# Nonlinear Impacts of Financial Development, Urbanisation, and Economic Growth on $CO_2$ Emissions in Egypt: Evidence from NARDL Analysis

**Aya Ebrahim ElSaid**
**1 Teaching Assistant, Department of Economics, Faculty of Commerce, Benha University (Egypt).**

**Under supervition**

**Nanis Fekry Mohamed**
**2 Assistant Professor, Department of Economics, Faculty of Commerce, Benha University (Egypt).**

**Doaa Akl Ahmed**
**3 Associate Professor of Economics, Department of Economics, Faculty of Commerce, Benha University (Egypt) and Academic Director of Faculty of Economics and Business Administration, Benha National University, Egypt**
**(doaa.ahmed01@fcom.bu.edu.eg)**

## Abstract

This study examines the nonlinear impact of financial development, urbanisation, and GDP per capita on CO2 emissions in Egypt from 1965 to ٢٠٢٢. We incorporate trade openness and energy use as control variables. The paper employs the Nonlinear Autoregressive Distributed Lag (NARDL) model to estimate Egypt's Environmental Kuznets Curve (EKC) and evaluate the characteristics of turning points by examining the necessary and sufficient conditions. Moreover, we anticipate the inflexion points of per capita GDP. The findings validate an N-shaped Environmental Kuznets Curve (EKC) with two turning points (LE17,395.64 in 1973–1975 and LE50,728.65 in 2007), revealing that Egypt is in the third phase of the EKC. Furthermore, evidence indicates that financial development does not affect environmental degradation in the long term. However, positive and negative financial development shocks strengthen ecological degradation in the short term. Moreover, our findings show that positive urbanisation shocks improve the environment in the long term while deteriorating the environment in the short term. Furthermore, the negative shocks of urbanisation do not affect the ecological quality in the short or long term. Finally, energy consumption degrades environmental quality, while trade openness mitigates CO2 emissions in both the long and short term.

JEL classifications: C22,Q53, Q56, O13, O44

**Keywords:** Economic Growth, Financial Development, Energy Consumption, CO2 Emissions, Urbanisation.

# الأثار غير الخطية للتنمية المالية والتحضر والنمو الاقتصادي على انبعاثات ثاني أكسيد الكربون في مصر: تحليل باستخدام نموذج NARDL

**أية إبراهيم السعيد**

**معيدة بقسم الاقتصاد- كلية التجارة – جامعة بنها**

**بحث مقدم للحصول على درجة الماجستير في الاقتصاد- كلية التجارة جامعة بنها**

**تحت اشراف**

**د. نانيس فكرى محمد**
**مدرس الاقتصاد بكلية التجارة – جامعة بنها**

**أ.م.د دعاء عقل أحمد**
**أستاذ الاقتصاد المساعد بكلية التجارة بجامعة بنها ومدير برامج كلية الاقتصاد وإدارة الأعمال بجامعة بنها الأهلية**

**الملخص**

تستهدف هذه الدراسة تقدير الأثار غير الخطية لكل من التنمية المالية والتحضر ونصيب الفرد من الناتج المحلي الإجمالي على التدهور البيئي (المعبر عنه بانبعاثات ثاني أكسيد الكربون) في حالة مصر خلال الفترة من ١٩٦٥ إلى ٢٠٢٢، مع الأخذ في الاعتبار بعض متغيرات التحكم التي تشمل الانفتاح التجاري واستهلاك الطاقة. وقد استخدمت الدراسة نموذج الإنحدار الذاتي بفترات ابطاء موزعة غير المتماثل (NARDL) لتقييم منحنى كوزنتس البيئي غير الخطي. وقد أوضحت نتائج الدراسة وجود منحنى كوزنتس البيئي على شكل حرف N بنقطتي تحول رئيسيتين وهما (١٧,٣٩٥.٦٤ ) جنيهًا مصريًا خلال الفترة ١٩٧٣-١٩٧٥ و(٥٠,٧٢٨.٦٥ ) جنيهًا مصريًا في عام ٢٠٠٧، مما يشير إلى أن مصر تمر حاليًا بالمرحلة الثالثة من هذا المنحنى والتي تعني أن ارتفاع النمو الاقتصادي يؤدى إلى زيادة التدهور البيئي. وقد أظهرت النتائج أن التنمية المالية ليس لها تأثير معنوي على التدهور البيئي على المدى الطويل بالرغم من التأثير قصير الأجل لكل من الصدمات الإيجابية والسلبية للتنمية

المالية في تفاقم التدهور البيئي. كما أوضحت الدراسة أن الصدمات الإيجابية للتحضر تؤدي إلى تحسين جودة البيئة على المدى الطويل بينما تساهم في تدهورها على المدى القصير، في حين لا تظهر الصدمات السلبية للتحضر أي تأثير ذي دلالة إحصائية على جودة البيئة في أي من المدى القصير أو الطويل. ومن النتائج المهمة أيضًا أن استهلاك الطاقة يساهم بشكل واضح في تدهور البيئة، في حين يعمل الانفتاح التجاري على تخفيف انبعاثات ثاني أكسيد الكربون في كل من الأجلين القصير والطويل.
**الكلمات المفتاحية: النمو الاقتصادي، التنمية المالية، استهلاك الطاقة، انبعاثات ثاني أكسيد الكربون، التحضر.**

## 1. Introduction

Environmental degradation, driven by greenhouse gas (GHG) accumulation, threatens infrastructure, agriculture, and human health (Shahbaz, Hye et al., 2013). Thus, governments' political and economic plans must meet the multi-directional links between economic, social, and environmental development features by attempting to minimise poverty, enhance economic opportunities, and protect the environment (Farhani and Rejab, 2012; Zakarya et al., 2015). For Egypt—Africa's second-largest $CO_2$ emitter—this challenge is acute due to heavy reliance on fossil fuels (94.4% of energy use; USEIA, 2018) and rapid urbanization, the increase in industrial production and economic growth, energy-intensive natural gas and oil industries, the surge of car sales, energy subsidies, and the high population growth rate (Hegazy, 2015; IMF, 2015; Rady et al., 2018).

According to British Petroleum data (2023), Africa's contribution to total world emissions increased from 1.7% to 3.6% during the period (1965-2020). Further, Egypt is considered the second African emitter of $CO_2$ after South Africa due to its high dependency on fossil fuels as the primary energy source. Moreover, Egypt's contribution to African and world emissions has risen from 11.6% and 0.2% to around 18% and 0.64%, respectively, over the abovementioned period. In March 2015, Egypt launched its strategy for sustainable development, known as "Egypt's Vision 2030," which includes three dimensions of sustainable development: economic, social, and environmental. The main aim of the vision is to effectively achieve convergence and balance between the three pillars of sustainable development to protect the rights of both present and future generations.

Aligning with Egypt’s Vision 2030, this study addresses the following question: What are the key determinants of $CO_2$ emissions in Egypt? The topic is crucial in the light of (Egypt's Vision 2030), which prioritises the environmental dimension of sustainable development. According to this vision, the seventh goal is to ensure access to affordable, reliable, sustainable, and modern energy for all. Further, the eighth goal is to take serious action to combat climate change and its effects. Based on that, clarifying the primary sources that cause greenhouse gas emissions is essential to setting the procedures required to combat climate change. Given that the environmental dimension of the 2030 vision is based on two pillars, namely, environment and urban development, examining the impact of urbanisation on ecological deterioration in terms of CO2 emissions is highly required. In literature, the CO2 emissions variable is extensively used as a proxy for environmental degradation due to data availability, its status as an international pollutant, and its significant share of greenhouse gas emissions.

The effect of financial development on greenhouse emissions is controversial as there are two schools of thought. Some studies argue that financial development could reduce carbon emissions (e.g., Dasgupta et al., 2001; Tamazian et al., 2009; Jalil and Feridun, 2011; Shahbaz, Hye et al. (2013); Islam et al., 2013). On the other hand, numerous studies advocate that financial development increases carbon emissions and degrades the quality of the environment (e.g., Sadorsky, 2010; Zhang, 2011). Moreover, the impact of financial development on the environment may be nonlinear, leading to a U-shaped or an inverted U-shaped relation. The U-shaped curve implies that financial development has a mitigating impact in the early stages of development, followed by a detrimental environmental impact.

In contrast, an inverted U-shaped curve implies that the early stage of financial development raises environmental pollution to a certain threshold level due to the failure of the financial sector to fund environmentally friendly technologies such as renewable energy resources and green technologies at low cost (Khan et al., 2019). Then, financial development mitigates the CO2 emissions if the financial sector can provide funds to new firms to adopt clean production techniques and encourage existing businesses to replace outdated or pollution-intensive methods with green technology (Ehigiamusoe et al., 2022).

Urbanisation also substantially impacts the environment and CO2 emissions. The compact city theory suggests that urban expansion can improve public infrastructure, reduce environmental issues, and promote economic growth (Burton, 2000). However, ecological modernisation argues that growth can lead to environmental degradation in the initial stages of development. Still, technological innovation and structural changes in economic sectors can mitigate these adverse effects (Mol and Spaargaren, 2000). Further, the impact of urbanisation on the environment may be nonlinear and modelled as an inverted U-shape curve (Shafiei and Salim (2014).

Environmental literature usually incorporates control variables such as GDP per capita, foreign direct investment, energy consumption and trade openness. Regarding the relationship between output and environmental degradation, one of the models that tested for this nonlinear relationship was proposed by Kuznets in 1955 and is known as the environmental Kuznets curve (EKC) in environmental economics. Most studies on environment-growth interaction focus on empirically verifying whether the *EKC* is *U*, inverted *U*, *N* or inverted N-shaped by ascertaining the signs of the linear, quadratic and cubic terms of GDP per capita.

Thus, the paper examines the impact of financial development and urbanisation on $CO_2$ emissions and other control variables, including GDP per capita, energy consumption, and trade openness. **Based on that, we hypothesize that** (1) financial development and urbanisation have asymmetric (nonlinear) effects on $CO_2$ emissions, (2) Egypt's EKC follows an N-shaped curve, and (3) energy use induces environmental degradation, (4) Trade openness's impact on environment depends on the offsetting power of scale technique effects.

While prior studies (e.g., Mahmoud et al., 2019; Shaker, 2022) examine the EKC in Egypt, none have simultaneously (1) tested the nonlinear effects of financial development and urbanization on environmental degradation using NARDL and (2) forecasted the precise turning points of EKC by examining the necessary and sufficient conditions. Hence, to address gaps in prior linear analyses, we employ the Nonlinear ARDL (NARDL) model to capture the asymmetric effects of financial development and urbanization while testing for an N-shaped EKC. We find that the environmental-growth relationship in Egypt follows an *N-shaped EKC* with two turning points. The first turning point is LE17395.64 per capita (lies between 1973 and 1975), showing a transition from the environmental degradation phase to the environmental improvement phase. The second point is

LE50728.65 per capita starting from 2007, showing the transition from ecological improvement to environmental degradation. Accordingly, Egypt is in the third phase of the N-shaped EKC relationship between economic growth and the environment.

Further, there is evidence that financial development does not affect environmental degradation in the long run. However, positive and negative financial development shocks increase ecological degradation in the short term. Estimation results suggest that positive shocks of urbanisation improve the environment in the long run while it increases environmental degradation in the short run. Further, negative shocks of urbanisation have no mitigating or detrimental impact on the environment in the long or short run. These results imply that financial development and urbanisation have asymmetric impacts on $CO_2$ emissions. Finally, energy consumption worsens the ecological quality while trade openness mitigates $CO_2$ emissions in the long and short term.

The paper is structured as follows: section two introduces a theoretical background and a brief literature review, section three overviews the environmental situation in Egypt, and section four introduces the methodology. Then, data and empirical results are displayed in section five, and section six concludes and presents some policy implications.

## 2. Theoretical Background and Literature Review:

There is extensive literature on various determinants that degrade the environment. To save space, we limit our literature review to include studies focusing on the link between economic growth, energy use, trade openness, financial development, urbanisation, and CO2 emissions as a proxy of environmental deterioration.

### 2.1 Linkage between Economic growth and environmental degradation:

The linkage between economic growth and environmental degradation and, implicitly, greenhouse gas emissions has been intensively studied. One of the models tested for this nonlinear relationship was proposed by Kuznets in 1955 and was re-interpreted as the environmental Kuznets curve (EKC) in environmental economics (Grossman and Krueger, 1991). According to them, economic growth influences the environment through three distinct channels: the scale effect, the composition effect, and the technical effect.

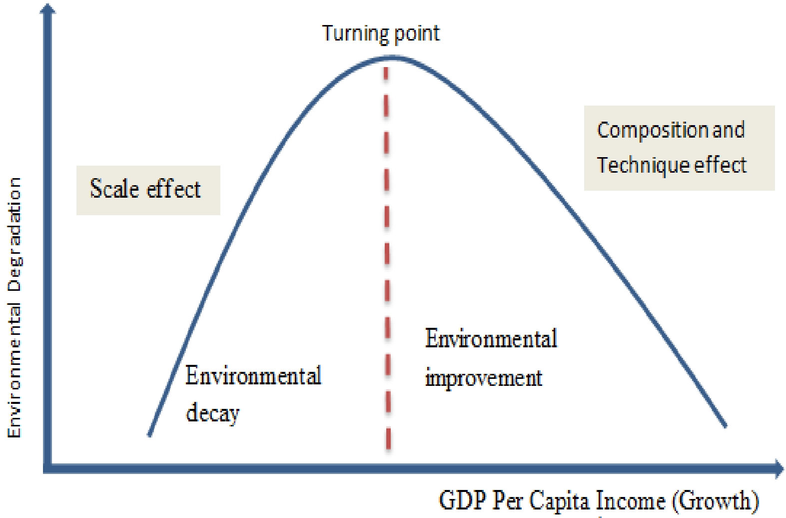
(a) The scale effect indicates that increasing production lowers environmental quality, meaning that economic growth from that effect is detrimental to the environment.

