Testing Environmental Kuznets Curve Hypothesis in Egypt: The role of industrialization, FDI and fossil fuel consumption

By

Dr. Mona Rabea Abd Elfattah Elsayed

Department of Economics, Faculty of Commerce, Mansoura University

mona_rabia@mans.edu.eg

Dr. Dina Khalil Ahmed Eletreby

Department of Economics, Faculty of Commerce, Mansoura University

d_eletreby@mans.edu.eg

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Testing Environmental Kuznets Curve Hypothesis in Egypt: The role of industrialization, FDI and fossil fuel consumption

Dr. Mona Rabea Abd Elfattah and Dr. Dina Khalil Ahmed Eletrebby

Abstract

This study explores the validity of the Environmental Kuznets Curve (EKC) hypothesis in Egypt, focusing on the impacts of industrialization, foreign direct investment (FDI), and fossil fuel consumption on greenhouse gas emissions. The autoregressive distributed lag (ARDL) model used in this study to investigate both short and long-run estimates at the same time. The results reveal a positive relationship between FDI and emissions in both the short and long term. Fossil fuel consumption also shows a consistent positive correlation with emissions, as indicated by the significant coefficients for both short-term and dynamic adjustments. Industrialization contributes positively to emissions in both the short and long run. the study finds no support for the EKC hypothesis in the Egyptian context, suggesting a linear rather than inverted U-shaped relationship between economic growth and environmental degradation. Based on the findings, it is recommended to strengthen environmental regulations, advance green technologies, and attract sustainable foreign direct investment to reduce greenhouse gas emissions and foster sustainable economic development.

Key words: Environmental Kuznets Curve, greenhouse gases emissions, FDI, industrialization, ARDL

1- Introduction:

In recent decades, the growing concentration of greenhouse gases has contributed to climate change and global warming, negatively impacting environmental quality (Elsayed,2024).

On the other hand, achieving economic growth at higher rates requires more energy use, which results in an increase in greenhouse gas emissions. Hence, the transition from fossil energy consumption to renewable energy consumption is necessary for reducing greenhouse gas emissions. On the macroeconomic level, to reduce the negative effects on the environmental condition, most countries of the world aim at turning their carbon economy into an ecological green economy (Saudi et al., 2019).

The Environmental Kuznets Curve (EKC) is one of the most common methods to analyze environmental performance and explain the path of pollution over time (Leal and Marques, 2022). Grossman and Krueger (1991) is one of the first studies that suggested the relationship between economic growth and pollution; then Kuznets (1955) shed light on the impact of development on income inequality (Ahmed and Long, 2012; Kostakis and Arauzo-Carod, 2023). The Environmental Kuznets Curve (EKC) is a hypothesized relationship between different indicators of environmental degradation and income per capita (Stern, 2004). This hypothesis forecasts that economic growth is a solution to environmental problems in the future without policy intervention (Omri et al., 2014).

The EKC is divided into three essential stages as shown in figure 1: first, In the early stages of economic development (preindustrial stage) which increasing the pollution is faster than income (Kuznets,1955). Second, the turning point, growth of emission level reaches a peak, in other words, at the level of per capita income when emissions decrease instead of increasing (Perman and stern, 2003). Third, postindustrial stage, environmental quality enriches as income per capita increases. This suggests that the indicator of environmental impact is an inverted U-shaped function of per capita income (Stern, 2003).

Economic growth affects the environmental quality through three channels (Dinda, 2004), First, the scale effect explains that growth in the scale of the economy would lead to proportional growth in pollution and other environmental effects (Stern, 2003). Second, the composition effect indicates how the economic structure changes as income increases and the environmental quality is improved (Dinda, 2004). Third, the technical effect shows that production, at this stage, depends on clean, friendly technology instead of polluted technology (Dinda, 2004; Grossman and Kruger, 1991).

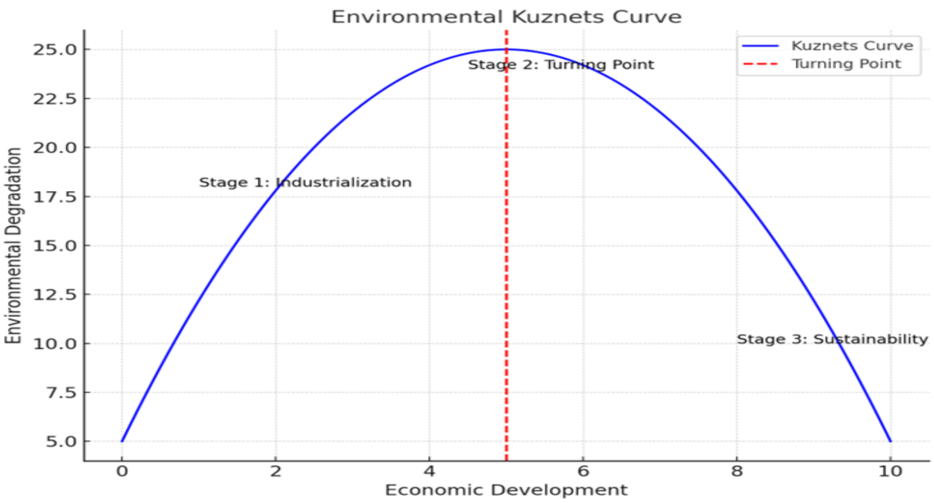


Fig.1: Environmental kuznets curve

Countries exhibit varying levels of income per capita, consumption patterns, and unique constraints. These differences mean that restrictions on carbon emissions will affect each country differently. To gain detailed insights into the economic impacts of such restrictions, it is essential to conduct analysis at the national level. Developing countries, like Egypt, possess distinct characteristics that influence policy modeling. Over the past 50 years, Egypt has focused heavily on industrial development, particularly in the construction sector. This sector became a cornerstone for goods production, job creation, and national wealth, playing a critical role in supporting the economy (Ibrahiem,2016).

However, this industrial growth, often pursued without prior environmental planning, has led to significant environmental issues, including pollution of air, water, and soil. Key industries in Egypt such as textiles, tanning, construction materials (cement, bricks, ceramics), food production, chemicals (pharmaceuticals, paints, fertilizers, detergents), metallurgy (iron, steel, aluminum, copper), and paper and pulp—are major contributors to pollution. Among these, the energy sector is the largest source of greenhouse gas emissions, followed by agriculture, industrial processes, and waste management.

Egypt faces many environmental and economic challenges. First, according to the World Air Quality Report, Egypt ranks ninth place for air pollution in the world and second place in Africa, which records 42.4 μg/m³ in 2023 (World Air Quality Report, 2023). In Egypt, the average PM2.5[1] concentration was 8.5 times the WHO annual air quality guidelines. Second, fossil fuels continued to represent 94.8% of the total energy supply as shown in figure 2, with natural gas comprising nearly 52.8%, followed by oil (42.0%) and coal (1.8%). So, CO_2 emissions from fuel combustion in Egypt increased by 118% from 2000 to 2022 (IEA, 2023). Third, Egypt's GHG rose rapidly between 1990 and 2022 by about 147%, driven by increases in both the transport sector and the power industry sector, 300% and 255%, respectively (Crippa et al., 2023).

