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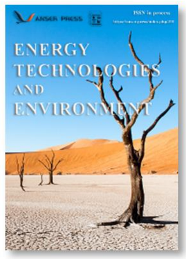


# ARDL and VECM Investigation of the Environmental Kuznets Curve Hypothesis in Egypt, India, Mexico, Pakistan, Thailand, and Turkey: Financial Development, Globalization, and Government Expenditure Implications for Sustainable Development

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## ABSTRACT

The present paper empirically examines the validity of the environmental Kuznets curve (EKC) hypothesis, which posits an inverted U-shaped relationship between CO2 emissions and economic growth, in Egypt, India, Mexico, Pakistan, Thailand, and Turkey for the period 1970-2020. The EKC validity is highly debated due to varying results across countries. This study is significant to addresses this controversy by estimating the EKC's robustness while considering the influence of financial development, globalization, and government expenditure. We employ two cointegration techniques, the autoregressive distributed lag (ARDL) and vector error correction model (VECM), also considering potential structural breaks in the data. Out key findings indicate that the EKC hypothesis is supported in India, Pakistan, and Turkey, with carbon emissions eventually declining after reaching a peak. The hypothesis is not supported in Egypt and Thailand, where emissions rise monotonically with economic growth. In Mexico, the results are mixed, with ARDL suggesting a U-shaped relationship and VECM supporting the EKC. From our empirical analysis of the EKC hypothesis, we derive the following policy implications: 1) countries should adopt comprehensive policy strategies that integrate these goals and fully consider the long-term environmental and societal impacts of their decisions; 2) countries should invest heavily in research and development to accelerate the creation of new technologies that can effectively reduce carbon emissions; and 3) countries must actively raise awareness about the environmental repercussions of economic growth.

## KEYWORDS

ARDL; VECM; Environmental Kuznets Curve Hypothesis; Sustainable Development; Emerging Economies

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**Acronyms**

| | | | |
|---|---|---|---|
| ADF-GLS | GLS augmented Dickey–Fuller | LS | Lee-Strazicich |
| AIC | Akaike information criterion | PHH | pollution haven hypothesis |
| ARDL | autoregressive distributed lag | PP | Phillips-Perron |
| COTWO | $CO_2$ emissions | SB | structural break |
| EG | economic growth | SBC | Schwarz Bayesian criterion |
| EGSQ | square of economic growth | SBONELS | structural break, one, LS test |
| EKC | environmental Kuznets curve | SBONEZA | structural break, one, ZA test |
| FDI | financial development | SBTWOLS | structural break, two, LS test |
| FDI | foreign direct investment | SDG | sustainable development goal |
| GE | government expenditure | VECM | vector error correction model |
| GHG | greenhouse gas | WDI | world development indicators |
| GL | globalization | ZA | Zivot-Andrew |
| GLS | generalized least squares | | |

## 1. Introduction

### *1.1. Decarbonization for Sustainable Development*

Environmental degradation has emerged as an urgent global challenge, posing a significant threat to human well-being. In 2015, the Paris Accord was adopted in response to the rapid increase in greenhouse gas (GHG) emissions, particularly $CO_2$, which has raised concerns about the catastrophic effects of climate change and global warming (United Nations, 2015). The UN Agenda 2030 and its 17 Sustainable Development Goals (SDGs) were also adopted in 2015 as the most comprehensive global political endeavor towards achieving sustainable development. The 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28) took place in 2023. It was the largest climate conference ever held, with representatives from nearly all countries participating (United Nations, 2024).

Nearly all countries have adopted the SDGs and committed to reporting on their progress. In light of these global circumstances, the relationship between carbon emissions and economic growth has gained prominence, with particular relevance to SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (United Nations, 2023).