(b) The composition effect positively impacts the environment. The transition from agriculture to resource-intensive heavy manufacturing increases pollution in the initial phases of economic development. Conversely, in later stages, pollution diminishes as the economy moves towards services and light manufacturing industries. This change in the industrial structure may consequently mitigate the detrimental impacts of economic growth on environmental degradation through the composition effect.

(c) The technical effect is relevant to technological improvements in productivity, cleaner technologies implementation, and environmental quality improvement. Thus, it pertains to technology advancements that allow for reduced input per unit of output or the implementation of cleaner technologies to supplant outdated production methods. Further, investment in environmental research and development stimulates the advancement of cleaner technology, which necessitates adequate economic growth (Lorente and Álvarez-Herranz, 2016).

Figure (1) presents the inverted U-shape EKC proposed by (Grossman and Krueger, 1991). According to this argument, a country's economic growth initially leads to an increase in ecological deterioration up to a turning point, at which point technological advances lead to the development of new technologies, resulting in environmental improvement ( Sterpu et al., 2018). Thus, if this hypothesis is valid, ecological degradation is not an unavoidable consequence of economic development. There is no need to sacrifice economic advancement to achieve environmental sustainability as both objectives could be simultaneously attained (Farooq et al. 2024).

**Figure (1): Inverted U-shape Environmental Kuznets Curve (EKC)**

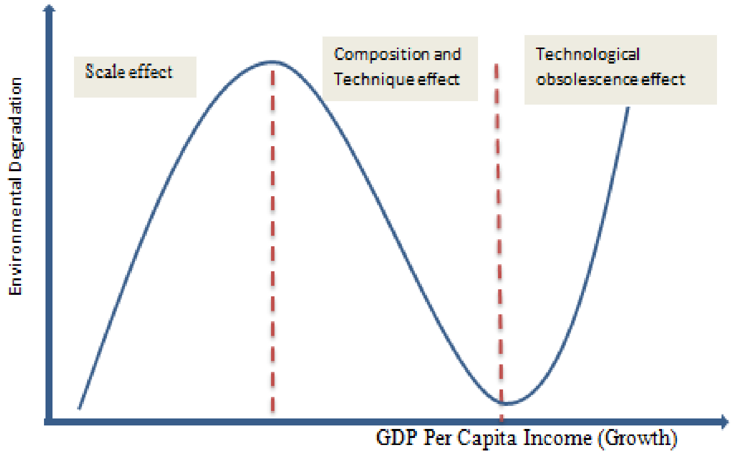



**Source:** Authors based on Farooq et al. (2024) and Lorente and Álvarez-Herranz (2016).

The existing literature on the environment-growth nexus shows evidence of an inverted U-shape EKC (e.g., Iwata et al.(2010) for France; Shahbaz, Tiwari et al., (2013) for South Africa, Tiwari et al. (2013) for India; Destek and Sarkodie, 2019 for a group of 11 countries). In such a case, an increase in the scale of economic activities initially occurs at the cost of the depletion of ecological assets. However, after a certain affluence level, the compositional and technological changes reduce the depletion of environmental assets, improving their quality. Contrastingly, studies like (Villanthenkodath et al., 2021 ) show that the growth-environment relation as an inverted U-shape EKC is invalid, suggesting that economic growth hinders the quality of the environment due to lenient environmental restrictions, immigration of filthy industries, and excessive use of fossil fuels.

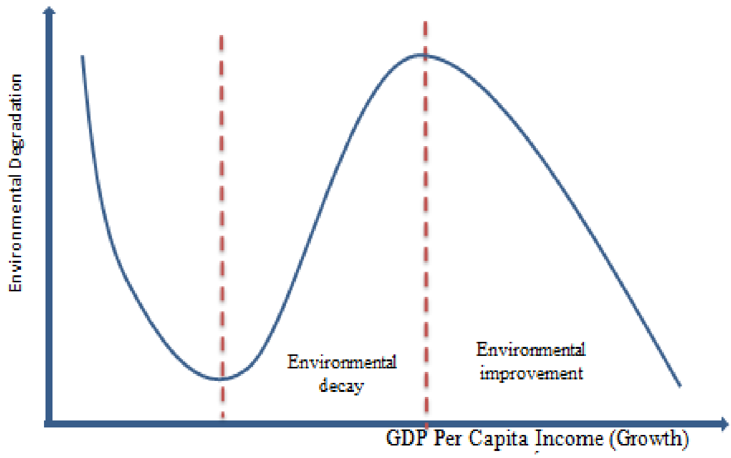
The EKC was then examined to provide alternative patterns of the environment-growth nexus. Thus, two variant forms of this relation are reported: N-shaped EKCs and inverted N-shaped EKCs. The N-shaped Environmental Kuznets Curve indicates a cubic link between income and pollution, characterised by an N-shaped curve with two turning points. Figure (2) illustrates the N-shaped Environmental Kuznets Curve (EKC), in which environmental deterioration initially rises with economic growth due to the higher scale effect and falls after reaching the first turning point where composition and technique effects offset the scale effect during this phase, and rises again beyond the second turning point. Ecological degradation could rebound at a more advanced stage of economic development if innovation lags behind economic growth and the scale effect outpaces the enhancement of technical impacts. This phenomenon of the growth-environment relationship is referred to as the technological obsolescence effect, which occurs after the second inflexion point when the scale effect exceeds the composition and technical effects (Lorente and Álvarez-Herranz, 2016; Wang et al., 2024).

**Figure (2): N-shape Environmental Kuznets Curve (EKC)**




**Source:** authors based on Farooq et al. (2024) and Lorente and Álvarez-Herranz (2016).

**Figure (3): Inverted N-shape Environmental Kuznets Curve (EKC)**

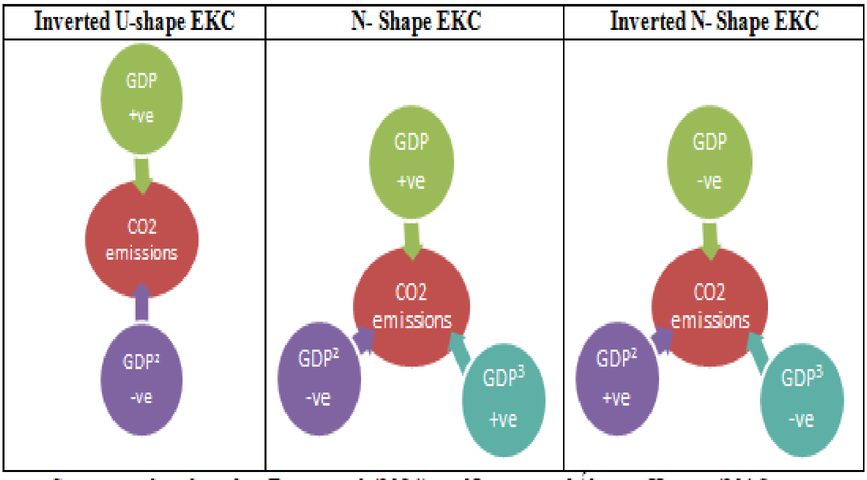


According to Panayotou (1993), environmental waste is limited in the early stages of economic development. As economic growth increases through agriculture, resource exploitation, and industrialisation, regeneration rates are lower than extraction rates, increasing waste volume and toxicity. After that stage, there was a gradual decline in ecological degradation due to the emergence of information and service sectors, associated with growing environmental concerns that encouraged the implementation of environmental regulations, technological innovations, and increased ecological investment (Andreoni and Levinson 2001). According to (Lorente and Álvarez-Herranz, 2016), the integration of technological innovation with environmental regulation can mitigate technological obsolescence and postpone emerging pollution trends. Thus, the environmental-growth nexus could be presented as an inverted N-shape curve, as displayed in figure (3). According to this argument, at low levels of economic development, higher levels of income lead to environmental improvement up to a specific turning point. A rise in economic growth leads to a polluting ecological impact up to the second turning point. After that point, the economy moves from the ecological degradation phase to the environmental improvement phase as GDP growth expands.

Numerous studies support the N and inverted N- shaped EKC (e.g., Fakher et al., 2023; Wang et al., 2023; Allard et al., 2018; Bekhet and Othman, 2018; Balsalobre-Lorente et al., 2017). (Bao et al., 2023; Tabash et al., 2023; Martial et al., 2023; Numan et al., 2022; Zhu et al., 2022; Can et al., 2021; Kassouri, 2021). More studies are mentioned in Table A1 in the appendix.

In order to test for the existence of EKC, specifications include level, squared and cubic GDP per capita as explanatory variables in environmental degradation models (usually expressed as CO2 emissions and Ecological footprint). Figure (4) summarises the expected signs of different forms of the environmental-growth relationship, given that environmental degradation is measured in terms of CO2 emissions.

**Figure (4): Expected signs between income and ecological deterioration in different EKC Forms**




**Source:** authors based on Farooq et al. (2024), and Lorente and Álvarez-Herranz (2016).

## 2.2. Financial development and CO2 emissions:

The effect of financial development on greenhouse emissions is controversial, as there are two schools of thought. Some studies argue that financial development could reduce carbon emissions, whereas other studies advocate that financial development increases carbon emissions and degrades the quality of the environment. According to (Dasgupta et al., 2001), stock market development helps listed firms decrease financing costs, expand financing channels, and minimise operating risk, which enhances investment in new projects, resulting in higher energy use and carbon emissions.

Further, Tamazian et al. (2009) found that listed enterprises promote technology innovation and adopt new technologies, suggesting that financial development reduces $CO_2$ emissions. Thus, financial development improves energy efficiency, leading to low-carbon economic growth. A developed financial system also eases firms' financing constraints, boosting domestic investment and attracting foreign direct investment. This leads to updating production technology and equipment and promoting investment in energy-efficient technologies. Consequently, this will cause a decrease in energy costs and reduce carbon emissions indirectly (Islam et al., 2013). Generally, the firms listed in the stock market are leading firms in the economy, where they try to establish a good image to the public, showing their social responsibility to protect the environment by employing environmentally friendly technologies, leading to a reduction in $CO_2$ emissions.

From the empirical perspective, Shahbaz, Hye et al., 2013) explored the linkages among economic growth, energy consumption, financial development, trade openness, and $CO_2$ emissions throughout the period (1975:1- 2011:4) in Indonesia using the ARDL method. They confirm that financial development and trade openness reduce $CO_2$ emissions, while economic growth and energy consumption increase these emissions. Saidi and Mbarek (2017) investigated the influence of financial development, income, trade openness, and urbanisation on $CO_2$ emissions for a group of emerging economies using panel data over the period (1990–2013). Results showed a positive monotonic relationship between income and $CO_2$ emissions. Also, financial development has a long-run negative impact on carbon emissions, implying that financial development reduces environmental degradation. Thus, financial reforms could help in improving the environment. Further, Zaidi et al. (2019) examined the dynamic linkages between globalisation, financial development and carbon emissions in the Asia Pacific Economic Cooperation (APEC), employing the panel data from 1990 to 2016; the empirical results indicate that globalisation and financial development significantly reduce carbon emissions.

On the other hand, (Sadorsky, 2010; Zhang, 2011; Dogan and Turkekul, 2016) see that financial development could lead to environmental degradation and an increase in carbon emissions. Sadorsky (2010) shows that a developed financial sector usually upsurges consumption credit, encouraging consumers to buy more commodities, including properties, cars, and other electric appliances. As a result, energy use and carbon emissions will grow significantly. Furthermore, a sound financial system reduces the problem of information asymmetry. It expands financing opportunities, leading to higher access to funds at lower costs, which implies a higher production level in traditional industries and ultimately leads to a significant rise in carbon emissions. Moreover, A well-functioning stock market indicates the rapid growth and welfare of the economy, which encourages both consumers and producers to increase their consumption and production activities. Accordingly, it induces higher energy consumption and CO2 emissions.

Some Empirical studies support these views. Ziaei (2015) investigated the effects of financial indicator shocks (i.e., credit market shock and stock market shocks) on energy use and CO2 emissions and vice versa, employing Panel Vector Auto Regression (PVAR) models. Findings emphasise the vital role of CO2 emissions and energy consumption in explaining each other's deviation. Although energy consumption and CO2 emission shocks on private sector credit are not very noticeable in both groups of countries, the strength of the energy consumption shock on the stock return rate in European countries is more significant than in East Asian and Oceania countries. On the other hand, shocks to stock return rate influence energy consumption, especially in the extended horizon of East Asia and Oceania countries. (Muhammad and Ghulam Fatima, 2013) investigated the effects of financial development, per capita real output, the square of per capita real output, per capita energy consumption, and trade openness on per capita CO2 emissions for Pakistan (1972–2013) using the bound ARDL model. They found a long-term relationship among these variables. Also, the EKC hypothesis is supported over short and long periods. Further, they found a significantly positive sign for the coefficient of financial development, suggesting that it has occurred at the expense of environmental quality. Also, the openness variable does not substantially influence short-term or long-term carbon emissions. Additionally, Katircioğl and Taşpinar (2017) state that financial development increases environmental degradation by increasing goods, intermediaries and financial services that could boost energy demand, increasing pollution.

(Khan et al., 2017) explored the nexus between greenhouse gas, financial development, energy consumption, trade, and urbanisation in 34 countries using panel data (2001-2014) using VECM and the Fully Modified Ordinary Least Square (FMOLS) method. They found that the relationship of variables changes from region to region and country to country. According to the study, the financial sector has the potential to support global efforts towards environmental protection. However, regional or country-specific experiences can differ depending upon the financial sector's priority towards environmental protection.