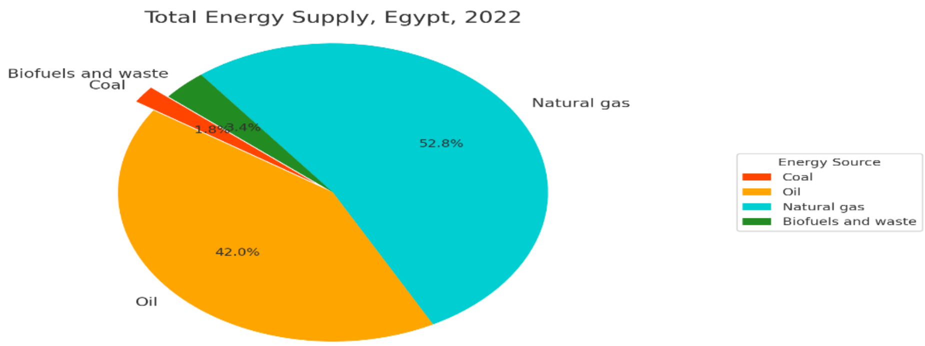


Fig.2. Total energy supply in Egypt
Source: IEA,2023

This study examines whether the Environmental Kuznets Curve (EKC) hypothesis for greenhouse gas emissions holds, focusing on the impact of industrialization, foreign direct investment (FDI), and fossil fuel consumption. The EKC suggests an inverted U-shaped relationship between environmental degradation and per capita income. In the early stages of industrialization, pollution increases rapidly as production expands, with priority given to income over environmental concerns. However, as income rises, the willingness to invest in environmental protection grows faster than income, leading to more effective regulatory institutions and a reduction in pollution levels. This study aims to explore how industrialization, FDI, and fossil fuel consumption affect greenhouse gas emissions in Egypt, providing insights into the economic impacts of these factors on environmental quality.

[1]PM2.5 is one of six common pollutants monitored and regulated by environmental agencies worldwide due to the significant impacts to human health and the environment. Common components of PM2.5 include sulfates, black carbon, nitrates, and ammonium.

The rest of the paper is organized as follows. Section 2 literature review, section 3 data and methodology, Results and discussion are presented in section 4. And section 5 conclusion and policy implication.

2- Literature review:

Greenhouse gas (GHG) emissions are the primary driver behind the rise in global average temperatures. The increase in GHG emissions can be attributed to the growth in production, consumption, and population (Leal and Marques, 2022). Numerous studies have explored the validity of the Environmental Kuznets Curve (EKC) hypothesis, incorporating various factors such as foreign direct investment (FDI) (Shaari et al., 2014; Omri and etal.,2014; Ochoa-Moreno et al., 2021) , trade (Cole, 2004), , financial development(Javid and Sharif, 2016), , GDP, squared GDP, inequality (Torras and Boyce, 1998) , deforestation (Ehrhardt-Martinez et al., 2002), and tourism (Ozturk et al., 2016). These studies employ diverse econometric methodologies and analyze both single-country and multi-country contexts.

Economic growth often relies on increased energy consumption, which consequently leads to a rise in GHG emissions. Therefore, energy consumption is a critical factor when evaluating the EKC hypothesis (Mahmood et al., 2021).

Various studies confirmed the validity of the EKC hypothesis as inverted U-shaped (Al-Mulali et al.,2014 in both upper-middle and high-income countries; Kostakis and Arauzo-Carod, 2023 in G7 countries through ecological footprint; Shahbaz et al., 2015 in middle-income countries; Ahmed and Long, 2012 in Pakistan in the long-run; Shahbaz et al.,2019 for MENA region; Apergis and Payne,2009 for six central American countries; Mahmood et al., 2021 for Egypt in the case of natural gas consumption; Saboori and Suliman,2013 when disaggregated energy consumption data was used in Malysia) and as N-shaped (Balıbey, 2015 in Turkey; Shahbaz et al., 2019 for MENA region; Mahmood and et al., 2021 for Egypt in the case of primary energy, oil ,coal, hydroelectricity and renewable consumption; Halkos, 2011) .

Another studies do not exist the EKC hypothesis (Ahmed and Long, 2012 in Pakistan in the short-run; Al-Mulali and et al.,2014 in low- and lower middle income countries; Al-Mulali and et al., 2015 in the short- and long-run; Ibrahim,2016 in Egypt; Ochoa-Moreno and et al.,2021 in 20 Latin American countries ; El-Aasar and Hanafy, 2018 in Egypt; Beşe and Kalayci, 2019 for 3 developing countries (Egypt, Kenya, and Turkey); Saboori and Suliman,2013 in Malysia when aggregated energy consumption data was analyzed). Thus, the validity of the EKC hypothesis is a debated subject.

There is various literature that has analyzed the EKC hypothesis including FDI inflows. Foreign Direct Investment is an essential driving factor of economic growth (Balıbey, 2015). On the other hand, FDI is considered as one of the main factors that could result in environmental degradation (Omri et al., 2014).

Several studies examined whether FDI supports or hinders environmental quality with different results. Therefore, in this study, the empirical evidence on the relationship between FDI and environmental degradation is classified into three categories in respect of the effects: first, studies indicated that there is no effect of FDI on CO2 emissions, such as Shaari et al. (2014). Second, studies emphasized that FDI hampers environmental quality (Omri et al., 2014; Ochoa-Moreno et al., 2021; Al-Mulali et al., 2015; Balıbey, 2015). Third, studies found that FDI promotes the environmental quality through transferring environmentally friendly techniques of production from developed countries to developing countries (Shahbaz et al., 2015). These findings have been found by Tamazain and Rao (2010) and Shahbaz et al. (2015) in high-income countries; Shahbaz et al. (2015); Mahmood et al. (2019) in Egypt.

Shaari et al. (2014) illustrated the effects of FDI and economic growth on CO2 emissions for 15 developing Asian countries between 1992 and 2012 by using FMOLS. They found that there is a co-integrated relationship between FDI, economic growth, and CO2 emissions using the Johansen co-integration. Also, the results showed that FDI does not have any effect on CO2 in the long run. So, any rise in FDI does not have any impact on the environment. According to the findings from Granger causality based on VECM, there is no relationship between FDI, economic growth, and CO2 emissions in the short run.

Omri et al. (2014) examined the causality relationship between CO2 emissions, FDI, and economic growth, applying dynamic simultaneous equation panel data models for 54 countries between 1990 and 1991. The study has categorized the countries for 3 regional sub-panels: Europe and Central Asia, Latin America and the Caribbean, and the Middle East, North Africa, and Sub-Saharan Africa that rely on a growth framework. There is a bidirectional causality between FDI and CO2 emissions for all panels, except Europe and North Africa. FDI inflows have a positive impact on CO2 emissions; a 1% increase in FDI flows increases the CO2 emissions by 0.19%.

Shahbaz et al. (2019) analyzed the relationship between Foreign Direct Investment (FDI) and carbon emissions for the MENA region over the period 1990 and 2015 through the Generalized Method of Moments (GMM). According to the GMM's findings, the study confirmed both an inverted U- and N-shaped fit EKC hypothesis and suggested that economic development, foreign direct investment (FDI), and biomass energy have a significant impact on CO2 emissions. Al-Mulali et al. (2015) investigated the EKC hypothesis between 1981 and 2011 in Vietnam using ARDL. The results showed (i) fossil fuel energy consumption raises pollution. (ii) The EKC hypothesis does not exist due to the positive relationship between GDP and pollution in both the short and long run. (iii) FDI has a positive effect on environmental pollution in the long run because of investing in polluted-intensive industries rather than the clean industries in the developing countries.