### *1.2. Environmental Kuznets Curve Hypothesis*

The Environmental Kuznets Curve (EKC) hypothesis, initiated by Grossman and Krueger (1991), suggests an inverted U-shaped relationship between environmental degradation and economic growth. In other words, environmental quality may worsen initially as a country develops economically, but eventually improves as a country becomes wealthier (Rayhan et al., 2020) (see “Theoretical Framework” in Section 2). By understanding the EKC hypothesis, we can design policies that promote sustainable development, a key tenet of the SDGs.

A key problem in EKC research lies in mixed results produced by several empirical studies[1]. As shown in Appendix 1(A1), some studies support the inverted U-shaped curve, while others find no significant correlation. This disparity in EKC findings can be attributed to several factors. For example, first, different studies use varying indicators of environmental degradation (e.g., air pollution, water quality), potentially leading to inconsistent results. Second, studies often analyze specific time periods and countries, limiting the generalizability of their findings. Third, the choice of statistical methods to analyze the data can influence the observed relationship between economic growth and environmental quality. Fourth, limited attention has been paid to potential model

1 For a comprehensive review of the EKC hypothesis, see Leel and Marques (2022).

inadequacies, such as omitted variable bias, which can skew results (Stern, 2004).

There is a growing recognition that additional variables, potentially aligned with the UN Agenda 2030 and its 17 SDGs, should be incorporated into EKC analyses (Rafindadi & Usman, 2019). This argument highlights a key research gap: the need for a more comprehensive understanding of how factors beyond just economic growth influence environmental outcomes. In response to this gap, numerous studies have begun examining the EKC hypothesis alongside various factors that influence environmental sustainability. While energy consumption, particularly non-renewable sources, is routinely incorporated into EKC estimations, we observe that financial development, globalization, and government expenditure are emerging as potentially key determinants; further research in this direction can offer valuable insights for policymakers aiming to achieve sustainable development[2].

Financial development can foster a shift towards less carbon-intensive industries, businesses, and consumption patterns, thereby contributing to economic growth while reducing environmental strain (Zafar et al., 2022; Le & Ozturk, 2020). However, this perspective overlooks the potential downsides of financial development, particularly its association with increased energy consumption and economic growth (Rjoub et al., 2021; Sadorsky, 2011). For producers, efficient financial intermediation can lower financial costs and expand financing options, enabling them to diversify financial risks associated with production activities. This enhanced access to capital can incentivize producers to invest in more resource-intensive technologies and expand production. Similarly, for consumers, financial development can expand credit opportunities, allowing them to purchase more goods and services, often with higher energy consumption.

Globalization, through trade (export + import) and foreign direct investment (FDI), significantly influences environmental outcomes. Trade liberalization promotes competition and innovation, leading to the development and adoption of more environmentally friendly products and production processes. FDI, particularly in developing countries, can introduce cleaner technologies and expertise, contributing to environmental improvements (Ridzuan et al., 2020). However, globalization can also have negative environmental impacts. Export-oriented industries in developing countries may prioritize production expansion over environmental considerations, leading to increased pollution and resource depletion (Kim & Baek, 2011; Copeland & Taylor, 2003). Additionally, FDI may contribute to environmental degradation in countries with lax environmental regulations (Destek & Okumus, 2019)[3].

For government expenditure, some argue that a larger share of government spending allocated to environmental protection and stricter environmental regulations are essential for achieving environmental progress (Mohammed et al., 2019). However, others caution that simply increasing government expenditure does not guarantee environmental improvement (Bernauer et al., 2013). Several factors may contribute to the effect of government expenditure on the environment. For example, expenditure on infrastructure development may outpace the implementation of environmental regulations, leading to increased environmental pressures (Ward et al., 2014). Additionally, government agencies themselves may contribute to pollution through their consumption of energy and other environmentally harmful products (Le & Ozturk, 2020). Furthermore, government subsidies for renewable energy and other environmental protection measures may not always be efficient, potentially leading to

[2] In addition to the core variables, the ECK estimation considers other factors such as governance index (Arif et al., 2022), natural resources (Hussain et al., 2021), output volatility (Genç et al., 2022), political risk (Adebayo, et al., 2023), renewable energy consumption (El-Aasar & Hanafy, 2018), urbanization and population growth (Villanthenkodath et al., 2021), value added of the service sector (Hashmi et al., 2020), and more.

