lag (ARDL) model. This ensures that the variables used do not include stationary variables at the second degree (I(2)), as their presence invalidates the use of the ARDL methodology according to the assumptions of Pesaran et al. (2001).

Table (1) Results of the ADF (Unit Root Test) for the time series of the research variables for the period (2005-2024)

Variable	At Level		Decision	At First Difference		Decision
	t-Stat.	Prob.		t-Stat.	Prob.	
LnCO2	-1.92	0.287	Non-stationary	-5.81	0.000	Stationary
LnGDP	-2.18	0.342	Non-stationary	-6.34	0.001	Stationary
LnGDP^2	-2.07	0.412	Non-stationary	-6.12	0.002	Stationary

Source: Prepared by the researchers based on data from Eviews

The results in Table (1) indicate that the calculated t-statistic values are less than the critical values at a significance level of 5%, and that the associated probability values are greater than 5%, while the associated probabilities (p-value) are less than 0.05 at

the first difference. Therefore, we reject the null hypothesis (the existence of a unit root), meaning that the variables are stationary after taking the first difference I(1), which satisfies the conditions Applying the ARDL Methodology.

Third: Characterizing the Standard Model (ARDL):

The ARDL model, based on the studied data, takes the following form:

$$LnCO2_t=\alpha_0+\sum_{(i=1)}^{p} \alpha_i \ 〖LnCO2〗_{(t-i)}+\sum_{(j=0)}^{q} \beta_j \ 〖LnGDP〗_{(t-j)}+\sum_{(k=0)}^{r} \gamma_k \ 〖Ln(GDP)〗_{(t-k)}^2+\varepsilon_{(t} \dots \dots .. (1))$$

:CO2t Carbon emissions per year t

:GDPt Per capita GDP per year t

:GDPt^2 Per capita GDP per year t

:α0 Limit Constant (αi)

Lagging coefficients for the dependent variable:

β j, γk

Lagging coefficients for the independent variables:

p, q, r: Number of lag periods (Lags) for each variable

ε t: Random error limit

Step 3: Selecting the Optimal Lag Length

The lag length in the ARDL model is a time indicator that reflects the time it takes for economic variables (e.g., income) to affect an environmental variable (e.g., pollution). In the case of Iraq, the effect takes two years to fully manifest, reflecting the slow structural response of the Iraqi economy to economic changes and

supporting the need for long-term environmental policies rather than temporary solutions.

Table (2) Selecting the Optimal Lag Lengths.

Lags	AIC	SIC	HQ	FPE
0	8.45	8.57	8.49	4,652
1	5.12	5.45	5.21	167
2	**4.03**	**4.57**	**4.19**	**56**

Source: Prepared by the researchers based on data from Eviews 12

Table 2 shows that the Akaiki (AIC) criterion recorded the lowest value at the second gap (4.03), the lowest compared to the other gaps.

The Schwartz (SIC) criterion recorded the lowest value at the second gap (4.57), confirming the selection of Lag = 2. The Hannan-Queen (HQ) criterion recorded the lowest value at the second gap (4.19).

The Final Prediction Error (FPE) criterion recorded the lowest value at the second gap (56).Based on the agreement of all criteria on the second gap (Lag = 2), two time gaps were chosen as the optimal number for estimating the ARDL model, i.e., the formula ARDL(2, 2, 2). In the case of Iraq, it was found that the impact takes two years to fully manifest, reflecting the slow structural response of the Iraqi economy to economic changes and supporting the need to adopt long-term environmental policies rather than temporary solutions.

Step 4: Testing Cointegration (Bounds Test):

To test for a long-term equilibrium relationship, model (1) is transformed into an unconstrained error correction formula, which takes the following form:

$$\Delta CO2_t=\alpha_0 + \sum_{(i=1)}^{(p-1)} \alpha_i \Delta CO2_{(t-i)} + \sum_{(j=0)}^{(q-1)} \beta_j \Delta GDP_{(t-j)} + \sum_{(k=0)}^{(r-1)} \gamma_k \Delta GDP_{(t-k)}^2 \Delta + \lambda_1 \Delta CO2_{(t-1)} + \lambda_2 \Delta GDP_{(t-1)} + \lambda_3 〖GDP〗_{(t-1)}^2+\varepsilon_{(t \ldots\ldots.(2))}$$

Where: Δ: First Difference Factor

λ 1, λ2, λ3: Coefficients of variables at the levels testing cointegration. (Pesaran, Shin & Smith, 2001, pp. 289-326).