Balıbey (2015) examined the causality relationship between economic growth, CO2 emissions and FDI as well, tested the EKC hypothesis for Turkey over the period 1974 to 2011. According to impulse-response functions, FDI has a positive effect on CO2 emission in the long run. In addition, the EKC hypothesis is valid in which the results indicated an N-shaped curve.

Ochoa-Moreno et al. (2021) aimed to examine the effects of FDI on CO2 emissions in 20 Latin American countries between 1990-2018 which applied BDOLSs and DOLSs. The results illustrated that FDI has affect negatively on environment quality which means an increase in FDI results in increasing CO2 emissions and the EKC hypothesis is not valid.

Shahbaz et al. (2015) showed the nonlinear relationship between FDI, economic growth, energy consumption and CO2 emission for 99 countries over the period 1975-2012 using FMOLS. The findings summarized the validation of the EKC as an inverted U-shaped curve termed the pollution haven hypothesis. Also, FDI declines CO2 emissions at the economic growth stage in high-income countries, but not in low-income countries. These results are consistent with Tamazain and Rao (2010) tested the EKC hypothesis for 24 transition economies over the period 1993-2004 applying GMM estimation. The results confirmed empirically the EKC hypothesis, and higher levels of FDI result in lowering CO2 per capita emissions. Similarly, Mahmood et al. (2019) highlighted that FDI has a role in improving the environmental quality thanks to foreign investors applying clean technology.

To verify the EKC hypothesis, almost all the previous studies used GDP and GDP square. Both variables are included to identify that if an inverted U-shaped relationship between environmental pollution indicator and GDP with its square is found the EKC hypothesis exists (Al-Mulali et al., 2015). An increase in economic growth leads to a rise in CO2 emissions. This, in turn, will result in increasing environmental degradation (Shaari,2014 in the developing countries; Omri and et al., 2014 in the countries of the Middle Eastern, North African, and sub-Saharan; Balıbey, 2015 in Turkey, Beşe and Kalayci, 2019 in 3 developing countries (Egypt, Kenya, Turkey); Beşe and Kalayci (2019), according to Impulse response analysis, higher GDP leads to increase CO2 in Egypt, 2.19% and 2.29%, respectively.

Although energy consumption is a factor of production, it is the main source for environmental degradation. So, several studies highlighted the positive relationship between energy consumption and environmental degradation (Ahmed and Long,2012 in Pakistan; Saboori and Suliman, 2013; Acaroglu et al.,2023 in Turkey; Al-Mulali et al.,2012 in all income groups; Al-Mulali et al., 2014 in all income groups; Beşe and Kalayci, 2019 in 3 developing countries (Egypt, Kenya, and Turkey).

Acaroglu et al. (2023) analyzed the relationship between environmental degradation, economic growth, trade openness, primary energy consumption, coal consumption, and hydroelectricity consumption for Turkey over the period 1971 to 2015 applying ARDL and confirmed that the EKC hypothesis is valid. The findings indicated that a 1% increase in both primary energy consumption and coal consumption increases CO2 emissions by 0.5394% and 0.3379%, respectively, in the short run. While an increase in Primary energy consumption has no effect on CO2 emissions in the long-run, a 1% increase in coal consumption increases CO2 emissions by 0.1896% in the long-run. While Beşe and Kalayci (2019), according to Impulse response analysis, energy consumption has positive effect on CO2 in the short- and long-run, 8.66% and 8.69%, respectively.

When investigating the EKC hypothesis through various variables like energy imports that may be fossil fuels or renewable energy. Thus, its effect on environmental quality is different.

Utilization of energy imports in capital-intensive goods production can result in energy consumption levels adding to the current production in the country. Therefore, the net impact of energy imports increasing can be either positive or negative, especially regarding developing economies (Tamazain and Rao, 2010). For instance, Turkey depends highly on imports in its energy use, and this results in a current account deficit so, its dependence on energy imports is harmful for the economic and environmental level (Acaroglu et al., 2023). Population also is a factor driving to the environmental degradation (Panayotou, 1997), so it is important to take population into consideration as a variable in the analysis like (Ahmed and Long, 2012) in Pakistan.

There are some studies that tested the EKC hypothesis in Egypt (Ibrahim,2016; El-Aasar and Hanafy, 2018; Beşe and Kalayci, 2019). Ibrahim (2016) confirmed the EKC hypothesis does not exist in the short and long run in Egypt through examining the relationship between CO2 emissions, economic growth, energy consumption, trade openness and population density applying Johansen cointegration analysis over the period 1980 -2010. The results have emphasized the long run relationship between the variables as detailed, there is positive bidirectional causality relationship between economic growth and CO2 emissions while there is positive unidirectional relationship from economic growth to energy consumption. Also, there is unidirectional causality from trade openness to economic growth, emphasizing the importance of trade in improving economic growth. El-Aasar and Hanafy (2018) followed the previous study as the EKC hypothesis does not exist in Egypt that tested over the period 1971-2012 through investing the relationship between GHG emissions, GDP per capita, renewable energy consumption and the trade openness applying ARDL. The results indicated higher economic growth leads to a rise in GHG emissions, thus increasing environmental degradation. Beşe and Kalayci (2019) emphasized that the EKC hypothesis is not valid in Egypt during the period from 1971 to 2014. Based on the findings of the Johansen Co-integration test, there is no co-integrated relationship between CO_2 emissions, GDP, and energy consumption. Conversely, Mahmood et al. (2019) confirmed that the EKC hypothesis is valid in Egypt for the period from 1990 to 2014 using the ARDL approach. According to the ARDL results, the study suggested that Egypt has been in the second stage of the EKC since 2003, implying that economic growth may have beneficial effects on the environment.

Although there are many studies that have examined the environmental Kuznets curve, with varying results, our study stands out in several ways. The study relied on a variety of variables, including manufacturing, fossil fuel imports, fossil fuel consumption, and foreign direct investment, which adds a new dimension to the analysis. In addition, unlike most studies that focus on carbon dioxide emissions alone, this study used greenhouse gas emissions in general, which provides a more comprehensive and integrated view of the environmental impact of economic development.

3- Data and Methodology

The current study uses the EKC model to investigate the relationship between greenhouse emissions, economic growth, fossil fuel consumption, foreign direct investment (FDI), fossil fuel imports, Industrial Value Added (INDU), and population growth.

The Environmental Kuznets Curve (EKC) hypothesis postulates an inverted U-shaped relationship between economic growth and environmental degradation Kuznets (1955). To capture this dynamic, real GDP per capita (Y) and its squared term (Y^2) are included as the primary economic indicators in the analysis. Greenhouse gas emissions (Tghgpc) serve as indicators of environmental degradation. Consumption and imports of fossil fuels are pivotal to Egypt's economic expansion and substantially exacerbate environmental degradation. With fossil fuels accounting for 88% of Egypt's electricity production in 2023(IEA,2024). And being a key component of industrial activity, adding these variables into the model is essential. This enables a complete examination of the combined impact of domestic energy consumption and reliance on external energy sources on environmental outcomes, providing greater insight into how energy dependence influences environmental conditions.