Moreover, the impact of financial development on the environment may be nonlinear, leading to a U-shaped or inverted U-shaped relation. According to Ehigiamusoe et al., 2022), the U-shaped relation is attributed to the fact that at the early stage, financial development reduces environmental problems to a certain threshold level. Beyond this level, the relation is reversed, where a developed financial system can spur ecological degradation. On the other hand, the inverted U-shaped implies that the early stage of financial development raises environmental pollution to a certain threshold level. This may be attributed to the failure of the financial sector to fund environmentally friendly technologies like renewable energy resources and green technologies at low cost (Khan et al., 2019). After that, the advancing financial system will lessen environmental problems if the financial sector can provide funds to new firms to adopt clean production techniques and encourage existing businesses to replace outdated or pollution-intensive methods with green technology (Ehigiamusoe, 2022).

## 2.3. Urbanisation and CO2 emissions:

Urbanisation also substantially impacts the environment and CO2 emissions through energy consumption channels. Generally, when a country focuses more on urbanisation and developing new and advanced infrastructure in its old and new cities, its energy use significantly increases for an extended period. Consequently, CO2 emissions from their use and wastes return to the air, soil, and water, leading to detrimental environmental influences (Mahmoud et al., 2020). Theoretical literature emphasises the effect of urbanisation on the environment. These theories include compact cities, ecological modernisation and urban environmental transition (Martínez-Zarzoso and Maruotti, 2011; Nathaniel, 2020). The compact city theory states that increased urban densities enhance economies of scale in public infrastructure, including transportation, hospitals, and schools, reducing environmental issues. (Burton, 2000). In addition, the ecological modernisation theory claims that environmental issues emerge as society transitions from a low- to middle-income economy, given that growth comes at the expense of environmental sustainability. However, increasing technological innovation might mitigate the detrimental effects of urban expansion (Mol and Spaargaren, 2000). Finally**, the urban environmental transition theory** claims that expanding manufacturing raises society's wealth, **causing increased industrial pollution**. However, technological innovation and structural changes in economic sectors lessen these harmful effects (McGranahan et al., 2010). The environmental influence of urbanisation could be good or detrimental, but the overall effect is complex to predict a priori (Sadorsky, 2014). Thus, urbanisation's final impact on the environment depends on the extent of economic development, level of economic activity, energy consumption and the growth in urban population.

Saidi and Mbarek (2017) found that greater urbanisation minimises carbon dioxide emissions, indicating that the potential benefits of urbanisation in these countries offset the disadvantages. Thus, policymakers in the included sample could induce economic growth in the short and long run by encouraging urbanisation in their economies while mitigating the damaging side effects of air pollution.

Andersson (2019) examined the relationship between CO2 emissions, economic growth, energy use, urbanisation, trade openness, and financial development in Canada, which is one of the major CO2 emitters over the period (1960-2014). They found that GDP growth, energy consumption, and trade openness tend to expand CO2 emissions in the long run, whereas financial development and urbanisation remain insignificant.

Ehigiamusoe et al. (2022) examined the nonlinear and moderating impacts of financial development and urbanisation in degrading the environment regarding CO2 emissions and ecological footprint (EF) in 31 African countries. The results revealed that urbanisation has an inverted U-shaped effect on $CO_2$, while financial development has a weak U-shaped impact. Further, both variables have a U-shaped relation with the ecological footprint. Moreover, they found that urbanisation mitigates the connection between $CO_2$ and energy use, while financial development worsens this relation.

### 2.4Other variables (energy use, Foreign Direct Investment and trade openness):

Another key factor that affects environmental degradation is trade openness. According to Fakher (2019), there is no theoretical consensus concerning the impact of trade openness on $CO_2$ emissions. Specifically, trade openness affects $CO_2$ emissions via various channels, including scale, composition, and technology. Following trade openness, the scale effect worsens environmental quality, whereas the technology effect improves it. The impact of composition depends on the nature or type of comparative advantage. If a country has a comparative advantage in polluting products and specialises in producing them (i.e., the composition of its manufactured products is oriented toward polluting products), it would deteriorate ecological quality. In contrast, if a country's comparative advantage in clean goods moves its product mix toward clean goods, composition effects will improve environmental quality (i.e., technology and the composition effects outweigh the scale effect).

According to Abid and Sekrafi (2021), strict environmental regulations in developed countries cause pollution-intensive industries to relocate to developing countries, transforming developing countries into 'pollution havens' via composition and scale effect. The pollution haven hypothesis implies that international firms attempt to avoid the cost of strict environmental regulations (and high energy prices) by locating production in countries where environmental norms are lax. Sarkodie and Strezov (2019) examined the effect of foreign direct investment, economic development, and energy consumption on greenhouse gas emissions for the top five CO2 emitters from fuel combustion in developing countries using a panel data regression. Their findings support the pollution haven hypothesis in the countries under consideration. In contrast, trade openness could lower environmental degradation through knowledge and technology spillovers, where he defined environmental innovation as innovations that comprise new or modified processes, practices or systems which benefit the environment and contribute to environmental sustainability. Further, cleaner technologies could decrease ecological risk and minimise pollution and overexploitation of resources (Dauda et al., 2021).

Table A1 in the appendix presents more studies on the determinants of environmental degradation in different countries. In contrast, Table A2 presents the studies that focused on the Egyptian case, with mixed results. Abdou and Atya (2013) analysed the relationship between CO2 Emissions and GDP per capita in Egypt from 1961 to 2008 using cointegration. It rejected the Environmental Kuznets Curve (EKC) hypothesis due to high energy subsidies and emphasised the importance of effective policies for pollution reduction. Ibrahiem (2016) also employed a Granger causality test and found no support for short- or long-term EKC. It indicated that energy consumption increases CO2 emissions, while trade openness and population density reduce environmental degradation. Further, El-Aasar and Hanafy (2018) concluded that the EKC hypothesis does not hold, but renewable energy significantly reduces greenhouse gas emissions, while trade openness has an insignificant effect.

In contrast, Saber (2022) and Altayeb (2024) claimed that EKC exists in Egypt. Further, Mahmoud et al. (2019) found evidence supporting an N-shaped EKC, indicating that Egypt is in the second stage of this nonlinear EKC. Unlikely, Shaker (2022) found an inverted N-shape growth-environment relationship, which he attributed to an environmentally friendly mindset in Egypt.

Concerning the impact of financial development on environmental quality, Ibrahiem (2020) found that alternative energy and technological innovation improve environmental quality, while financial development and economic growth worsen it. Further, Ahmed et al. (2020) reported a negative relationship between financial development, economic growth, and CO2 emissions. The impact of urbanisation on CO2 emission in Egypt is investigated by Adebayo and Kalmaz (2021. This study supported a positive relationship between energy usage and GDP growth with CO2 emissions, while urbanisation and gross capital formation had an insignificant impact. In contrast, Rashdan and Ibrahim (2024) found that urbanisation and foreign direct investment positively affect CO2 emissions, while energy consumption and economic growth mitigate CO2 emissions.

The variations in results may be attributed to different samples, structural breaks (2011 revolution, energy subsidy reforms) and methodological differences (ARDL vs. VECM). Despite extensive global literature, Egypt's context remains understudied in two ways: (1) non-linear impacts of financial development and (2) urbanisation thresholds. This paper addresses these gaps by evaluating the non-linear impact of financial development and urbanisation on environmental degradation in Egypt, examining the nature of the growth-environment relationship, and forecasting the turning points of the environment-growth nexus.

## 3. An overview of the environmental situation in Egypt:

### 3.1 Efforts of the Egyptian government to improve environmental quality:

Table (1) summarises the institutional efforts of consecutive Egyptian governments to improve environmental quality. These efforts were initiated with the enforcement of Environmental

Law No. 4 of 1994, which resulted in the establishment of the Environmental Affairs Agency (EEAA**).** In February 2008, Egypt's Supreme Council of Energy announced an ambitious plan to generate 20% of the country's electricity from renewable sources by 2020, including a 12% contribution from wind energy. These efforts include providing incentives to invest in renewable energy. Another important area of political action is the incremental reform of gasoline, diesel and natural gas energy subsidies launched by the Egyptian government in 2014. The government has raised energy prices for residential and commercial applications, raising electricity bills by around 40% in July 2016, 40% in July 2017, and 26% in July 2018. In June 2018, the government increased fuel prices by an average of 44% for gasoline, diesel, kerosene, and fuel oil. Consequently, the overall subsidies as a percentage of government expenditure decreased from 28.2% to around 18.3% between 2011/2012 and 2017/2018. During the same timeframe, the proportion of energy subsidies to total subsidies dropped from around two-thirds to 50% (Ahmed and Ahmed, 2019). The elimination of energy subsidies may reduce consumption growth in the short term; nevertheless, the rising population and expanding transportation sector are anticipated to drive energy demand in the long term (USEIA, 2018). This surge in energy demand may trigger CO2 emissions and deteriorate environmental quality.

**Table (1): Efforts of the Egyptian Government related to environmental quality regulations**

| Date | Policy/ strategy | Status | Commitment/ Main Targets |
|---|---|---|---|
| 1994 | Environmental Law (Law 4 of 1994) | In force | The Environmental Law outlines land, air, and water pollution regulations and creates the Environmental Affairs Agency (EEAA), endowing it with the powers to enforce these requirements:<br>• It determines that oil exploration, extraction, refining, storage, and transport companies are subject to environmental impact assessment procedures during their licensing process.<br>• Firms holding an oil and gas permit must maintain a register of information related to their impact on the environment, including emissions or discharges; procedures of follow-up and environmental safety applied; periodic tests, measures and their results. |
| 2006 | Energy Efficiency Regulation in Residential Buildings | In force | The regulatory document established energy efficiency criteria and requirements for designing and constructing new residential buildings. |
| 2008 | New National Renewable Energy Strategy | In force | Egypt's Supreme Council of Energy announced an ambitious plan to generate 20% of the country's electricity from renewable sources by 2020, including a 12% contribution from wind energy. |
| 2009 | Egypt building code: commercial buildings | In force | Egypt adopted mandatory energy efficiency regulations to benefit from the potential of energy efficiency in the building sector. |
| 2012 | Egyptian Solar Plan | In force | The Cabinet approved the Egyptian Solar Plan in July 2012. It targets installing around 3,500 MW of solar power plants by 2027. The Private investment share in these installations is estimated at 67% through competitive bidding, feed-in tariff (FIT)*. The incentives provided for wind energy projects will be applied to solar projects. |
| 2014 | Renewable energy custom tax reduction for renewable equipment | In force | Egypt's feed-in tariff program for renewable generation includes a 2% reduction in customs duties on new and renewable energy equipment. |
| 2014 | Feed-in tariff (FIT) for wind and solar PV projects | In force | In September 2014, the Ministry of Electricity and Energy and the Regulatory Agency launched a feed-in tariff support system for solar and wind projects with less than 50 MW capacity. The FIT program aims to boost renewable energy production in Egypt. |
| 2015 | Egypt renewable energy tax incentives (Presidential Decree No 17/2015) | | In 2015, Egypt amended its 1997 Investment Law to attract more energy investments, including in renewable energy. Key incentives include reducing sales tax to 5% (up to 10%) and setting customs duties on production equipment at 2%. Non-tax incentives for energy producers include:<br>1. Refunding infrastructure extension costs** after project commencement.<br>2. Subsidising employee training programs and social insurance subscriptions.<br>3. Allocating government-owned land free of charge or at discounted prices. This incentive reduces upfront costs and facilitates project development, making investments in the energy sector more attractive. |
| 2024 | Egypt's economic strategy for 2024-2030 | Announced | There are different targets for different sectors in Egypt. One target for electricity and renewable energy is to increase the penetration of renewable energy in the Egyptian power grid to 42% by 2030. |

**Source:** Authors based on Climate Watch (https://www.climatewatchdata.org/)

* **A feed-in tariff (FIT)** is a policy designed to support the development of renewable energy sources by guaranteeing an above-market price for producers

** **Refunding Infrastructure Costs**: The government will compensate expenses incurred for extending infrastructure facilities to the project's land, but only after the project has begun operations. This incentive aims to reduce the initial financial burden on energy producers.

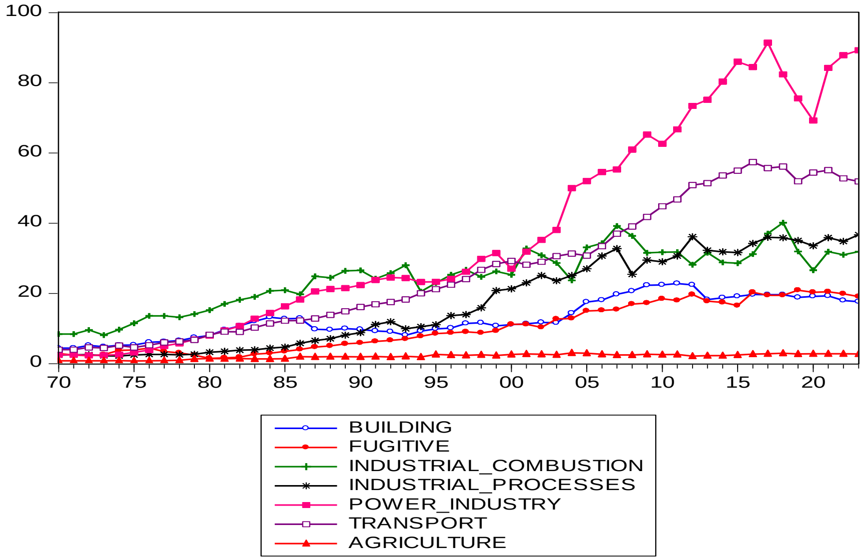
Concerning Financing the programs that support environmental quality, Egypt initiated the SEFF (Egypt Sustainable Energy Financing Facility) in 2016. The SEFF is a new credit line dedicated to energy efficiency and investments in renewable energy in Egypt, offering an inclusive solution to develop sustainable energy projects. European Bank for Reconstruction and Development (EBRD) launched this credit line as part of the Green Economy Financing Facility (GEFF). It provides up to €140 million for sustainable energy investments, paying more attention to promoting energy efficient and renewable energy technologies in Egypt by promoting awareness of the benefits of investments in such technologies, thus increasing the demand. The funds provided by this facility will reach the private sector borrowers through the participating financial institutions. The funds are available to small, medium and large enterprises, suppliers, manufacturers and installers of renewable energy and energy-efficient equipment (Schimschar et al., 2020). According to them, the current practices in the field of energy efficiency by the banking sector in Egypt are insignificant. Some banks have credit lines that generally support a green economy, but there are no specific loans or grants for applying energy efficiency measures. This requires the establishment of a financing scheme and dedicated credit lines in banks. The central bank must support such an initiative, given that the banks alone can't initiate a mechanism like that without prior approval from the central bank.