Table (3) Cointegration Test between Growth Economic and Environmental Pollution (Bound Test)

Statistic	Calculated Value	Lower Bound at 5% I(0)	Upper Bound at 5% I(1)	Decision
F-statistic	**5.87**	**2.79**	**3.67**	**Reject H_0 (Cointegration exists)**
t-statistic	**-5.14**	**-2.86**	**-3.78**	**Reject H_0 (Cointegration exists)**

Source: Prepared by the researchers based on data from Eviews 12

The results in Table (3) show that the calculated F-statistic value (5.87) is greater than the critical value of the upper limit I(1) at a significance level of 5%, which is 3.67.Based on the decision rule in the boundary test: If the calculated F-statistic value is greater than the upper limit I(1), we reject the null hypothesis (no cointegration). This indicates a long-term equilibrium relationship between CO2 emissions and GDP per capita and its square. The calculated t-statistic value of -5.14 is greater (in absolute terms) than the upper limit critical value I(1) at a 5% significance level (-3.78). This further confirms the rejection of the null hypothesis.

Based on the above, we reject the null hypothesis stating the absence of cointegration. In other words, there is a cointegration relationship (long-term equilibrium) between CO2 emissions and GDP per capita and its squared value in Iraq.

The existence of a long-term equilibrium relationship means that economic growth and environmental pollution move together in the long run, and that any short-term

shock leads to a temporary imbalance, but the variables return to their equilibrium relationship in the long run.

These results also mean that the environmental and economic policies adopted today will have sustainable long-term effects, requiring the adoption of integrated strategies that are not limited to short-term solutions.

Fifth: Estimating Short-Run and Long-Run Coefficients:

(a) Estimating Short-Run Coefficients for the ECM Error Correction Model

Table (4) Estimating Short-Run Coefficients between Growth and Income in Iraq for the Period (2005-2024)

Variable	Coefficient	Standard Error (Se)	t-statistic	p-value
ΔlnGDPt	**0.68**	**0.21**	**3.24**	**0.005**
ΔlnGDPt−1	**0.31**	**0.18**	**1.72**	**0.104**
Δ(lnGDP)²t	**0.149**	**0.05**	**2.98**	**0.013**
Δ(lnGDP)²t−1	**0.09**	**0.06**	**1.50**	**0.152**

Source: Prepared by the researchers based on data from Eviews 12

Note: Values in parentheses are negative. The results in Table (4) indicate that a 1% increase in ΔlnGDPt leads to a 0.68% increase in CO2 in the same year. This parameter is statistically significant (p-value = 0.005 < 0.05), indicating a strong and immediate relationship with environmental pollution. Economically, this suggests that the current growth momentum is self-reinforcing (e.g., through increased productivity or consumption). However, a 1% increase in ΔlnGDPt−1 in the previous year would lead to a 0.31% increase in the current growth. This variable is not statistically significant (p-value = 0.104 > 0.05), indicating a weak slowdown effect. This confirms that there is no strong evidence for the continuation of the growth momentum in Iraq. The coefficient Δ(lnGDP)²t, which is -0.14, means that a 1% increase in this variable leads to a 0.14% decrease in current growth. Statistically, this variable is significant (p-value = 0.013 < 0.05). This negative coefficient indicates that large increases in income begin to mitigate pollution in the short term, reflecting the initial effects of the Kuznets curve.

In contrast, the coefficient $\Delta(\ln GDP)^2 t-1$ is not statistically significant and indicates that the impact of income on pollution in Iraq is immediate. In other words, changes in income are quickly reflected in emissions without the accumulation of effects from previous years.