The value added by the industrial sector is viewed as critical due to its significant contribution to economic development and direct impact on environmental deterioration. As the industrial sector is one of the most energy-intensive and emitting industries, its inclusion provides important insights into how industrialization affects environmental quality. Furthermore, Population growth has also been identified as a critical component, as it increases demand for resources and energy, putting further strain on the ecosystem. Table 1 shows the variables, their explanations, their units, and their sources

Table 1. Data and definitions of variables

Variable	explanations	Source
Tghgpc	Total greenhouse gas emissions per capita (t CO2e/capita)	World Development Indicators
FDI	Foreign direct investment, net inflows (% of GDP)	World Development Indicators
Y	GDP per capita growth (annual %)	World Development Indicators
Y^2	GDP per capita square	World Development Indicators
POP	Population growth (annual %)	World Development Indicators
INDU	Industry, value added (annual % growth)	World Development Indicators
Focsl	Fossil fuel energy consumption (% of total)	World Development Indicators
Fuel-imp	Fuel imports (% of merchandise imports)	World Development Indicators

When the conditions $\beta_1 > 0$ and $\beta_2 < 0$ are met for the estimated equations in this study, the Environmental Kuznets Curve (EKC) hypothesis for emissions is considered valid. The threshold value or turning points is calculated as $Y = -\frac{\beta 1}{2\,\beta 2}$. Based on the outlined framework, the log-linear quadratic model used to test the EKC hypothesis for Egypt incorporates the following variables(as shown in equation 1) : total greenhouse gas emissions per capita measured in tons of CO_2 equivalent per capita, foreign direct investment as a percentage of GDP), annual GDP per capita growth (Y) along with its square (Y^2) to capture non-linear effects, population growth, annual growth of industrial value-added, fossil fuel energy consumption as a percentage of total energy use, and fuel imports as a percentage of total merchandise imports. The inclusion of both linear and quadratic GDP terms allows for testing the inverted U-shaped relationship central to the EKC hypothesis, offering insights into whether economic development in Egypt leads to environmental improvement after reaching a certain income threshold.

$$\text{Tghgpc} = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \beta_3 \text{Focsl} + \beta_4 \text{Fuel-imp} + \beta_5 \text{FDI} + \beta_6 \text{IND} + \beta_7 \text{POP} + \epsilon_t \qquad (1)$$

The descriptive statistics for all the variables used in this analysis are presented in Table 2:

Table 2. Descriptive statistics

variables	Tghgpc	Y	FDI	POP	Focsl	Fuel-imp	IND
mean	2.831707	2.856138	2.111011	2.219695	93.83375	7.523619	5.712957
median	2.782424	2.330412	1.553499	2.196283	94.07344	5.709745	5.384586
maximum	3.741524	10.78415	9.348567	2.755098	98.46009	18.69008	16.61376
Minimum	1.619444	-1.283898	-0.204543	1.543565	85.96118	0.809954	1.167652
Standard deviation	0.656049	2.292030	2.033622	0.303145	3.670749	5.567444	4.306328
skewness	-0.225275	0.969372	٠.831598	0.021547	-0.738032	0.495854	0.688835
kurtosis	1.913520	4.380486	1.663455	2.644888	2.480749	1.764626	2.722586
Jarque bera	3.055087	1.74505	2.38979	0.287914	5.406858	5.646672	4.361306

-Methodology

In this study, the Autoregressive Distributed Lag (ARDL) bounds testing approach is employed to examine the relationship between greenhouse gas emissions per capita and various economic, demographic, and energy-related factors in Egypt. The ARDL method, introduced by Pesaran et al. (2001), offers several key advantages that make it particularly suitable for this analysis. First, the ARDL framework is flexible in handling variables with mixed orders of integration. It allows for the inclusion of both stationary variables I (0)) and variables integrated of order one I (1) within the same model, provided none of the variables exhibit integration of order two I(2)). This flexibility is critical in the context of environmental and economic data, where variables often exhibit diverse integration properties. Second, the ARDL approach is well-suited for studies with relatively small sample sizes. Third, the ARDL model distinguishes itself by capturing both short- and long-run dynamics between the dependent and independent variables. Given these strengths, the ARDL bounds test is used to explore the potential cointegration among total greenhouse gas emissions per capita and explanatory variables such as GDP per capita growth, foreign direct investment, industrial growth, population growth, fossil fuel energy consumption, and fuel imports. The model helps identify both short-term fluctuations and long-term trends, thereby offering valuable insights into the Environmental Kuznets Curve (EKC) hypothesis in the context of Egypt's economy. Equation (2) illustrates the ARDL model applied in this study to assess the existence of a cointegration relationship among the selected variables.

$$\Delta Tghgpc_t = \propto_0 + \sum \propto_1 \Delta Y_{t-i} + \sum \propto_2 \Delta Y2_{\ t-i} + \sum \propto_3 \Delta Focsl_{\ t-i} + \sum \propto_4 \Delta Fuel - imp_{\ t-i} + \sum \propto_5 \Delta FDI_{\ t-i} + \sum \propto_6 \Delta IND_{\ t-i} + \sum \propto_7 \Delta POP_{\ t-i}\ \varphi ECT_{t-1} + \beta_1 Y_{t-1} + \beta 2\ Y2_{t-1} + \beta 3\ Focsl_{t-1} + \beta 4\ Fuel - imp_{t-1} + \beta 5\ FDI_{t-1} + \beta 6\ IND_{t-1} + \beta 7\ POP + \varepsilon_t \qquad (2)$$

Where Δ is First Difference, $\propto_0$ is Intercept, $\propto_1 : \propto_7$ short term parameters, $\beta_1 : \beta_7$ long term parameters, φ Error Correction Term, ε_t residuals.

Equation No. (2) can be divided into two equations as follows:

The first equation: The error correction model (ECM), developed to estimate the short-term coefficients, is presented in Equation (3) as follows:

$$\Delta Tghgpc_t == \propto_0 + \sum \propto_1 \Delta Y_{t-i} + \sum \propto_2 \Delta Y2_{\ t-i} + \sum \propto_3 \Delta Focsl_{\ t-i} + \sum \propto_4 \Delta Fuel - imp_{\ t-i} + \sum \propto_5 \Delta FDI_{\ t-i} + \sum \propto_6 \Delta IND_{\ t-i} + \sum \propto_7 \Delta POP_{\ t-i}\ \varphi ECT_{t-1} + \varepsilon_t \qquad (3)$$

The second equation represents long-term information and takes the following form:

$$\Delta Tghgpc_t = \beta_1 Y_{t-1} + \beta 2\ Y2_{t-1} + \beta 3\ Focsl_{t-1} + \beta 4\ Fuel - imp_{t-1} + \beta 5\ FDI_{t-1} + \beta 6\ IND_{t-1} + \beta 7\ POP + \varepsilon_t \qquad (4)$$

To validate the statistical results from the ARDL model, diagnostic tests are performed. Additionally, the stability of the model's coefficients is assessed using CUSUM and CUSUMSQ tests. The methodology is summarized in Figure 3.