### 3.2. Environmental degradation and economic growth:

Figure (5) shows the development of CO2 emissions by sector during the period (1970-2022),[1] while Figure (6) compares the emissions from these sectors in the specified years 1974, 2007 and 2022. Generally, most sectors' emissions gradually increase, while the shares of these sectors to total emissions have different patterns. The power industry is the highest CO2 emitter, with its emissions rising from 2.49 to 87.88 Mt during the period above, while the agriculture sector is the lowest emitter over the sample span, with emissions ranging between 0.8258 and 2.7872 Mt CO2 from 1970 to 2022. The contribution of the power industry, industrial process, and transport in environmental degradation grew from 8.67% to 35.6%, 7.44% to 14.08% and 17.4% to 21.35%, respectively, from (1974-2022) while the shares of industrial combustion, fugitive energy, buildings, and agriculture declined from 32.97 % to 12.55%, 12.85% to 8.04%, 17.8% to 7.28%, and from 2.83% to 1.01% respectively.

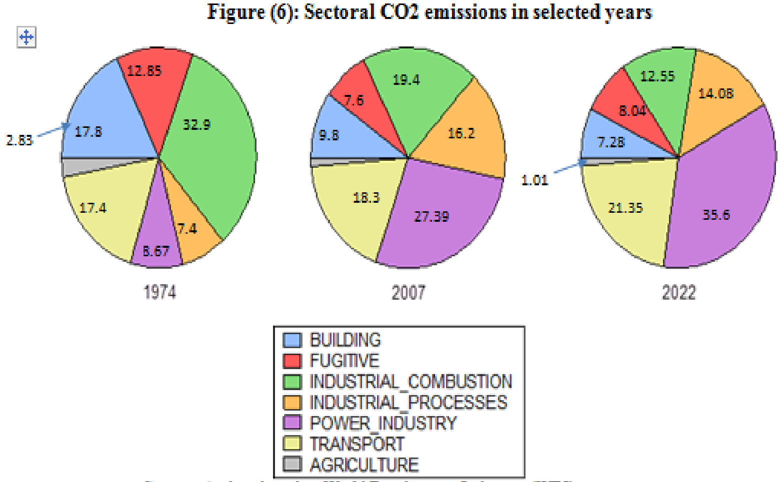
[1] Due to data availability.

**Figure (5): The development of CO2 emissions by sector during the period (1970-2022)**




**Source:** Authors based on World Development Indicators

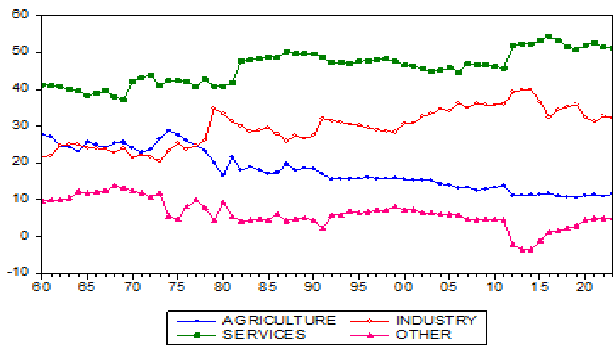
**Figure (6): Sectoral CO2 emissions in selected years**




**Source:** Authors based on World Development Indicators (WDI).

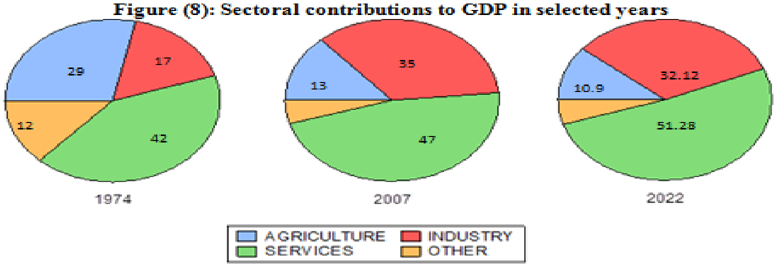
Figure (7) displays the development of different sectors in generating GDP during the period (1960-2022) while figure (8) compares the contributions of these sectors to GDP in specified years 1970, 2007 and 2022. As shown in the figure, there is a gradual increase in the contribution of the industry and services sectors to GDP, while the share of the agriculture sector has declined from 24.1% to 10.9% over the period (1970-2022). On the other hand, the share of services is the dominant sector, as it increased from 42.05% to 51.28%, whereas the industry share increased from 21.4% to 32.12% over the same period.

**Figure (7): Development of sectors shares to GDP in Egypt during (1960- 2022)**




Source: Authors based on World Development Indicators (WDI).

**Figure (8): Sectoral contributions to GDP in selected years**

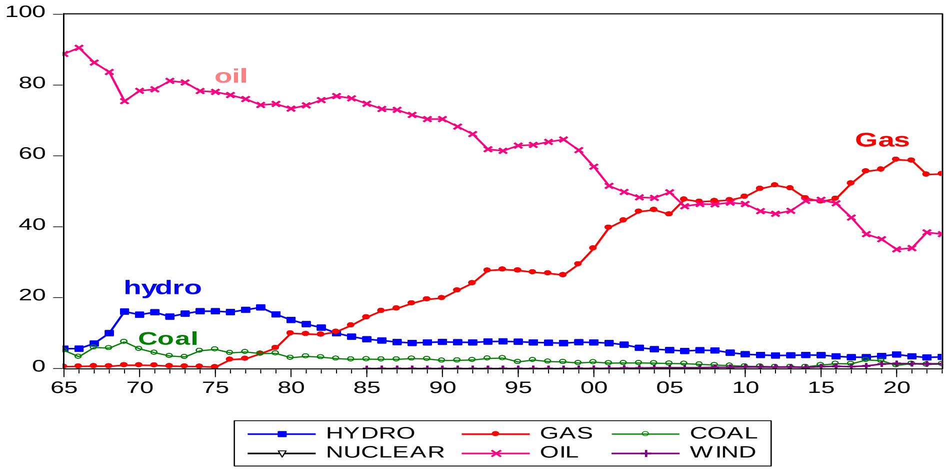



**Source:** Authors based on World Development Indicators (WDI).

Regarding energy consumption, Egypt is Africa's largest non-OPEC oil producer and the third-largest natural gas producer, followed by Algeria and Nigeria. Further, Egypt is the largest oil and natural gas consumer in Africa. The electricity sector is the dominant natural gas and oil consumer since it consumes around 36.4% and 42.4% of total oil and gas use in 2010/2011 and 2014/2015, respectively (Ahmed and Ahmed, 2019). Figure (9) shows Egypt's energy mix (i.e., the balance of sources of energy in the supply) over the period (1965-2023). As shown in the figure, Egypt depends mainly on fossil fuels. During the analysis period, oil and coal's share in energy consumption declined from 89% to 38% and from 5.11% to 1.28%.

In contrast, the share of natural gas increased from 1% to 55% over the same period. Diversification of energy towards exploiting more renewable energy resources is becoming increasingly important as countries shift away from fossil fuels to low-carbon energy sources such as nuclear or renewables, including hydropower, solar and wind. Hydropower contribution to total energy use increased at the beginning of the study period from 6% to 16% in 1965 to 1970, respectively. It increased slightly to reach 17% in 1978, to start a gradual decline to the end of the study period. Egypt began to utilise wind in 1999, with a share of 0.0066% of total energy consumption, which grew slowly to 1.36% in 2023. Compared with the New National Renewable Energy Strategy implemented in 2008, there is a significant gap between the planned share of renewable energy in the total energy mix and the actual values of this proportion. This may indicate the inadequacy of incentives for investing in renewable energy and the ineffectiveness of subsidy reductions within the energy system. Given the high dependence on fossil fuels as the primary energy source in Egypt, Egypt is considered the second-largest emitter of CO2 emissions in Africa, after South Africa, according to (Statistical Review of World Energy, 2024) data.

**Figure (9): Shares of Energy Consumption by Source (1965-2023)**

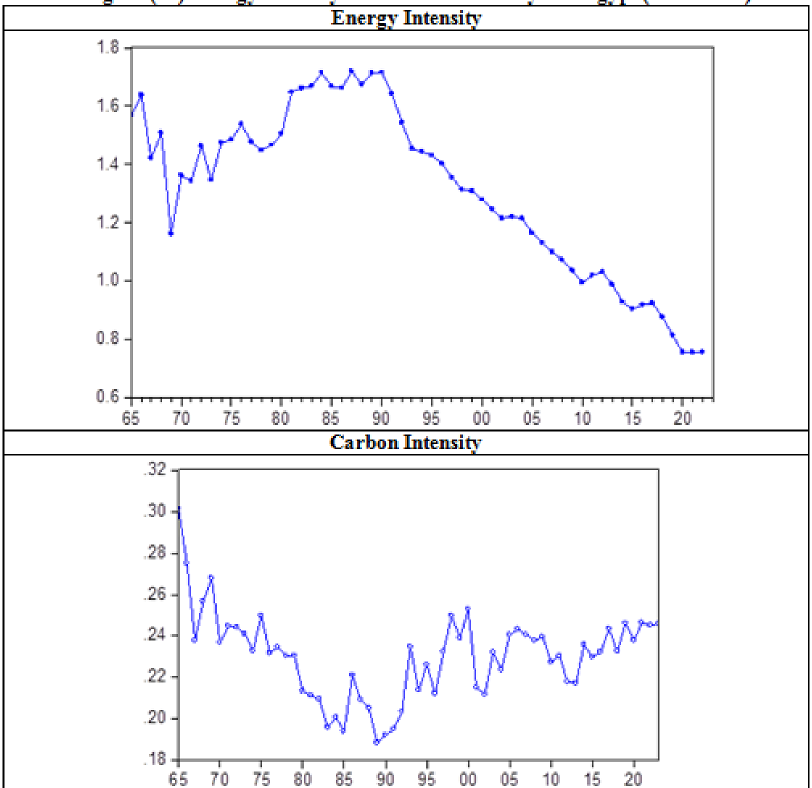



**Source: Energy Institute - Statistical Review of World Energy (2024)**

To assess if the country is progressing in reducing CO2 emissions, we can use two measures, namely energy intensity and carbon intensity. The first measures how efficiently a country uses energy to produce a given economic output. It is calculated by measuring the energy consumed per unit of GDP. The latter measure is computed by the amount of $CO_2$ emitted per unit of energy, which can be improved by altering the energy mix to lower-carbon sources such as renewables or nuclear energy. Figure (10) A displays both measures in Egypt (1965-2022). As shown in the figure, at the beginning of the study period, energy intensity was relatively high, indicating the need to use a large amount of energy to produce GDP. Then, starting in 1990, this measure gradually declined to the end of the period, implying an improvement in energy efficiency. The reasons behind this drop in energy intensity measures may include the economic shifts or the transition from energy-intensive manufacturing to service-based, as explained in Figure (8).

Regarding carbon intensity, measured in kilograms of $CO_2$ emitted per kilowatt-hour of electricity generated, there was a sharp decline at the beginning of the period as it decreased from 0.30 in 1965 to 0.24 in 1966. Then it starts to fluctuate all over the period. It ranged between (0.301 and 0.188) in 1965 and 1990 respectively. This implies a significant improvement during (1965-1990). This decline in carbon intensity may be attributed to switching to cleaner energy (i.e., the transition from fossil fuels (like coal and oil) to low-carbon energy sources (such as natural gas, solar, wind, or hydroelectric power) reduces emissions, as indicated earlier. In other words, the oil and coal's share in energy consumption dropped from 89% to 70% and from 5.11% to 2% between 1965 and 1990, whereas the share of natural gas increased from 1% to 20% over the same period. During the period (1990-2022), carbon intensity fluctuated with a slightly upward trend to the end of the period. However, it did not exceed 0.24, which is lower than its initial value.

**Figure (10): energy intensity* and carbon intensity** in Egypt (1965-2022)**




**Source:** * U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2024); Bolt and van Zanden - Maddison Project Database 2023.
** Global Carbon Budget (2024), U.S. Energy Information Administration (2023), Energy Institute - Statistical Review of World Energy (2024)

# 4. Methodology:

## 4.1 Model specification:

In this study, we employ time-series data from 1965 to 2022 to estimate the determinants of ecological degradation measured in CO2 emissions. According to the theory, the dependent variable is affected by many macroeconomic variables: economic growth (linear, quadratic, and cubic form), financial development, urbanisation, trade openness and energy consumption. Equation (1) expresses the relation between CO2 emissions and the abovementioned variable as follows:

$$\ln CO2_t = \beta_1 \ln PGDP_t + \beta_2 (\ln PGDP)_t^2 + \beta_3 (\ln PGDP)_t^3 + \beta_4 OPEN_t + \beta_5 ENU_t + \beta_6 \mathrm{FD}_t + \beta_7 \mathrm{URB}_t + \varepsilon_t \qquad (1)$$

Where:

Ln indicates the natural logarithm of the following variables:

CO2: environmental degradation, proxied by carbon dioxide emissions per capita.

$PGDP$: real GDP per capita ((in 2010 constant USD).

$PGDP^2$: square of real GDP per capita.

$PGDP^3$: cubic form of real GDP per capita.

$OPEN$: trade openness

$ENU$: energy consumption.

$FD$ : financial development (proxy by private sector credit as a ratio of GDP).

$URB$ : urbanisation (i.e., percentage of urban population to total population).