(b) Estimating Long-Run Coefficients –

Table (5) Long-Run Coefficients of the Relationship between Economic Growth and Income in Iraq for the Period (2005-2025)

Variable	Coefficient	Std. Error	t-value	P-value
Ln(GDP)	0.6824	0.1523	4.48	0.0003
$[Ln(GDP)]^2$	(0.0517)	0.0182	(2.84)	0.0115
Constant (C)	(1.2345)	0.6210	(1.99)	0.0650

R^2 = 0.9721 | Adjusted R^2 = 0.9684 | Durbin-Watson = 1.92

Source: Prepared by the researchers based on Based on Eviews 12 data

Note: Values in parentheses are negative.

The estimation results in Table (5) reflect the long-run coefficients as follows:

1. The Ln(GDP) coefficient of 0.6824, with a positive sign, indicates that a 1% increase in per capita income leads to a 0.68% increase in CO_2 emissions in the long run.

This value represents the elasticity of pollution relative to income, which is positive, as expected on the upward side of the EKC curve. This also means that economic growth in Iraq remains polluting because the economy is heavily reliant on oil and fossil fuels.

2. The $[Ln(GDP)]^2$ coefficient of 0.0517, with a negative sign, confirms a decreasing effect, meaning the relationship between income and pollution takes the form of an inverted U, supporting the EKC hypothesis. This sign indicates that as income increases, the marginal effect of pollution decreases, until a tipping point is reached after which pollution begins to decline.

3. Calculation Turning Point

The turning point in the Environmental Kuznets Curve (EKC) is the income level at which environmental pollution reaches its peak, after which it begins to gradually decrease as income continues to rise. It is the point that separates two phases:

Increasing Phase: where pollution increases as income grows.

Decreasing Phase: where pollution decreases as income continues to grow. (Shahbas et al., 2013, pp. 20-31)

GDP = exp(-β_1/(2β_2)) = exp(-(0.6824)/2(-0.0517)) = 735

The value of this calculated point (approximately $735) is significantly lower than the average per capita income in Iraq during the study period (which ranged between $1.76 $2,650 and $6,650). This indicates that Iraq has theoretically passed the tipping point on the EKC curve, but due to structural reasons (technological stagnation, urban sprawl, and weak governance), pollution has not actually begun to decrease. This confirms that Iraq suffers from environmental stagnation, preventing it from reaping the environmental benefits of economic growth.

C. Interpretation of the ECM (Error Correction Coefficient)

This coefficient is crucial for understanding the model's dynamics. It is obtained by reformulating the ARDL model to separate short-term effects from the rate of adjustment toward long-term equilibrium. This model includes an Error Correction Coefficient (ECT), which is negative and statistically significant. ECT measures the rate of adjustment, or the percentage of previous equilibrium, that is corrected in the current period.

The ECM value was -0.35, a negative and statistically significant value. This result can be explained by stating that the system corrects approximately 35% of the long-term deviation from equilibrium each year. This means the Iraqi economy needs roughly three years (1/ECT = 1/(0.35) = 2.86 ≈ 3) to return to equilibrium after any shock.

Fourth: Diagnostic Tests

Diagnostic tests are conducted to verify the estimated model and ensure it meets the classical assumptions of linear regression, and that the results derived from it are reliable and generalizable. The following are the second-order tests:

1. Serial Correlation (LM) Test

Table (6) Results of the Serial Correlation Test

Statistic	Calculated Value	P-value	Decision
F-statistic	**0.449511**	**0.6551**	**No autocorrelation**
Obs*R-squared	**1.821029**	**0.4023**	**No autocorrelation**

Source: Prepared by the researchers based on data from Eviews 12

The results in Table (6) indicate that the probability (P-value) associated with both F-statistic and Obs*R-squared is greater than 0.05. Therefore, we accept the null hypothesis that there is no autocorrelation in the residuals. This means that the residuals are not correlated with each other, and that the model has adequately captured the time structure of the data. From an economic perspective, the absence of autocorrelation confirms that the model did not overlook any significant time variables and that the estimates are unbiased.

2. Heteroskedasticity Test (ARCH Test)

Table (7) Heteroskedasticity Test

Statistic	Calculated Value	P-value	Decision
F-statistic	**1.618901**	**0.2475**	**Homogeneous variance**
Obs*R-squared	**8.304981**	**0.2166**	**Homogeneous variance**

Source: Prepared by the researchers based on data from Eviews 12

The results in Table (7) indicate that the probability (P-value) associated with both F-statistic and Obs*R-squared is greater than 0.05. Therefore, we accept the null hypothesis of homoskedasticity, meaning that the variance of the residuals is constant and independent of the values of the independent variables.