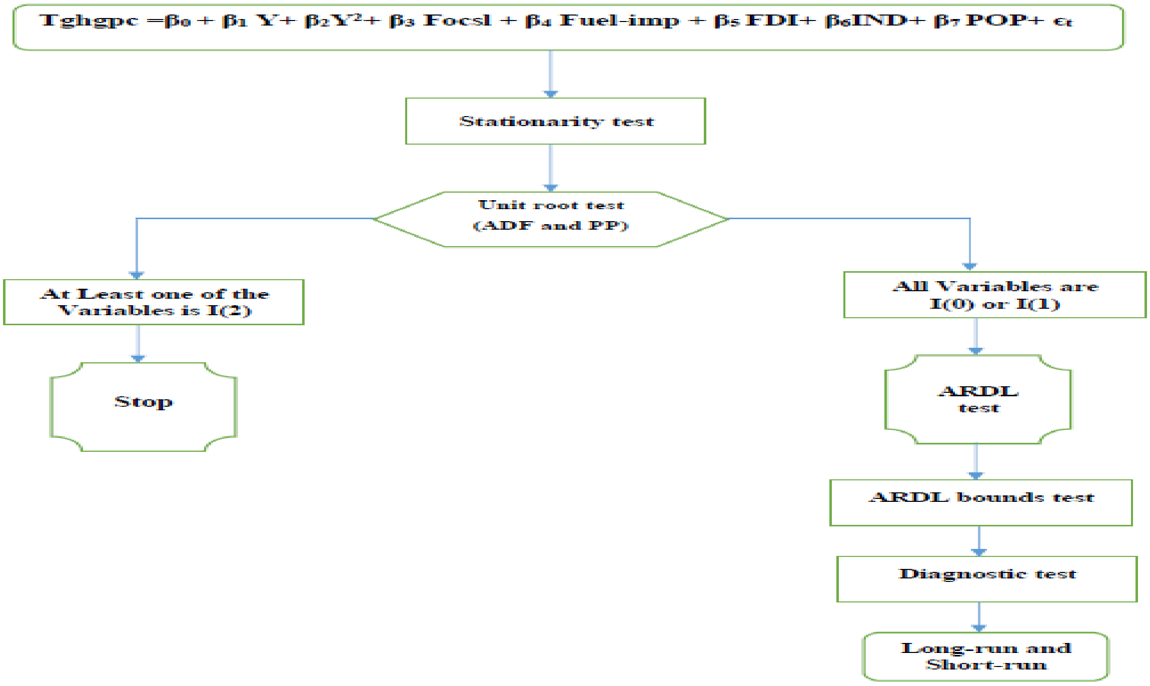


Fig.3: Diagram of the Methodology applied

Empirical Results and discussion:

1-unit root test

Initially, the stationarity of the variables is evaluated using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. The results are summarized in Table 3.

The results of the stationarity tests, including the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, reveal that several variables in the model exhibit different levels of integration. For the variables **FDI**, **Y**, **Y²**, and **Tghgpc**, the results show stationarity at the first difference for both tests, as indicated by their significant t-statistics (ADF and PP values are well below the critical values) and p-values less than the 5% significance level. This suggests that these variables are I(1), meaning they become stationary after first differencing. Conversely, **POP** and **INDU** show stationarity at the level in both tests, as their p-values are below the 5% threshold, indicating they are I(0), meaning they are stationary without any differencing required. However, the variables **Focsl** and **Fuel-imp** do not appear to be stationary at the level for either test, as their p-values are greater than the 5% significance level, requiring first differencing to achieve stationarity. Overall, the results suggest that most of the variables are either I(0) or I(1), which is suitable for conducting the ARDL bounds testing approach for cointegration analysis.

Table 3: the ADF and PP unit root test results

		ADF TEST		PP test	
variables	level	Probability	T-static	prob	T-stat
FDI	At level	0.9591	1.825163	0.0802	-3.283361
	First difference	0.0000***	-6.590708	0.0000***	-6.956834
Y	At level	0.0940	-1.644347	0.0027	-4.608211
	First difference	0.0000***	-10.47022	0.0001	-20.14939
Y^2	At level	0.0035**	-4527262	0.0010**	-4.952405
	First difference	0.0000***	-10.93994	0.0001***	-25.06713
Tghgpc	At level	0.9275	-1.050142	0.8907	-1.242540
	First difference	0.0001***	-5.635174	0.0001***	-5.716041
POP	At level	0.1164	-3.103171	0.7901	-1.573948
	First difference	0.0045**	-2.902812	0.0038**	-2.957437
INDU	At level	0.0013**	-4.846807	0.0535*	-1.916589
	First difference	0.0000***	-6.354500	0.0001***	-4.087961
Focsl	At level	0.9615	-0.776346	0.9814	-0.483651
	First difference	0.0000***	-9.377732	0.0000***	-9.299503
Fuel-imp	At level	0.8702	-0.559008	0.6623	-1.213238
	First difference	0.0000***	-6.593191	0.0000***	-6.763162

*The ADF test lag lengths were selected using the Schwarz Information Criterion (SIC), while the PP test lag lengths were determined using the Newey-West criterion for robust error adjustments.

2- ARDL Framework

-The ARDL bounds test results

To determine the optimal lag length for resolving the issue of autocorrelation in the residuals, the Akaike Information Criterion (AIC) suggests that the ideal number is (1, 4, 3, 1, 3, 4, 0, 4), as illustrated in the following table 4:

Table 4. The ARDL bounds test results

F-Bounds Test	Null Hypothesis: No levels relationship				
Lag length	Test Statistic	Value	Signif.	I(0)	I(1)
((1, 4, 3, 1, 3, 4, 0, 4)	F-statistic	4.353994	10%	1.92	2.89
	k	7	5%	2.17	3.21
			2,5%	2,43	3,51
			1%	2,73	3,9

Table 4 shows the results of the F-Bounds test, which include the F-statistic, critical values, and their interpretations. This test assesses the existence of a long-term equilibrium relationship among the study variables. The null hypothesis (H_0) states there is no cointegration, while the alternative hypothesis (H_1) suggests cointegration exists. The F-statistic of 4.353994 surpasses the upper critical bound for I (1) at all significance levels. As a result, the null hypothesis is rejected, confirming strong evidence of a long-term cointegrating relationship between the variables.