According to (Balsalobre-Lorente et al. 2017; Bekhet and Othman, 2018; Sinha et al., 2019), the cases that could occur to express the relationship between environmental degradation and economic development are summarised below:

1. **Case 1: If $\boldsymbol{\beta_1 > 0, \beta_2 = \beta_3 = 0}$,** EKC follows as a monotonically increasing function (i.e., economic growth has a determinantal impact on the environment).
2. **Case 2: If $\boldsymbol{\beta_1 < 0, \beta_2 = \beta_3 = 0}$,** EKC follows as a monotonically decreasing function (i.e., economic growth has a mitigating impact on the environment over time).
3. **Case 3: If $\boldsymbol{\beta_1 > 0, \beta_2 < 0, \beta_3 = 0}$,** EKC follows an inverted U-shaped curve (i.e., economic growth initially leads to increased ecological deterioration up to a turning point at which technological advances lead to the development of new technologies, resulting in environmental improvement).
4. **Case 4: If $\boldsymbol{\beta_1 < 0, \beta_2 > 0, \beta_3 = 0}$,** EKC follows a U-shaped curve (i.e., economic growth initially leads to ecological improvement up to a turning point at which economic growth leads to environmental deterioration).
5. **Case 5: If $\boldsymbol{\beta_1 > 0, \beta_2 < 0, \beta_3 > 0}$,** EKC follows an N-shaped curve (i.e., economic growth initially leads to environmental deterioration up to a turning point at which an increase in economic growth leads to ecological

improvement, and then a rise in GDP growth induces environmental degradation).

6. **Case 6: If $\boldsymbol{\beta_1 < 0, \beta_2 > 0, \beta_3 < 0}$,** EKC follows an inverted N-shaped curve (i.e., economic growth initially leads to ecological improvement up to a turning point at which economic growth leads to environmental deterioration, followed by another improvement in environmental quality).

However, using the above cases to validate the existence of EKC is misleading as the sign of the estimated parameters is insufficient and ignores the realistic part of EKC. To find the sufficient condition for the existence of EKC, (Farooq et al. 2024) suggest conducting the following steps.

1- Step 1: partially differentiate equation (1) concerning income level as

$$\frac{\mathrm{d}(\ln CO2_{t})}{d(PGDP)} = \frac{d}{d(PGDP)}[\beta_1 \ln PGDP_t + \beta_2 (\ln PGDP)_t^2 + \beta_3 (\ln PGDP)_t^3 + \beta_4 OPEN_t + \beta_5 ENU_t + \beta_6 \mathrm{FD}_t + \beta_7 \mathrm{URB}_t + \varepsilon_t]$$

This implies that,

$$\frac{\mathrm{d}(\ln CO2_{t)}}{d(PGDP)} =$$
$$\beta_1 \times \frac{1}{PGDP} + 2\beta_2(\ln PGDP_t) \times \frac{1}{PGDP} + 3\beta_3(\ln PGDP)_t^2 \times \frac{1}{PGDP} \quad (2)$$

To find the turning points of EKC, equation (2) should equal zero such that,

$$\beta_1 \times \frac{1}{PGDP} + 2\beta_2(\ln PGDP_t) \times \frac{1}{PGDP} + 3\beta_3(\ln PGDP)_t^2 \times \frac{1}{PGDP} = 0 \quad (3)$$

Multiplying both sides by PGDP, equation (3) could be written as follows,

$$3\beta_3(\ln PGDP)_t^2 + 2\beta_2(\ln PGDP_t) + \beta_1 = 0 \quad (4)$$

To find the quadratic roots,

$$(\ln PGDP_t) = \frac{2\beta_2 \pm \sqrt{(2\beta_2)^2 - 4(3\beta_3)(\beta_1)}}{2(3\beta_3)} \quad (5)$$

Based on that, the value of the term $(2\beta_2)^2 - 4(3\beta_3)(\beta_1)$ is used to examine the existence of EKC as follows:

1- If $(2\beta_2)^2 - 4(3\beta_3)(\beta_1) > 0$, the roots of the equation are real and distinct. This implies the existence of N or inverted N-shape EKC.

2- If $(2\beta_2)^2 - 4(3\beta_3)(\beta_1) = 0$, the roots of the equation are real and equal, implying that a single threshold income exists at which *EKC* changes its curvature. Thus, *N* or inverted *N*-shape is not possible

3- If $(2\beta_2)^2 - 4(3\beta_3)(\beta_1) < 0$, the roots of the equation are imaginary, implying an inability to find *EKC* with threshold income levels.

Consequently, if the first condition is valid and there is a possibility of the existence of N or inverted N-shape EKC, then the threshold level of income could be found as follows:

$$PGDP_t = Antilog\left(\frac{-2\beta_2 \pm \sqrt{(2\beta_2)^2 - 4(3\beta_3)(\beta_1)}}{2(3\beta_3)}\right) \qquad (6)$$

### 4.2 Econometric Methodology:

The current study applies the Nonlinear Autoregressive Distributed Lag (NARDL) model to explore the relationship between CO2 emissions and its main determinants. The ARDL model and the bounds test of cointegration proposed by Pesaran et al. (2001) outperform other cointegration approaches. In this model, the long and short-run coefficients of the model are estimated simultaneously. Further, the ARDL approach could be applied regardless of the degree of integration of the included variables. Moreover, this method is superior to multivariate cointegration techniques in small samples Narayan, 2005. Equation (7) represents the model under consideration, Where variables are in the logarithmic format and $FD^+$, $FD^-$, $URB^+$and

$URB^{-}$ represent the positive and negative shocks of financial development and urbanisation, respectively.

$$\Delta CO2_t = \alpha_0 + \sum_{i=1}^{m} \alpha_{1i} \Delta PGDP_{t\_i} + \sum_{i=1}^{m} \alpha_{2i} PGDP_{t-i}^{2} + \sum_{i=1}^{m} \alpha_{3i} PGDP_{t-i}^{3} + \sum_{i=1}^{m} \alpha_{4i} \Delta OPEN_{t\_i} + \sum_{i=1}^{m} \alpha_{5i} \Delta ENU_{t\_i} + \sum_{i=1}^{m} \alpha_{6i} \Delta FD_{t-i}^{+} + \sum_{i=1}^{m} \alpha_{7i} \Delta FD_{t-i}^{-} + \sum_{i=1}^{m} \alpha_{8i} \Delta URB_{t-i}^{+} + \sum_{i=1}^{m} \alpha_{9i} \Delta URB_{t-i}^{-} + \theta_1 PGDP_{t-1} + \theta_2 PGDP_{t-1}^{2} + \theta_3 PGDP_{t-1}^{3} + \theta_4 OPEN_{t-1} + \theta_5 ENU_{t-1} + \theta_6 FD_{t-i}^{+} + \theta_7 FD_{t-i}^{-} + \theta_8 URB_{t-i}^{+} + \theta_9 URB_{t-i}^{-} + \varepsilon_t \qquad (7)$$

The other control variable, trade openness, could positively or negatively influence the environmental quality, as illustrated in section 2. Also, the current model accounts for the impact of energy use on the environment, where a positive sign of its coefficient denotes that energy use degrades the environment. In contrast, a negative sign means it mitigates CO2 emissions. As explained earlier, financial development and urbanisation could have detrimental or mitigating environmental impacts. A positive sign of their coefficients implies a harmful effect of these variables on the environment, whereas a negative sign means that these variables improve environmental quality.

The first stage is to apply the bounds test. Consequently, we test the null hypothesis of no cointegration (i.e., $H_0$: $\theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6 = \theta_7 = \theta_8 = \theta_9 = 0$) against the alternative hypothesis ($H_1$: $\theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5 \neq \theta_6 \neq \theta_7 \neq \theta_8 \neq \theta_9 \neq 0$). The bounds test of cointegration is based on the F with a non-standard distribution. Therefore, Pesaran et al. (2001) introduce two sets of critical values for different significance levels, with and without a time trend. The first set of critical values assumes that all variables are stationary, whereas the second set assumes all variables are integrated of order 1. According to them, if the computed F-statistic exceeds the upper critical bounds value, the null hypothesis is rejected, implying cointegration between the employed variables. In contrast, if the F-statistic is lower than the lower critical bounds value, we cannot reject the null hypothesis, and there is no cointegration. Finally, the test is inconclusive if the computed F-statistic lies between the bounds.

The second step is to estimate the short-run relationship shown in equation (7). Also, it is possible to perform a parameter stability test for the selected representation of the error-correction model:

$$\Delta CO2_t = \alpha_0 + \sum_{i=1}^{m} \alpha_{1i} \Delta PGDP_{t\_i} + \sum_{i=1}^{m} \alpha_{2i} PGDP_{t-i}^2 + \sum_{i=1}^{m} \alpha_{3i} PGDP_{t-i}^3 + \sum_{i=1}^{m} \alpha_{4i} \Delta OPEN_{t\_i} + \sum_{i=1}^{m} \alpha_{5i} \Delta ENU_{t\_i} + \sum_{i=1}^{m} \alpha_{6i} \Delta FD_{t-i}^+ + \sum_{i=1}^{m} \alpha_{7i} \Delta FD_{t-i}^- + \sum_{i=1}^{m} \alpha_{8i} \Delta URB_{t-i}^+ + \sum_{i=1}^{m} \alpha_{9i} \Delta URB_{t-i}^- + \lambda EC_{t-1} + \epsilon_t \qquad (8)$$

Where:

$\lambda$: speed of adjustment coefficient (i.e., $-1 < \lambda < 0$)

$EC_{t-1}$: the Error correction term resulting from the estimated cointegration model.

# 5. Empirical Results

## 5.1 data and preliminary analysis:

This study examines the determinants of ecological degradation in terms of CO2 emissions in Egypt during (1965-2022). The employed variables and data sources are displayed in Table (2). Table (3) presents the descriptive statistics of the variables, which are expressed in logarithmic form. As shown in the table, the employed variables, excluding CO2 emissions and urbanisation, have normal distributions at a 1% significance level, as confirmed by the Jarque-Bera test statistics. To test for the existence of unit root in the variables, we apply the Augmented Fickey Fuller (ADF) test. Table (4) shows that all variables are integrated of order one, excluding urbanisation, which is level stationary, implying the possibility of applying the NARDL model.

**Table (2) data sources for employed variables.**

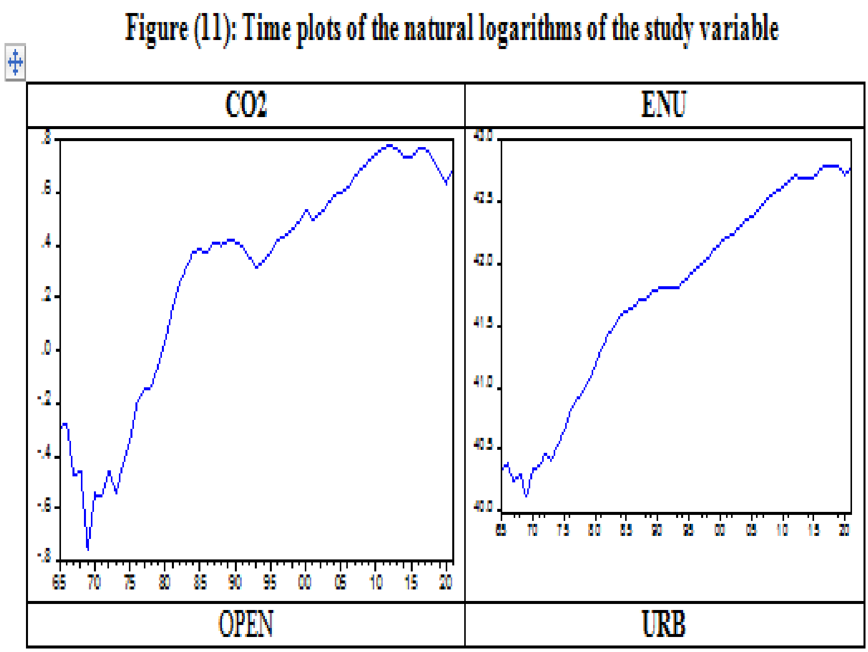
| Symbol | **Variable description and measurement** | **Data Sources** |
|---|---|---|
| $CO2_t$ | CO2 emissions (Tons per capita) | British Petroleum. Statistical Review of World Energy |
| $FD_t$ | Domestic credit to the private sector | WDI |
| $PGDP_t$ | GDP per capita | WDI |
| $URB_t$ | Percentage of urban population to total population | WDI |
| $ENU_t$ | Energy use | WDI |
| $OPEN_t$ | Trade openness per capita (Exports + imports)/ population | WDI |

**Table (3): Descriptive Statistics of the employed variables**

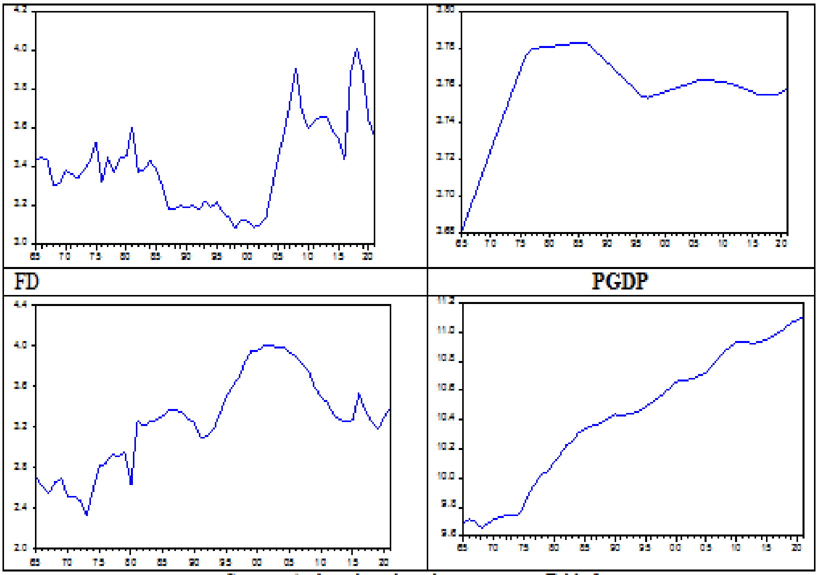
| | *CO2* | *OPEN* | *ENU* | *PGDP* | $PGDP^2$ | $PGDP^3$ | *FD* | *URB* |
|---|---|---|---|---|---|---|---|---|
| **Mean** | 0.285907 | 6.392053 | 41.72922 | 10.42255 | 108.8325 | 1138.514 | 3.258731 | 3.757846 |
| **Median** | 0.412839 | 6.247989 | 41.80222 | 10.44548 | 109.1080 | 1139.685 | 3.270192 | 3.759944 |
| **Maximum** | 0.782622 | 7.603324 | 42.79246 | 11.10213 | 123.2572 | 1368.417 | 4.006080 | 3.783144 |
| **Minimum** | -0.76115 | 5.503794 | 40.11530 | 9.657714 | 93.27143 | 900.7888 | 2.329977 | 3.680998 |
| **Std. Dev.** | 0.441722 | 0.579569 | 0.845864 | 0.454399 | 9.412735 | 146.4559 | 0.457804 | 0.022441 |
| **Skewness** | -0.82125 | 0.459218 | -0.4637 | -0.297931 | -0.247305 | -0.196329 | -0.11904 | -1.67437 |
| **Kurtosis** | 2.384710 | 2.120788 | 1.948260 | 1.862593 | 1.844159 | 1.829536 | 2.215676 | 5.953699 |
| **Jarque-Bera** | 7.306342 | 3.839280 | 4.669907 | 3.915769 | 3.753939 | 3.619895 | 1.595630 | 47.35355 |
| **Probability** | 0.025909 | 0.146660 | 0.096815 | 0.141157 | 0.153053 | 0.163663 | 0.450312 | 0.000000 |

Source: Author's calculations.