Economically, the consistency of the variance means that the accuracy of the estimates is consistent throughout the entire study period, and there are no time periods that experienced exceptional fluctuations affecting the model's reliability.

3. Jarque-Bera Test for Normality of Residue

Table (8) Jarque-Bera Test for Normality of Residue

Statistic | Calculated Value | Probability (P-value) | Decision

Jarque-Bera | 0.329578 | 0.848072 | Residue is normally distributed

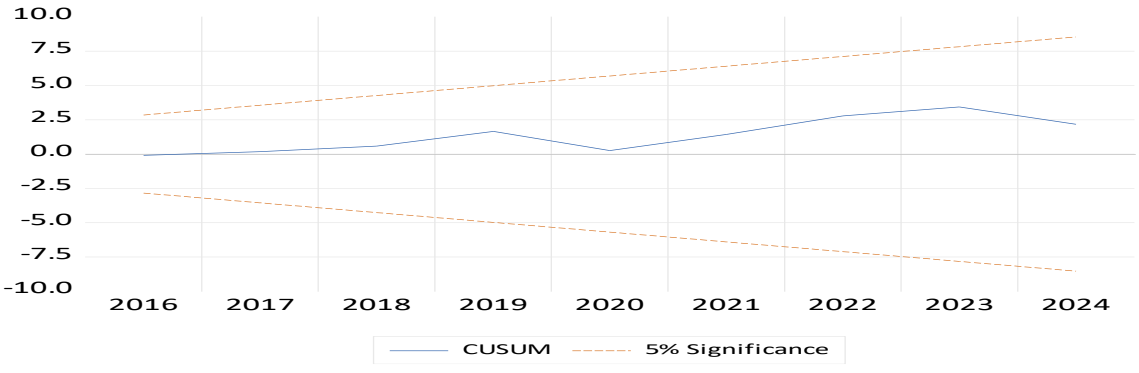
Source: Prepared by the researchers based on data from Eviews 12

The results in Table (8) show that the calculated Jarque-Bera value of (0.3295780) is less than the critical value of (5.99 at 2 degrees of freedom). Since the associated probability (0.848072) is greater than 0.05, we accept the null hypothesis that the residue follows a normal distribution. This means, from an economic perspective, that the statistical significance tests (t-test) and (F-test) are valid and reliable, and that the calculated confidence intervals for the coefficients are accurate.