<u>-Results of autoregressive distributed lagged short run and long run</u>

Table 5: The ARDL short-run estimation and Error Correction model results**.**

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(POP)	0.654132	0.277848	2.354282	0.0284
D(POP(-1))	-0.563154	0.420391	-1.339596	0.1947
D(POP(-2))	-0.373243	0.443275	-0.842012	0.4093
D(POP(-3))	0.887517	0.285921	3.104061	0.0054
D(INDUS)	0.010263	0.004379	2.343680	0.0290
D(INDUS(-1))	0.056903	0.008160	6.973794	0.0000
D(INDUS(-2))	0.026159	0.005954	4.393895	0.0003
D(GDPS)	0.007423	0.001421	5.222308	0.0000
D(GDP)	-0.058561	0.011112	-5.270307	0.0000
D(GDP(-1))	-0.077698	0.013311	-5.837283	0.0000
D(GDP(-2))	-0.029669	0.007436	-3.989757	0.0007
D(FUELIMPO)	0.037225	0.007674	4.850784	0.0001
D(FUELIMPO(-1))	0.021995	0.006936	3.171162	0.0046
D(FUELIMPO(-2))	0.007009	0.006452	1.086293	0.2897
D(FUELIMPO(-3))	0.010745	0.006543	1.642275	0.1154
D(FDI)	0.005214	0.008055	0.647352	0.5244
D(FDI(-1))	0.010704	0.008052	1.329431	0.1980
D(FDI(-2))	0.038867	0.009232	4.209837	0.0004
D(FDI(-3))	0.046675	0.009496	4.915209	0.0001
CointEq(-1)*	-0.383130	0.052082	-7.356217	0.0000

The short-run results from the Error Correction Model (ECM) provide clear insights into how the variables interact. Population growth shows a statistically significant positive effect on greenhouse gas emissions, with a coefficient of 0.654. This suggests that an increase in population growth leads to higher emissions in the short run. However, the lagged effects of population growth are not significant, meaning past population growth has little impact on emissions beyond the first period.

Industrial output has a negative impact in the first period, with a coefficient of -0.010, indicating a short-run inverse relationship with emissions. However, in the following periods, its lags show a positive relationship, with significant positive coefficients (0.0569 and 0.0262). This suggests that industrial growth has a delayed positive effect on emissions. GDP per capita has a positive effect on emissions, with a coefficient of 0.0074. This means that as GDP per capita increases, emissions tend to rise. However, overall GDP growth (D(GDP)) shows a negative relationship, with a coefficient of -0.0586. This could be the result of other factors in the economy that are impacting emissions in the short term. Fuel imports consistently show a positive and statistically significant relationship with emissions in the short run, across multiple lags, indicating that higher fuel imports lead to higher emissions. Foreign direct investment (FDI) shows mixed results. Only some of the lagged effects are significant, with positive coefficients, suggesting that FDI has a delayed effect on emissions. The cointegration error correction term (CointEq(-1) is negative and statistically significant at -0.3831, with a t-statistic of -7.356. This indicates that the model is correcting past imbalances at a rate of 38.3% per period, meaning it adjusts toward long-term equilibrium after a shock.

In the long run as shown in table 6, (POP) shows a positive relationship with emissions, this indicates a marginally significant impact on emissions, suggesting that population growth is positively related to emissions in the long term. The industrial sector also has a positive relationship with emissions, indicating that industrial output may contribute to higher emissions. The squared GDP per capita is statistically significant, suggesting a positive effect on emissions. However, GDP itself (GDP) does not show a significant relationship with emissions, as its coefficient of 0.043120 has a t-statistic of 0.480811 and a high p-value of 0.6356. Similarly, fuel imports show a weak, non-significant negative relationship with emissions, while fossil fuel consumption (FOCSL) has a positive and statistically significant impact on emissions. Foreign direct investment (FDI) is positively associated with emissions indicating a statistically significant positive impact on emissions. Overall, the results indicate that population, industrial output, fossil fuel consumption, and foreign direct investment play significant roles in determining greenhouse gas emissions per capita in the long run, while GDP and fuel imports do not show substantial effects.

Table 6. ARDL long-run coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
POP	0.261668	0.118324	2.211462	0.0579
INDUS	0.231219	0.113250	2.041668	0.0539
GDPS	0.033372	0.014750	2.262575	0.0344
GDP	0.043120	0.089681	0.480811	0.6356
FUELIMPO	-0.007815	0.015579	-0.501677	0.6211
FOCSL	0.095808	0.044710	2.142865	0.0440
FDI	0.306974	0.150728	2.036607	0.0495
C	-5.501313	4.340115	-1.267550	0.2188

-Impulse Response Function Analysis

The impulse response function results as shown in table 7 and figure 4 indicate the dynamic effects of various macroeconomic variables on greenhouse gas emissions (TGHG) over ten periods. Population (POP) has a positive impact on emissions in the early periods, but this effect diminishes and turns negative in later periods, potentially reflecting mitigation efforts or demographic shifts. Industrialization (INDUS) initially exhibits a slight negative impact, which becomes positive in the long run, suggesting that industrial growth increases emissions over time. GDP per capita (GDP) and its square (GDPS) consistently show a positive effect on emissions, highlighting the non-linear relationship between economic growth and environmental degradation, where higher levels of GDP amplify emissions. Fuel imports (FUELIMPO) contribute positively to emissions in the short term but shift to a negative impact in later periods, possibly due to a transition toward cleaner energy sources. Fossil fuel consumption (FOSCL) has a sustained positive impact, emphasizing its role as a primary driver of emissions. Foreign direct investment (FDI) initially increases emissions, but its impact gradually declines over time, reflecting a potential shift toward more sustainable investments. Overall, the results underscore the complex interplay between economic activities and environmental sustainability, with varying short and long-term implications for policy interventions.