**Figure (11): Time plots of the natural logarithms of the study variable**




**Source:** Authors based on data sources in Table 2.




**Source:** Authors based on data sources in Table 2.

**Table (4): Results of ADF unit root test**

| | ADF test statistic | P-value |
|---|---|---|
| $CO2$ | -1.012411 | 0.9337 |
| $\Delta CO2$ | -8.133268 | 0.0000* |
| $OPEN$ | -2.434767 | 0.3584 |
| $\Delta OPEN$ | -6.373685 | 0.0000* |
| $ENU_r$ | -0.298214 | 0.9888 |
| $\Delta ENU_r$ | -8.173332 | 0.0000* |
| $GDP$ | -1.911653 | 0.6350 |
| $\Delta GDP$ | -4.636249 | 0.0025* |
| $GDP^2$ | -2.147108 | 0.5087 |
| $\Delta GDP^2$ | -4.595472 | 0.0028* |
| $GDP^3$ | -2.561769 | 0.2988 |
| $\Delta GDP^3$ | -4.559077 | 0.0031* |
| $FD$ | -1.289764 | 0.8803 |
| $\Delta FD$ | -7.816696 | 0.0000* |
| $URB$ | -3.782325 | 0.0054* |

- Lag length is chosen according to SIC.
- * indicates significance at 1% level of significance.
- All variables are expressed in the logarithmic form.
- Source: Authors calculations.

## 5.2 Long-run and short-run findings:

This study examines the determinants of ecological degradation in terms of $CO_2$ emissions in Egypt from 1965 to 2022. The employed variables and data sources are displayed in Table 2. Table (3) presents the descriptive statistics of the variables, which are expressed in logarithmic form. As shown in the table, the employed variables, excluding $CO_2$ emissions and urbanisation, have normal distributions at a 1% significance level, as confirmed by the Jarque-Bera test statistics.

**Table (5): Bounds test for cointegration**

| Model | Computed F-stat. | Sample size | 1% critical values | | 5% critical values | |
|---|---|---|---|---|---|---|
| | | | I0 Bound | I1 Bound | I0 Bound | I1 Bound |
| ARDL, (k=9) | 5.391374* | N = 55 | 2.97 | 4.24 | 2.43 | 3.56 |

According to the AIC, the maximum lags for the NARDL model are (2, 1, 0, 0, 0, 1, 0, 1, 1, 1) for CO2, $FD^+$, $FD^-$, ENU, OPEN, $URB^+$, $URB^-$, GDP, $GDP^2$and $GDP^3$respectively. Table (6) shows the results of the employed model where panel (A) presents the long-run estimation, panel (B) shows the short-run relation and panel (C) displays the diagnostic tests. The results reveal that financial development has no mitigating or harmful impact on CO2 emissions in the long run. However, positive and negative financial development shocks are sources of short-term environmental degradation (i.e., positive shocks increase emissions by 0.70%, negative shocks by 0.78%). The short-term determinantal effect of financial development suggests that an advanced financial sector enhances consumer credit, prompting increased purchases of goods such as real estate, automobiles, and electronic devices, which results in higher energy consumption and greater carbon emissions; however, this impact lasts only in the short-run with no long term consequences. This could be attributed to Egypt’s banking sector's lack of dedicated green financing instruments, given that only 2% of SEFF’s €140 million reached energy-efficient projects. This requires building particular credit lines and a funding structure inside financial institutions with the central bank's support.

Concerning the effects of urbanisation on ecological degradation, we found that positive shocks of urbanisation decrease CO2 emissions in the long run while it increases environmental degradation in the short run. Further, adverse shocks of urbanisation have an insignificant impact on ecological quality in the long or short run. Thus, urbanisation positive shocks temporarily raise emissions by 6.04% while reducing emissions in the long run. The long-run environmental benefits of urbanisation are consistent with the compact city theory, which states that higher urban densities enhance economies of scale in public infrastructure, including transportation, hospitals, and schools, reducing environmental issues. In the Egyptian case, the government's energy efficiency regulations in buildings (2006, 2009) and renewable energy strategy (2008) may investigate these results. Hence, enforcing energy-efficient designs in residential and commercial structures and promoting renewable energy enhanced the economies of scale in urban infrastructure density. This explains why Egypt's urban centres ultimately contributed to long-run $CO_2$ mitigation through structural and policy-driven efficiency gains despite short-run emission spikes from construction and manufacturing.

Further, **the urban environmental transition theory confirms** that, although expanding manufacturing initially increases **industrial pollution**, technological innovation and structural changes in economic sectors lessen these harmful effects. In the Egyptian case, the share of services increased gradually from 42.05% to 51.28% over the study period, which may have contributed to this result. Additionally, the results align with the findings of Saidi and Mbarek (2017), who found that greater urbanisation minimises carbon dioxide emissions. Based on this result, policymakers could induce economic growth in the long run by encouraging urbanisation while mitigating the damaging side effects of air pollution.

The results also indicate that trade openness has a modest mitigating effect on CO2 emissions in both the long and short run. Over the long term, increasing trade openness by 1% leads to a decrease of 0.048% in CO2 emissions. This implies that combined technology and composition effects (oriented towards clean goods) offset the scale effect, improving environmental quality. Further, energy use has a determinantal influence on environmental quality in the long and short run, as indicated by a significant and positive coefficient of energy use.

The estimated long-run elasticity of environmental degradation to GDP is significant and equal to 200.7%, -19.5%, and 0.63 for GDP per capita, its square, and its cubic form, respectively. Therefore, the relationship between economic growth and environmental degradation satisfies the conditions of case five, which confirms that the relationship between economic growth and the environment has an N-shape curve, given that economic growth initially leads to a higher environmental degradation up to a turning point at which the ecological degradation starts to fall with economic growth to reach the second turning point at which increasing production starts to increase pollutants and negatively affects the environment. Thus, Egypt is currently in the third phase of the N-shape curve with its present economic growth, where a further rise in GDP will increase $CO_2$ emissions (i.e., the technological obsolescence effect where the scale effect exceeds the composition and technical impact). The results contradict the findings of Shaker (2022), who found an inverted N-shape relationship between $CO_2$ emissions and real GDP in Egypt due to Egypt's initial environmentally-friendly mindset, as he claimed. However, the results are consistent with those of Mahmoud et al. (2019), who provide evidence of the validity of the N-shape EKC hypothesis in Egypt.

A further step is to test the sufficient condition, i.e. whether $\beta_1 > 0, \beta_2 < 0, \beta_3 > \mathbf{0}$, following (Farooq et al.,2024), we find the two real and distinct percapita income thresholds by taking anti-logs of 9.76 and 10.83, corresponding to LE17395.64 and LE50728.65, respectively. Thus, The first turning point of the N-shaped EKC is LE17395.64 per capita, and the next is LE50728.65 per capita. The first point lies between 1973 and 1975, while the second turning point corresponds to 2007.

Before 1975, increasing per capita income deteriorated the environment. Egypt's economic performance during the nineteenth and early twentieth centuries could be described as "lopsided" progress, given that cotton dominated national economic activity in terms of its farming, ginning, processing, crop financing, irrigation, public works, internal trade, and exports (Mabro and O'Brien, 2015). Further, this phase was initially characterised by the dependence on basin irrigation, with Nile silt being the only fertiliser. This fertile silt yielded high yields for most crops. However, the introduction of perennial irrigation and continuous cropping, mainly cotton, led to the need for chemical fertilisers. Chemical fertiliser consumption increased rapidly, leading Egypt to have the highest nitrate fertiliser inputs among less developed countries. Moreover, with the completion of the High Dam, silt was deposited as sediment in a new lake, requiring a further increase in chemical fertiliser use. Therefore, fertiliser input increased substantially from 1960-

61 to 1965-66 but fell somewhat thereafter due to the war in 1967 and foreign exchange shortages (Hansen and Nashashibi, 1975). This suboptimal fertiliser input may have negatively influenced the environment. This result is consistent with Panayotou (1993), who claims that environmental waste is limited in the early stages of economic development, higher economic activities through agriculture, resource exploitation, and industrialisation lead to lower regeneration rates than extraction rates, increasing waste volume and toxicity(i.e., the scale effect dominates during this phase).

In contrast, the economy's transition to services leads to decreased pollution. Consequently, the composition effect may mitigate the adverse effects of economic growth on environmental degradation due to this shift in economic structure. As discussed in section 3, the proportion of services and industry to GDP grew steadily from 42% to 47% and from 17% to 35% between 1974 and 2007, whilst agriculture decreased from 29% to 25% within the same time frame. The gradual decrease in environmental degradation may be attributed to the emergence of information and services sectors, which are associated with increased environmental concerns during the second phase. From 2007 onwards, the scale effect exceeded the technical and composition effects, leading to the technological obsolescence effect. Possible reasons could be changes in consumer and producer preferences towards high energy-intensive products, low effective enforcement of environmental regulations, and lagging investments in renewable energy technology, as indicated in section 3. Despite 2008's 20% renewable target, fossil fuels still dominate (55% natural gas in 2023), reflecting inadequate incentives (e.g., only 2% of customs cuts for renewable equipment). This policy failure worsens the third EKC phase's technological obsolescence.

As shown in panel (B), the error-correction term is −0.363 with the expected sign, suggesting that about 36.8% of any deviation from the long-run relationship is adjusted in the same year (i.e., the complete convergence process to its equilibrium level takes around 3 years).

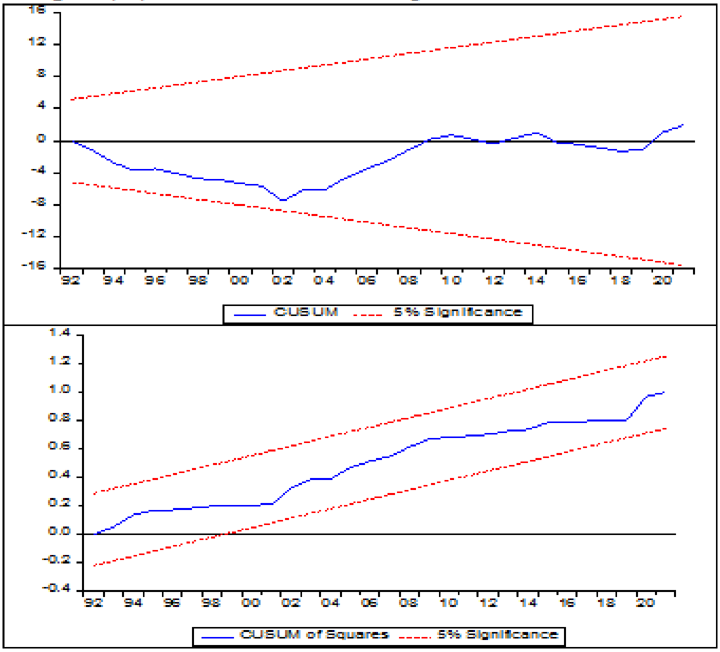
**Table (6): Model estimation in the long and short run**

| **Panel A: Long-run elasticities** | | |
|---|---|---|
| Variable | Coef. | P-value |
| $\mathrm{GDP}_t$ | 200.700647 | 0.0001* |
| ${GDP^2}_t$ | -19.539936 | 0.0001* |
| ${GDP^3}_t$ | 0.632415 | 0.0001* |
| $\mathrm{ENU}_t$ | 1.404450 | 0.0000* |
| $\mathrm{OPEN}_t$ | -0.048466 | 0.0127* |
| $FD_t^+$ | -0.023883 | 0.3659 |
| $FD_t^-$ | 0.007762 | 0.7813 |
| $URB_t^+$ | -1.390351 | 0.0116* |
| $URB_t^-$ | -0.398330 | 0.7271 |
| Constant | -742.223793 | 0.0000* |
| Trend | -0.031567 | 0.0000* |
| **Panel B: Short-run elasticities** | | |
| $\Delta\mathrm{CO2}_{t-1}$ | 0.0322 | -0.056432 |
| $\Delta\mathrm{GDP}_t$ | 6.779841 | 0.9416 |
| $\Delta {GDP^2}_t$ | -0.869704 | 0.9233 |
| $\Delta {GDP^3}_t$ | 0.034873 | 0.9055 |
| $\Delta\mathrm{ENU}_{t-2}$ | 1.185257 | 0.0000* |
| $\Delta\mathrm{OPEN}_t$ | -0.040902 | 0.0108* |
| $\Delta FD_t^+$ | 0.7014 | 0.009143* |

| | | |
|---|---|---|
| $\Delta FD_t^-$ | 0.7816 | 0.006551* |
| $\Delta URB_t^+$ | 6.035876 | 0.0348* |
| $\Delta URB_t^-$ | -0.336163 | 0.7248 |
| Trend | -0.026641 | 0.0000 |
| $ECT_{t-1}$ | -0.843929 | 0.000 |
| **Panel C: Digansotic tests** | | |
| Heteroscadsticity test Breusch-Godfrey | 0.587603 | 0.8664 |
| Breusch-Godfrey Test for serial correlation | 0.012007 | 0.9881 |
| Ramsey RESET Test | 0.078342 | 0.7812 |
| Jarque-Bera | 7.23 | 0.023 |
| CUSUM and CUSUM SQUARE | Stable (Figure (12)) | |