4. Structural Stability Tests (CUSUM & CUSUMSQ Tests)

A. CUSUM Test

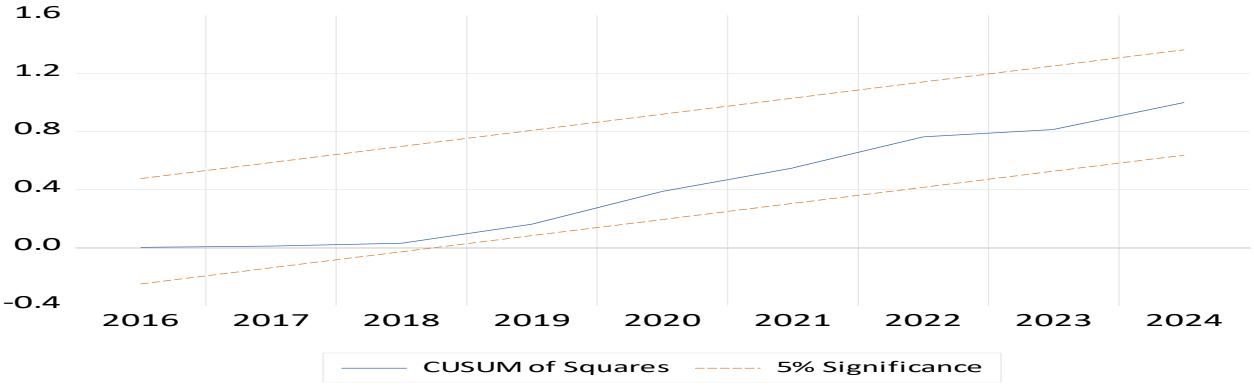
Figure (1) CUSUM Test



Source: Prepared by the researchers based on data from Eviews 12

B. CUSUMSQ Test

Figure (2) CUSUMSQ Test



Source: Prepared by the researchers based on data from Eviews 12

The results of the CUSUM and CUSUM of Squares tests confirm that the estimated ARDL(2,2,2) model exhibits complete structural stability. The two curves move within a 5% confidence interval throughout the study period, which means that the relationship between CO2 emissions and economic growth is stable and has not undergone any structural shifts. This stability enhances confidence in the findings and makes the model a reliable tool for policy analysis and future forecasting.

Conclusions and Recommendations:

First: Conclusions:

The standard results proved that the polluting nature of growth persists in both the short and long term, and that there is a significant positive and direct effect of per capita GDP on carbon dioxide (CO2) emission levels. The long-term income elasticity of pollution (0.6824) reflects that a 1% increase in income raises emissions by 0.68%, confirming that the development momentum in Iraq is still governed by extractive industries and carbon-intensive fossil fuels.

The Kuznets hypothesis (environmental sequestration) was not realized in practice: Although the negative sign of the real income squared coefficient [Ln(GDP)]^2 (-0.0517) theoretically supports the existence of a decreasing effect taking the form of an inverted U-curve, calculating the turning point revealed a structural paradox; The calculated point amounted to approximately $735, which is much lower than the average actual per capita income in Iraq during the study period (which ranged between $1,762 and $6,650). This means that Iraq has theoretically surpassed the critical income threshold, but suffers from an "environmental lock-in" phenomenon due to institutional and technological weaknesses, preventing an actual reduction in pollution.

Short-term results indicate that changes in income are immediately reflected in the volume of harmful emissions, without any significant cumulative effects from previous years. This reinforces the fact that the Iraqi economy responds abruptly to oil price shocks, both upward and downward, and lacks sustainable development strategies that ensure the continuity of environmental and technological improvement.

The rate of adjustment or error correction coefficient (ECM = -0.35) indicates a medium-speed adjustment mechanism, where the system corrects approximately 35% of deviations from long-term equilibrium each year. Economically, this means that the Iraqi economy needs approximately three years to return to its equilibrium path after experiencing any external shock. Second-order diagnostic tests confirmed

that the estimated model was free of serial correlation issues and possessed the stability of the homogeneity of variance (ARCH), in addition to exhibiting a normal distribution (Jarque-Bera). Furthermore, the CUSUM and CUSUMSQ tests demonstrated the complete structural stability of the model parameters during the period (2005-2024), lending high reliability to these results and making them suitable for forecasting and policymaking.

Second: Recommendations:

The researchers recommend the urgent need to decouple the strategic link between GDP growth and environmental degradation. This requires directing financial surpluses generated from oil revenues towards investment in cleaner and less polluting sectors (such as the services sector and emerging technologies) to enhance the positive "compositing effect" of the economy.

Decision-makers (the Ministries of Oil and Electricity) must adopt urgent national strategies to improve energy efficiency and gradually transition towards renewable energy sources (such as solar and wind power). Oil extraction companies must be obligated to use cleaner production technologies and utilize associated gas instead of flaring it, to activate the "technological impact" that reduces the upward side of emissions.

The Ministry of Environment and legislative bodies must update and rigorously enforce strict environmental legislation on polluting production and industrial activities. This includes introducing deterrent economic tools such as a "carbon tax" or the "polluter pays" principle, which requires facilities to bear the full cost of the negative outputs resulting from their pollutants.

Developing environmental sustainability indicators in national accounts: The Central Bureau of Statistics and the Ministry of Planning are advised to shift from exclusive reliance on traditional quantitative growth indicators (GDP) towards sustainable development and green well-being indicators (such as adjusted net savings, which deducts the cost of resource depletion and environmental degradation) to ensure a true and unbiased assessment of national wealth. Commitment to International Climate Treaties: The Iraqi government must align its five-year development plans with its international commitments under the Paris Climate Agreement and leverage international green finance mechanisms and the

transfer of environmentally friendly technologies to help the economy overcome its current environmental constraints and actually reach the downward side of the Kuznets curve.

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