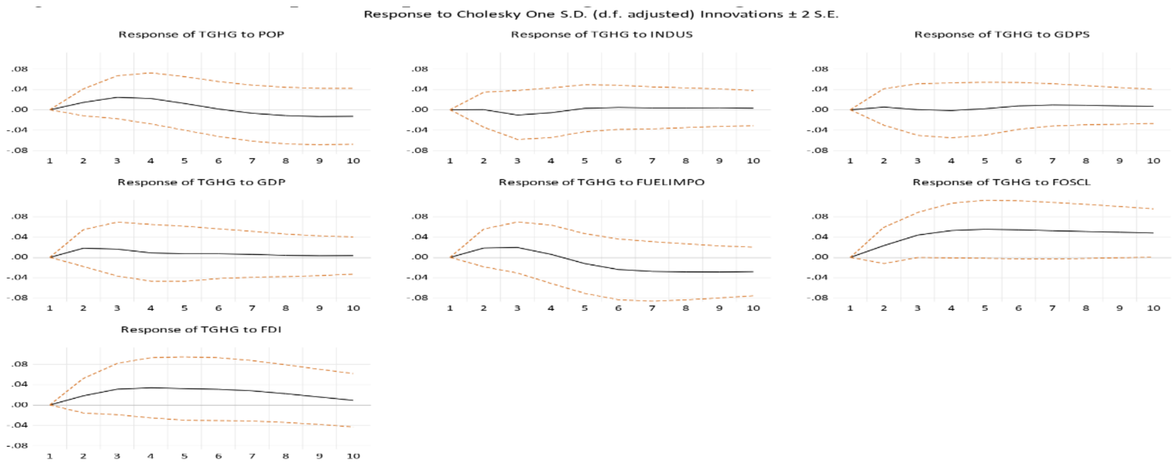


Fig.4 **Results of the impulse response of total greenhouse gas emissions**

Tab. 7 the impulse response of total greenhouse gas emissions

Period	POP	INDUS	GDPS	GDP	FUELIMPO	FOSCL	FDI
1	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
2	0.014761	0.000266	0.005440	0.018367	0.018485	0.023496	0.018163
	(0.01332)	(0.01732)	(0.01802)	(0.01816)	(0.01860)	(0.01784)	(0.01708)
3	0.024758	-0.010256	0.000486	0.016371	0.019508	0.044139	0.031406
	(0.02114)	(0.02414)	(0.02539)	(0.02654)	(0.02517)	(0.02220)	(0.02524)
4	0.022458	-0.005699	-0.001124	0.009133	0.006029	0.052914	0.033905
	(0.02516)	(0.02451)	(0.02702)	(0.02790)	(0.02874)	(0.02690)	(0.02957)
5	0.012494	0.003142	0.002179	0.007169	-0.011953	0.055312	0.032410
	(0.02639)	(0.02309)	(0.02603)	(0.02714)	(0.02941)	(0.02858)	(0.03113)
6	0.001710	0.004836	0.007607	0.007252	-0.023626	0.054351	0.031099
	(0.02703)	(0.02176)	(0.02305)	(0.02447)	(0.02988)	(0.02862)	(0.03095)
7	-0.006523	0.003843	0.009735	0.006087	-0.027501	0.052665	0.027963
	(0.02752)	(0.02068)	(0.02080)	(0.02262)	(0.02922)	(0.02785)	(0.02978)
8	-0.011378	0.004005	0.009039	0.004056	-0.028435	0.051157	0.022441
	(0.02782)	(0.01956)	(0.01923)	(0.02099)	(0.02755)	(0.02665)	(0.02843)
9	-0.013234	0.004122	0.007689	0.003310	-0.028571	0.049756	0.015945
	(0.02775)	(0.01843)	(0.01803)	(0.01957)	(0.02559)	(0.02522)	(0.02723)
10	-0.012735	0.003385	0.006790	0.003617	-0.027702	0.048062	0.009254
	(0.02741)	(0.01737)	(0.01686)	(0.01834)	(0.02390)	(0.02377)	(0.02631)

-Diagnostics tests

After analyzing both the long-term and short-term relationships, it is essential to perform diagnostic tests to assess the model's predictability and uncover any potential flaws that could undermine the reliability of its outcomes.

Table 8. Results of diagnostic testing

Test type	Value	Probability characteristic	P-value
Heteroskedasticity test: Breusch-Pagan-Godfrey F statistics Obs*R-squared Scaled explained SS	 1.247807 30.18513 4.257984	Prob. F (27,21) Prob. Chi-square (27) Prob. Chi-square (27)	0.3042 0.3059 1.0000
Heteroskedasticity test: ARCH F statistics Obs*R-squared	 1.907410 1.911096	Prob. F (1,46) Prob. Chi-square (1)	0.1739 0.1668
Breusch-Godfrey serial correlation LM test F-statistic Obs*R-squared	 1.88401 3.739376	Prob. F (2,41) Prob. Chi-square (2)	0.2166 0.1542
Ramsey RESET Test t-statistic F-statistic Likelihood ratio	 0.316710 0.100305 .121654	Probability	0.7530 0.7530 0.7272
CUSUM CUSUMQ	Stable stable		

Table 8 indicates that the model adheres to essential diagnostic criteria, displaying homoscedasticity and an absence of serial, auto, correlations. Figures 3 revealed that the value of Jarque-Bera was 0.479737 and the probability (Prob = 0.786) was greater than the level of significance (5%). As a result, the null hypothesis that the residuals follow the normal distribution is accepted.

Fig. 5: Normal Distribution

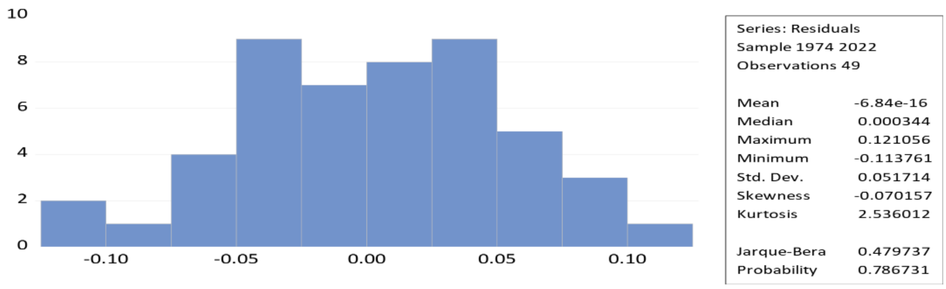
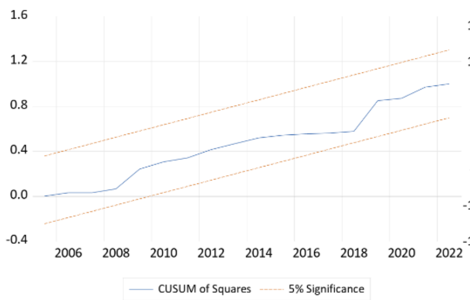


Fig. 5: Normal Distribution

According to (Brown et al., 1975), The CUSUM Test and the CUSUM of Squares Test are considered the most important stability tests for identifying structural changes in the data under consideration and assessing the consistency of long-term and short-term variables. The CUSUM Test and the CUSUM of Squares Test show that structural stability of the estimated model's parameters is obtained when the graph falls inside the critical limits at a considerable level (5%). The results of the tests are shown in figures 5 and 6, respectively. The figures show that the estimated model remained fundamentally stable throughout the study period.



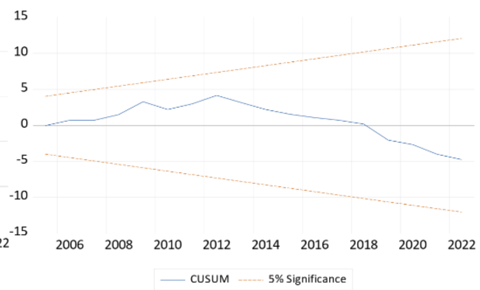


Figure 5. Results of CUSUM square test **Figure 6. Results of CUSUM test**

4- Results and Discussion

With an emphasis on testing the Environmental Kuznets Curve (EKC) hypothesis in Egypt, this study intends to investigate the long-term relationship between industrialization, fossil fuel consumption, FDI and environmental degradation by means of an analysis of the effects of various economic and industrial variables on environmental indicators, so evaluating the validity of the EKC in the Egyptian setting.

In the short run, the regression results reveal significant relationships between various economic factors and greenhouse gases emissions in Egypt. There is a direct relationship between population growth and emissions in the short run. This suggests that as Egypt's population increases, emissions rise accordingly. Higher population growth typically leads to higher demand for energy, housing, transportation, and other resources, which can increase environmental pressure. This finding aligns with the environmental Kuznets curve (EKC) hypothesis, where early stages of population growth correlate with increased emissions, primarily due to urbanization and industrialization. In the long run population expansion contributes to increased emissions. This result aligns with the economic theory that higher population levels can escalate resource demand and environmental strain, especially in developing economies where sustainable practices may be less prevalent. This result also aligns with (Panayotou, 1997; Ahmed and Long, 2012).

Industrial activity plays a significant role in the short-run increase in emissions. As industries expand, particularly in a developing country like Egypt, energy consumption rises, often fueled by fossil fuels such as coal and oil. This aligns with the broader economic understanding that industrialization, while contributing to economic growth, tends to increase environmental pollution due to higher energy demands and emissions from industrial processes. The industrialization coefficient is also positive and marginally significant in the long run, underscoring the role of industrial activities as a significant driver of emissions. This finding reflects Egypt's reliance on energy-intensive and less environmentally efficient industrial processes, suggesting that industrial growth currently outweighs any mitigating technological advancements.