- lag length is chosen according to AIC
- *, **, *** indicate significance at 1%, and 5%, level of significance.
- Source: Authors' calculation

**Figure (12): CUSUM and CUSUMSQ Plots of the ARDL model**




Source: Authors' calculation

## 6. Conclusion:

This study investigates how **financial development** and **urbanisation** nonlinearly impact $CO_2$ emissions in Egypt (1965–2022), using **NARDL** to model asymmetric effects and testing for an **N-shaped EKC** while accounting for other control variables, such as trade openness energy use. We found a cointegrating relationship between the employed variables. The results reveal that financial development does not impact environmental degradation in the long term; positive and negative financial development shocks strengthen ecological degradation in the short term. The short-term detrimental impacts of financial development are consistent with (Sadorsky, 2010), who argues that financial development increases emissions due to higher industrial activity by easing credit access for industrial expansion in traditional industries and consumer spending (e.g., cars and appliances). These results advocate the findings of (Schimschar et al., 2020), which reported the lack of substantial green financing in Egypt's banking sector.

On the other hand, we found that positive shocks of urbanisation mitigate CO2 emissions in the long run, whereas they deter environmental quality in the short run. Further, adverse shocks of urbanisation have an insignificant impact on ecological quality in the long or short run. Thus, urbanisation's environmental effects are nonlinear and depend on development stages. The findings of the long-run impact are consistent with

Saidi and Mbarek (2017) and support the compact city theory that higher urban densities enhance economies of scale in public infrastructure, including transportation, hospitals, and schools, reducing environmental issues. Additionally, the urban ecological transition theory suggests that although expanding manufacturing initially increases industrial pollution, technological innovation and structural changes in economic sectors lessen these harmful effects in the long run.

Furthermore, trade openness has a mitigating impact on the environment. Thus, combined technology and composition effects (oriented towards clean goods) offset the scale effect, improving environmental quality and against the pollution haven hypothesis. Moreover, energy consumption has a determinantal influence on environmental quality in the long and short run. The inverted N-shape EKC hypothesis is confirmed in the long and short run with two turning points (LE17,395.64 in 1973–1975 and LE50,728.65 in 2007). However, the results contradict the findings of Shaker (2022), who claim an inverted N-shape EKC in Egypt; they are consistent with those of Mahmoud et al. (2019), who provide evidence of the validity of the N-shape EKC hypothesis in Egypt. According to these findings, before 1975, the scale effect dominated the composition and technical impact; during (1975–2007), composition and technology effects reduced emissions; post-2007, the technological obsolescence effect occurred. Thus, Egypt entered its third phase (rising emissions) post-2007 due to technological obsolescence, where energy-intensive consumption and weak environmental regulations reversed prior gains from structural economic shifts (1975–2007).

Based on these results, to avoid the adverse consequences of financial development on the environment, it is recommended that the Central Bank of Egypt support building particular credit lines within financial institutions that provide specific loans and certain incentives for firms that use energy-efficient practices, given that directed financial policies are crucial for sustainable development. Further, better regulation and technology adoption are required. Therefore, the Egyptian government should pursue and encourage more environmentally friendly industrial technologies and actively employ programs to reduce polluting emissions to improve the environment's overall state. Moreover, given the positive impact of urbanisation on environmental quality, policymakers could induce economic growth in the long run by encouraging urbanisation while mitigating the damaging side effects of air pollution. Finally, energy consumption per capita can be reduced by deploying energy-efficient machinery and other policies, given that previous literature shows that lowering overall energy consumption is more environmentally worthwhile than investing in renewable energy generation facilities, at least in the early phases of green energy adoption.

The paper is limited by focusing on one measure of environmental degradation and could be extended by exploring the influence of financial development and urbanisation on ecological footprint. Further research may examine the impact of environmental regulations, institutional quality, and political stability on ecological quality.

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**Appendix 1: Summary of Literature**

**Table A1: Summary of recent literature**

| Authors | Countries | Sample | Purpose | Methodology | Main findings |
|---|---|---|---|---|---|
| Iwata et al.(2010) | France | 1960-2003 | Estimate France's environmental Kuznets curve (EKC) while accounting for the contribution of nuclear energy to the country's electricity output. | ARDL | -The results support the inverted U-shape EKC hypothesis. |
| Sharma (2011) | 69 nations | 1985-2005 | Investigating the effect of trade openness, per capita GDP, energy consumption, per capita electric power consumption, per capita total primary energy consumption, and urbanisation on $CO_2$ emissions. | GMM | -All variables have positive effects on CO2 emissions, while urbanisation has a negative impact on CO2 emissions. |
| Zhu et al. (2012) | 20 countries | 1992-2008 | Analysing the relationship between urbanisation and $CO_2$ emissions. | FE | -Urbanisation has an insignificant impact on CO2 emissions |
| Shahbaz, Hye et al., (2013) | Indonesia | 1975-2011 | Exploring the linkages among economic growth, energy consumption, financial development, trade openness, and $CO_2$ emissions | ARDL bounds testing, VECM | -The study revealed that economic growth and energy consumption increase CO2 emissions, while financial development and trade openness compact it. |
| Shahbaz, Solarin et al., (2013) | Malaysia | 1971-2011 | Examining the impact of financial development, economic growth and energy consumption on $CO_2$ emissions | ARDL | -Financial development decreases CO2 emissions, while economic growth and energy consumption increase CO2 emissions. |
| Shahbaz, Tiwari et al., (2013) | South Africa | 1965-2008 | Exploring the effects of financial development, economic growth, coal consumption and trade openness on environmental performance | ARDL bounds testing, ECM | - Economic growth and coal consumption increase energy emissions, while financial development and trade openness reduce them.<br>-Evidence of the validity of the inverted U-shaped EKC hypothesis implies that the level of CO2 emissions initially increases with income until it reaches its stabilisation point, and then it declines. |

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|---|---|---|---|---|---|
| Tiwari et al. (2013) | India | 1966-2011 | Examining the dynamic link between CO2 emissions, trade openness, economic growth, and coal usage. | ARDL bounds testing | -Evidence of EKC is present.<br>-A bidirectional causal relationship exists between economic growth and CO2 emissions and a feedback hypothesis between coal consumption and CO2 emissions. |
| Ozturk and Acaravci (2013) | Turkey | 1960-2007 | Examining the relationships between trade, financial development, economic growth, energy consumption, and CO2 emissions. | ARDL | -There is a positive relationship between the foreign trade-to-GDP ratio and per capita CO2 emissions, whereas financial development has an insignificant impact on CO2.<br>-An inverted U shape EKC is validated |
| Shahbaz et al. (2014) | UAE | 1975-2011 | Exploring the relationship between urbanisation, economic growth, electricity consumption, and environmental degradation | ARDL bounds testing, and VECM | -There is an inverted U-shaped EKC<br>-Electricity consumption declines CO2 emissions, while urbanisation increases CO2 emissions. |
| Al-Mulali, Weng-Wai, et al. (2015) | 93 countries | 1980-2008 | Investigating the effect of energy consumption, urbanisation, trade openness, and financial development on ecological footprint. | Fixed Effects (FE) and Generalised Method of Moments (GMM) | -Energy consumption, urbanisation, and trade openness positively affect the ecological footprint, while financial development has a negative effect on the ecological footprint.<br>-An inverted U-shaped relationship exists between the ecological footprint and GDP growth in countries at a stage of economic development where technologies are available to improve energy efficiency, save energy, and utilise renewable energy. |
| Al-Mulali, Tang et al. (2015 | Latin America and Caribbean countries | 1980-2010 | Examining the effect of economic growth, renewable energy consumption and financial development on $CO_2$ emissions | Kao cointegration test and Fully Modified OLS (FMOLS) | -An inverted U-shaped EKC is confirmed.<br>-Financial development can improve environmental quality (recommending the need to increase banking loans on green energy, energy efficiency and energy-saving projects), whereas using renewable energy does not contribute to CO2 reduction. |

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|---|---|---|---|---|---|
| Charfeddine and Khediri (2016) | UAE | 1975-2011 | Investigating the relationship between $CO_2$ emissions, electricity consumption, economic growth, financial development, trade openness and urbanisation | Cointegration with regime shifts | -Financial development has an inverted U-shaped impact on CO2 and electricity consumption; urbanisation and trade openness reduce CO2 emissions.<br>-EKC hypothesis is confirmed. |
| Abbasi, and Riaz, (2016) | Pakistan | 1971-2011, | Exploring the effect of economic and financial development on $CO_2$ emissions | ARDL, ECM, VECM and | Financial variables played a significant role in emission mitigation during the sub-period (1988-2011), particularly where greater liberalisation and financial sector development occurred. |
| Javid, and Sharif, (2016) | Pakistan | 1972-2013 | analysing the effects of financial development, per capita real income, the square of per capita real income, per capita energy consumption and openness on per capita $CO_2$ emissions | The bound F-test for cointegration | -An inverted U-shaped EKC is validated for both the short-term and long-term.<br>-Income, energy consumption, and financial development deteriorate the environment, while the openness variable has no significant influence on short- or long-term carbon emissions. |
| Sugiawan and Managi (2016) | Indonesia | 1971-2010 | Examining the notion of the environmental Kuznets curve (EKC) | ARDL | -inverted U-shaped (EKC) relationship between CO2 emissions and economic growth.<br>-The beneficial impacts of renewable energy on reducing CO2 emissions are observable both in the short and long term. |
| Ali et al. (2016) | Nigeria | 1971-2011 | Examining the effect of urbanisation, trade openness, energy consumption, and economic growth on $CO_2$ emissions. | ARDL | -Energy consumption and economic growth have a deteriorating effect on CO2 emissions.<br>-Trade openness negatively impacts CO2 emissions, while there is an insignificant relationship between urbanisation and CO2 emissions. |
| Behera and Dash (2017) | 17 nations | 1980-2012 | Analysing the relationship between energy consumption, urbanisation, foreign direct investment (FDI), and $CO_2$ emissions. | DOLS FMOLS | -Primary energy use, fossil fuel energy use, and FDI substantially affect CO2 emissions.<br>-Primary and fossil fuel energy consumption in middle-income countries considerably increases CO2 emissions. |

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|---|---|---|---|---|---|
| Kwakwa and Alhassan (2018) | Ghana | 1971-2013 | Examines the impact of energy and urbanisation on $CO_2$ emissions. | FMOLS | -combustible renewables and waste consumption, electricity production from hydro and trade openness reduce CO2 emissions, while fossil fuel consumption, electricity production from fossil fuels, urbanisation and industrialisation increase CO2 emissions |
| Shahbaz et al. (2018) | France | 1955-2016 | Exploring the effects of FDI, financial development, economic growth, energy consumption, and energy research innovations on influencing CO2 emissions. | Cointegration, bootstrapping bounds testing approach, developed by McNown et al. (2018), | -FDI and energy use have a positive impact, while energy research innovations and financial development have a determinantal impact on CO2 emissions.<br>-An inverted-U shape EKC is confirmed |
| Allard et al. (2018) | 74 Countries | 1994-2012 | Investigating the relation between GDP per capita, CO2 emissions, renewable energy consumption, technological development, trade, and institutional quality. | Panel Quantile regression | -An N-shaped relationship exists between CO2 and GDP in lower-middle-income countries.<br>-A negative relationship between renewable energy consumption and CO2 emissions, |
| Khan et al. (2019) | 52 countries | 1990-2016 | Analysing the connections among GDP, energy use, financial development, foreign investment, and ecological footprint to test four hypotheses: the pollution haven, environmental Kuznets curve hypothesis, energy push emission hypothesis, and finance push emission hypothesis. | Augmented mean group (AMG) along with common correlated effect mean group (CCEMG) estimator and panel heterogeneous causality | -All four hypotheses are supported partially across the regions. |
| Ehigiamusoe et al. (2019) | 58 countries | 1991-2015 | Examining the relationship between financial development and environmental quality. | dynamic common correlated effect (CCE) and the dynamic panel generalised method of moments (GMM) | -There is a non-linear relationship between financial system development and environmental quality.<br>-Bank-based financial development enhances environmental quality, but the impact of market-based financial development is uncertain. |

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|---|---|---|---|---|---|
| Seetanah et al. (2019) | 12 countries | 2000-2016 | Investigating the effect of economic and financial development on environmental degradation | Panel Vector Autoregressive (PVAR) | -There is a negative relationship between economic development and environmental degradation.<br>- Financial development has no significant impact on environmental degradation. |
| Jian et al (2019) | China | 1982-2017 | Analysing how energy use, financial development, and economic growth affect carbon dioxide emissions (CO2). | Johansen cointegration test and VECM | -CO2 emissions are positively impacted by energy use and financial development. Economic growth can reduce CO2 emissions. |
| Destek and Sarkodie(2019) | 11 countries | 1977-2013 | Investigating the relationship between economic growth, energy consumption, financial development, and ecological footprint. | Augmented mean group (AMG) estimator and heterogeneous panel causality | -There is a negative relationship between financial development and the ecological footprint.<br>-There is an inverted U-shaped relationship between economic growth and ecological footprint. |
| Shah et al. (2019) | 101 countries | 1995-2017 | Estimating the relation between $CO_2$ emissions and financial development in the presence of economic institutions as an interactive term. | Fully Modified Ordinary Least Square (FMOLS) | -Financial development has a positive relationship with CO2 emissions. However, with the inclusion of economic institutions (e.g., assurance of property rights, government integrity, and liberalisation in the financial sector), the adverse impact of financial development on the environment is reduced.<br>-EKC is confirmed |
| Andersson, (2019) | Canada | 1960-2014 | Examining the relationship between CO2 emissions, economic growth, energy use, urbanisation, trade openness, and financial development | ARDL bounds testing approach and a Granger causality test based on a VECM | -Financial development and urbanisation are insignificant, whereas trade openness, GDP growth and its square, and energy consumption tend to increase CO2 emissions in the long run.<br>-EKC hypothesis is rejected. |
| Wang and Dong (2019) | 14 countries | 1990-2014 | Examining the impact of economic growth, non-renewable and renewable energy consumption, and urbanisation on environmental degradation. | AMG | -Economic growth, non-renewable energy consumption, and urbanisation have a detrimental effect on CO2 emissions, while renewable energy consumption has a mitigating impact on the environment. |
| Godil et al. (2020) | Turkey | 1986-2018 | Exploring the impact of financial development, tourism, and globalisation on ecological footprint. | Quantile Autoregressive Distributed Lag model | -All variables are positively associated with the ecological footprint.<br>-U-shaped EKC is confirmed. |

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|---|---|---|---|---|---|
| Nathaniel et al. (2020) | 6 countries | 1990-2014 | Examining the relationship between renewable energy, urbanisation, economic growth, trade openness, and ecological footprint. | Augmented mean group (AMG), panel cointegration, and causality tests. | -Non-renewable energy consumption and urbanisation are the main contributors to environmental degradation.<br>-The use of renewable energy enhances environmental quality.<br>-Economic expansion mitigates environmental deterioration in Colombia, South Africa, and Turkey but contributes to pollution in Egypt, Indonesia, and Vietnam. |
| Nathaniel (2020) | Nigeria | 1980-2016 | Exploring the effect of urbanisation, trade flow and energy consumption on the environment. | ARDL bounds test and cointegration | -The two main factors causing CO2 emissions are urbanisation and energy use. While trade mitigates the CO2 emissions |
| Zeraibi et al. (2021) | 5 Asian countries | 1985-2016 | Investigate the effect of renewable electricity generation capacity, technological innovation, financial development, and economic growth on the ecological footprints. | Cross-sectional Augmented Autoregressive Distributed Lag (ARDL) | -There is a negative relationship between renewable electricity generation capacity, technological innovation, and the ecological footprint, but the relationship between financial development, economic growth, and the ecological footprint is positive. |
| Zia et al. (2021) | China | 1985-2018 | Investigating the effect of economic growth, natural resources, human capital, and financial development on the ecological footprint. | ARDL | -The included variables show a considerable positive relation with the ecological footprint, implying their determinantal environmental impact. |
| Usman and Hammar (2021) | Asia Pacific Economic Cooperation (APEC) countries | 1990-2017 | Analysing the impact of technological innovation, financial development, economic growth, renewable energy consumption, and population on the ecological footprint | principle component analysis | -There is a Bidirectional causality relationship between financial development, technological innovations, renewable energy use, economic growth, and population with the ecological footprint. |
| Qayyum et al. (2021) | 5 Asian countries | 1991-2017 | Examining the effect of urbanisation and informal economy on the ecological footprint | ARDL | -Urbanisation positively affects the ecological footprint. The informal sector exacerbates environmental degradation in all the selected countries except Bangladesh. |

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|---|---|---|---|---|---|
| Ajmi and Inglesi-Lotz (2021) | Tunisia | 1965-2013 | Examining the validity of the EKC hypothesis | ARDL | -EKC hypothesis is not valid when CO2 emissions represent environmental degradation, while it is valid when the ecological footprint is used as a proxy for environmental degradation |
| Bulut (2021) | Turkey | 1970-2016 | Examining the determinants of the ecological footprint (EF) | ARDL DOLS | - The EKC hypothesis exists, whereas the pollution haven hypothesis is not supported.<br>-The ecological footprint is negatively related to renewable energy consumption, whereas industrialisation does not affect the ecological footprint. |
| Villanthenkodath et al. (2021) | India | 1971-2014 | Determines how economic structure affects the EKC. | ARDL | -The findings showed that an inverted U-shape EKC theory is not valid.<br>-Urbanisation reduces environmental degradation due to efficient infrastructure and energy efficiency in urban areas. |
| Ehigiamusoe et al. (2022) | 31 African countries | 1990-2019 | examining the nonlinear and moderating impacts of financial development and urbanisation on degrading the environment regarding CO2 emissions and ecological footprint (EF) | Panel cointegration techniques and Fully Modified Ordinary Least Squares (FMOLS) | -Urbanisation has an inverted U-shaped effect on CO2, while financial development has a weak U-shaped impact.<br>- Further, both variables have a U-shaped relation with the ecological footprint.<br>-Urbanisation mitigates the connection between CO2 and energy use, while financial development worsens this relationship. |
| Ju et al(2023) | Arab nation | 1991-2019 | Examining the relationship between environmental deterioration and financial development, foreign direct investment (FDI), technological innovation, and good governance. | error correction-based cointegration, cross-sectional ARDL, Non-linear ARDL and Heterogeneous causality test for directional causality | -Financial development harms environmental sustainability, whereas FDI, good governance, and technological innovation help mitigate environmental adversity. |
| Navarro-Chavez ́ et al. (2023) | Asian-Pacific Economic Cooperation Countries | 1995-2020 | Determining the relationship between economic growth, tourism and environmental degradation. | Dynamic Ordinary Least Squares (DOLS) and Dumitrescu–Hurlin test | -Tourism and economic growth reduce environmental quality in both developed and developing economies.<br>- |

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|---|---|---|---|---|---|
| Hossain et al. (2023) | India | 1970-2018 | Analysing how environmental degradation is affected by natural resource rent, GDP, and the relationship between natural resource rent and GDP | Dynamic autoregressive distributed lag (DARDL) | -Validation of an N-shaped EKC using CO2 emissions as the dependent variable, but no EKC using ecological footprint (EF).<br>-Natural resource rent, energy consumption, and urbanisation are positively linked to long-term environmental degradation. |
| Aldegheishem (2024) | Saudi Arabia Jordon Egypt | 1990-2023 | Examining the nexus among energy consumption, urbanisation, economic growth, and $CO_2$ emissions. | ARDL | -Economic growth and energy consumption have a detrimental impact on the environment.<br>-Urbanisation reduced CO2 emissions in Saudi Arabia and Jordan, implying that urban policies are well-matched with environmental goals in both countries (but not in Egypt). |

AMG = Augmented Mean Group, ARDL = Autoregressive Distributed lag, CCE = Common Correlated Effects, DOLS = Dynamic Ordinary Least Squares, FMOLS = Fully Modified Ordinary Least Squares, GMM = Generalized Method of Moments, PVAR = Panel Vector Autoregressive.

**Table A2: Summary of recent studies on Egypt**

| Authors | Countries | Period | purpose | methodology | Main findings |
|---|---|---|---|---|---|
| Abdou and Atya (2013) | Egypt | 1961-2008 | Examining the contribution of carbon dioxide emissions on growth | Cointegration | -There is a negative relationship between GDP per capita and carbon dioxide emissions.<br>-The EKC hypothesis is unsupported because Egypt's energy products are highly subsidised.<br>- Institutions play an essential role in achieving progress by setting effective policies and regulations to reduce the pollutants arising from industries and rationalise energy consumption. |
| Ibrahiem (2016) | Egypt | 1980-2010 | Examining the relationship between CO2 emissions and real GDP per capita energy use, trade openness, and population density | Granger causality test | -There is no evidence to support the existence of the EKC in the short or long term.<br>-Energy consumption is positively related to CO2 emissions, whereas trade openness and population density have an inverse effect on environmental degradation. |
| El-Aasar and Hanafy (2018) | Egypt | 1971-2012 | Examine whether the environmental Kuznets curve (EKC) exists and the potential role of renewable energy and trade in alleviating greenhouse gas emissions. | ARDL | -The EKC hypothesis does not exist for greenhouse gas emissions in the short and long term.<br>-Renewable energy potentially significantly reduces GHG emissions, whereas trade openness has an insignificant impact on GHG emissions. |

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|---|---|---|---|---|---|
| Mahmoud et al. 2019) | Egypt | 1990–2014 | Examining the environmental EKC hypothesis | ARDL | -There is evidence of the validity of the N-shape EKC hypothesis over both the long and short terms, with a turning point of LE 14,861 per capita, indicating that Egypt is in the second stage of the EKC, given its current economic growth.<br>-Energy consumption accelerates CO2 emissions per capita, whereas FDI helps reduce them per capita. |
| Ibrahiem (2020) | Egypt | 1971-2014 | Examining the connections between financial development, economic growth, alternative energy sources, technological innovation, and CO2 emissions. | (ARDL), (FMOLS), dynamic ordinary least square (DOLS), and Toda-Yamamoto | -Alternative energy sources and technological innovation enhance the quality of the environment. Financial development and economic growth deteriorate it.<br>- |
| Ahmed et al. (2020) | Egypt | 1965-2014 | Examining the effects of economic growth, financial development, and trade openness on $CO_2$ emissions. | VEC | -There is a negative relationship between financial development, economic growth, and CO2 emissions. |
| Adebayo and Kalmaz (2021) | Egypt | 1971-2014 | Estimating the effect of energy usage, urbanisation, gross capital formation, and GDP growth on $CO_2$ emissions. | ARDL | -A positive relationship exists between energy usage, GDP growth and CO2 emissions.<br>-Urbanisation and gross capital formation have an insignificant impact on CO2 emissions. |
| Shaker (2022) | Egypt | 1965-2020 | Investigating the relationship between CO2 emissions, real GDP, energy consumption and trade openness | ARDL | -evidence of an inverted N-shape relationship between CO2 emissions and real GDP. He attributed this result to Egypt's initial environmentally friendly mindset. |
| Saber (2022) | Egypt | 1975-2017 | Evaluating the Environmental Kuznets Curve Hypothesis in Egypt. | ARDL | -The environmental Kuznets curve hypothesis applies to the Egyptian economy.<br>- |
| Rashdan and Ibrahim (2024) | Egypt | 1990-2021 | Investigating the impact of urbanisation, energy consumption, economic growth, and FDI on $CO_2$ emissions. | VAR<br>ECM | -FDI and urbanisation have a positive effect on CO2 emissions. In contrast, energy consumption and economic growth decrease CO2 emissions. |

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|---|---|---|---|---|---|
| Altayeb (2024) | Egypt | 1990-2020 | Estimating the effect of energy consumption, economic growth, financial development and globalisation on $CO_2$ emissions. | ARDL VCEM | -Environmental sustainability is reduced by financial development, globalisation, energy consumption, and economic growth.<br>-EKC is confirmed when the income level's effect on the emissions scale becomes negative, as the annual real income per capita exceeds LE 33841.5. |

VCEM= Vector Error Correction Model, ECM= Error Correction Model, VAR= Vector Autoregressive

**Appendix 2. Estimation of per capita GDP thresholds based on *NARDL* estimations**

For a valid EKC, both necessary and sufficient conditions must be satisfied. The signs of GDP elasticities determine the necessary condition.

To illustrate the sufficient condition, we consider the regression equation (21) estimated based on long-run elasticities:

$$\ln CO2_t = 200.7(lnPGDP) - 19.5(lnPGDP)^2 + 0.63(lnPGDP)^3 - 0.048(lnOPEN) + 1.4(lnENU) + 0.007(lnFD)^+ - 0.023(lnFD)^- - 1.39(lnURB)^+ - 0.39(lnURB)^- - 742.2 - 0.03(trend)$$

To investigate the sufficient condition, we partially differentiate the above equation with respect to per capita GDP:

$$\frac{d(\ln CO2_t)}{d(PGDP)} = 200.7 \times \frac{1}{PGDP} - 39.07(LnPGDP) \times \frac{1}{PGDP} + 1.89(lnPGDP)^2 \times \frac{1}{PGDP}$$

To find the critical point, we equate the above equation to zero (i.e., $\frac{d(\ln CO2_t)}{d(PGDP)} = 0$). Thus, we get the following quadratic equation:

$$1.89(lnPGDP)^2 - 39.07(LnPGDP) + 200.7 = 0$$

To get the two real and distinct income levels, $(2\beta_2)^2 - 4(3\beta_3)(\beta_1) > 0$, must be greater than zero to suggest the existence of N-shaped or inverted N-shaped EKC. Based on that,

$$(2\beta_2)^2 - 4(3\beta_3)(\beta_1) = (-39.07)^2 - 4(1.89)(200.7) = 4.12 > 0$$

Thus, the sufficient equations are met, and we can use the quadratic formula to compute the roots of the quadratic equation (equation 5) as follows:

$$(\ln PGDP_t) = \frac{-39.07 \pm \sqrt{(-39.07)^2 - 4(1.89)(200.7)}}{2(1.89)}$$

The computed roots of the above equations are 9.76 and 10.83. the final step is to get the antilog of these values

$$PGDP_t = Antilog\left(\frac{-39.07 \pm \sqrt{(-39.07)^2 - 4(1.89)(200.7)}}{2(1.89)}\right)$$

Hence, the two turning points of per capita GDP equal LE17395.64 and 50728.65.