Higher levels of GDP per capita are associated with an increase in carbon emissions in the short run. As income levels rise, so does the demand for goods and services, many of which are energy intensive. This finding supports the hypothesis that economic growth, while improving living standards, can have a detrimental effect on the environment in the early stages of development, especially if growth is driven by energy-intensive sectors. In Egypt, rising income levels may increase the consumption of electricity, transportation, and other goods contributing to carbon emissions. But in long run the results indicate that the relationship between GDP growth rate and GDPS does not strongly support the environmental Kuznets hypothesis in the long run. GDP growth rate shows a positive but statistically insignificant coefficient, indicating that there is no direct and significant effect on environmental degradation. In contrast, GDPS squared shows a positive and statistically significant coefficient, which is contrary to the expected pattern according to the environmental Kuznets hypothesis, which assumes that this coefficient should be negative to reflect the reversal effect that occurs at certain levels of income. Thus, these results do not provide strong evidence for a nonlinear inverted U-shaped relationship between economic growth and environmental degradation as shown in figure 7. This results consistent with many previous studies (Ahmed and Long, 2012; Al-Mulali et al.,2014; Al-Mulali et al., 2015; Ibrahim,2016; Moreno et al.,2021; El-Aasar and Hanafy; Beşe and Kalayci, 2019). However, the results of our study contradict the findings of a study conducted by Mahmood et al. (2019).

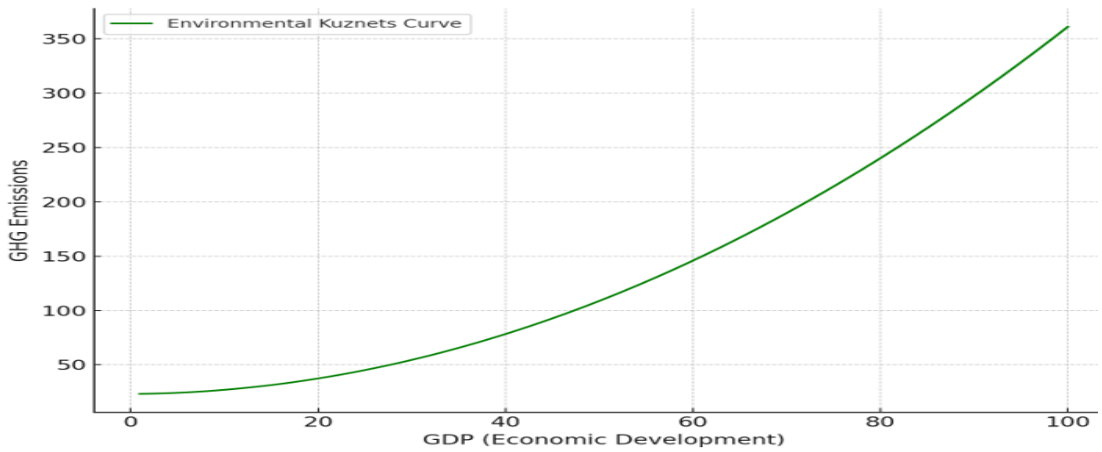


Fig.7.the relationship between economic growth and GHG emissions in Egypt

an increase in fossil fuel imports leads to higher carbon emissions in Egypt in short and long run. This is a straightforward result, as fossil fuels, particularly oil and coal, are major contributors to greenhouse gas emissions when burned for energy. As Egypt imports more fossil fuels, the country's reliance on carbon-intensive energy sources increases, driving up emissions. This is consistent with the understanding that developing nations with growing energy needs often turn to fossil fuel imports, further exacerbating environmental degradation. This result aligns with (Mahmood et al., 2021; Mulali et al, 2015; Acaroglu et al, 2023).

In the short run, foreign direct investment does not have an immediate effect on emissions. This result aligns with Shaari et al. (2014). This could imply that FDI in Egypt is not yet concentrated in energy-intensive industries, or that the environmental standards attached to foreign investment are not stringent enough to prevent emissions. However, when examining the lagged effects (D(FDI (-2)) and D(FDI(-3))), significant positive coefficients were observed, suggesting that FDI can increase emissions over time as it encourages industrialization and energy consumption. But in long run the foreign direct investment (FDI) coefficient is positive and significant, implying that FDI inflows, potentially concentrated in pollution-intensive industries, contribute to environmental challenges. This underscores the need for stringent environmental policies to guide foreign investments toward greener sectors. This result aligns with (Omri et al. 2014; Al-Mulali et al. 2015; Balıbey,2015; Ochoa-Moreno et al. 2021).

Conclusion and policy implication

This study seeks to address the gap by examining the short- and long-term effects of key economic variables—such as FDI, industrialization, fossil fuel consumption, and population growth—on greenhouse gas emissions. It also investigates the applicability of the Environmental Kuznets Curve (EKC) hypothesis in Egypt, which posits an inverted U-shaped relationship between economic growth and environmental degradation. Understanding these relationships is crucial for formulating policies that promote sustainable economic development while minimizing environmental impact.

The Environmental Kuznets Curve (EKC) hypothesis posits an inverted U-shaped relationship between environmental degradation and economic growth, where emissions initially rise with economic growth but eventually decline after reaching a certain income threshold as economies transition to cleaner technologies and prioritize sustainability. In the context of Egypt, the results of this study do not provide conclusive evidence supporting the EKC hypothesis. While variables like per capita GDP growth (GDPS) show a positive and significant relationship with emissions, suggesting that economic growth is a driver of environmental degradation, the lack of significant results for total GDP and the persistently positive relationship between industrialization and emissions indicate no clear turning point in the emissions-growth trajectory.

This outcome can be economically explained by Egypt's reliance on fossil fuels and the absence of widespread adoption of clean energy technologies. Additionally, the industrial sector, a key contributor to GDP, remains carbon-intensive, reflecting a developmental stage where environmental considerations are secondary to economic priorities. The positive relationship between FDI and emissions further suggests that foreign investments may be concentrated in sectors that are not environmentally sustainable. Therefore, Egypt appears to be in the early stages of the EKC curve, with no evidence of a transition to the declining phase, emphasizing the need for strategic policy interventions to decouple economic growth from environmental harm.

The policy implications derived from this study can be outlined as follows. Firstly, environmental regulations should be strictly implemented in metropolitan and industrial regions where both population and industrial activities are high. Secondly, government must promote technological innovations aimed at reducing energy consumption, which has been identified as key driver of GHG emissions. Additionally, adopting more environmentally friendly industrial processes is essential to address emissions.in Egypt, this requires a focus on identifying the source of various types of emissions and implementing effective strategies to reduce overall emissions. This goal cannot be achieved if industries continue to produce polluting goods and consumers persist in their demand for such products. Moreover, foreign direct investment (FDI) should be strategically directed towards sustainable industries. Policymakers should encourage FDI that supports green technologies and environmentally friendly practices, ensuring that foreign investments contribute to reducing the environmental footprint rather than exacerbating pollution. The findings of this study are anticipated to contribute to a deeper understanding of environmental issues and to help identify strategies for mitigating the adverse effects of GHG emissions.

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