[3] Specifically for the impact of FDI on $CO_2$ emissions, which is more controversial, two opposing hypotheses have been proposed. The Pollution Haven Hypothesis (PHH) is an economic theory that posits that firms will relocate their production to countries with less stringent environmental regulations in order to reduce their costs (e.g., Copeland and Taylor, 1994). The Halo Effect hypothesis for carbon emissions is the opposite of the Pollution Haven Hypothesis, which posits that FDI can lead to a decrease in carbon emissions in host countries (e.g., Esty and Porter, 1998).

higher costs than alternative approaches such as carbon pricing (Nordhaus, 2008).

### 1.3. Objective and Contributions

This paper's objective is to resolve the ongoing debate surrounding the EKC hypothesis by examining its validity in six emerging economies: Egypt, India, Mexico, Pakistan, Thailand, and Turkey. A novel aspect of this study is to consider the explanatory variables of financial development, globalization, and government expenditure, along with the element of structural break. To this end, we conduct time series analysis for each country in our sample, utilizing two prominent cointegration techniques: the autoregressive distributed lag (ARDL) and the vector error correction model (VECM).

The present paper makes three contributions to the literature. Firstly, by investigating the EKC hypothesis in six emerging countries, it provides more robust, country-specific policy implications for each sample country. Secondly, it considers the roles of financial development, globalization, and government expenditure in shaping the carbon-growth relationship, adding to the understanding of the factors influencing environmental degradation. Thirdly, by examining the EKC hypothesis in countries representing a significant portion of the world's population, it contributes to the broader discussion on sustainable development and the attainment of the SDGs.

This paper is structured as follows. The next section, "Research Strategy," outlines the overall approach and data taken to investigate the topic. "Methodology" then details the specific methods used. "Empirical Results" presents a comprehensive analysis of the findings. Finally, "Policy Implications and Conclusion" draws connections between the research and potential policy applications.

## 2. Research Strategy

### 2.1. Theoretical Framework

The theoretical framework of the EKC hypothesis is explained with the following equation:

$$Y = \alpha + \beta X_t + \gamma X_t^2 + \delta_1 Z_{1t} \cdots + \delta_n Z_{nt} + \mu_t \quad (1)$$

In Equation 1, $Y_t$ is $CO_2$ emissions, $X_t$ is economic growth, $X^2{}_t$ is the square of economic growth, $Z_1$t to $Z_{nt}$ represent additional explanatory variables, $\alpha$ is the intercept, $\beta$, $\gamma$, and $\delta_1$ to $\delta_n$ are the coefficients, and $\mu_{it}$ is the error term, respectively. As seen in the equation, the EKC specification is a nonlinear model. To validate "the more economic growth, the better the environment", we need to find evidence that $\beta > 0$ and $\gamma < 0$. While other cases are also possible, the most concerning scenario is when $\beta > 0$ and $\gamma > 0$. In this case, the environment monotonically degrades as the economy grows, leading to a vicious cycle of environmental destruction and economic growth.

### 2.2. Basic Model

The present study's estimation includes additional explanatory variables that are deemed important for understanding the relationship between the dependent and independent variables. To elucidate the empirical strategy, Equation 1 is rewritten as the following basic model:

$$COTWO = \alpha + \beta EG_t + \gamma EGSQ_t + \delta_1 FD_t + \delta_2 GL_t + \delta_3 GE_t + \mu_t \quad (2)$$

In Equation 2, COTWO is $CO_2$ emissions that is treated as the dependent variable proxied by annual per capita $CO_2$ emissions. EG is economic growth, measured as real per capita GDP. EGSQ is the square of economic growth. FD is financial development, measured as the ratio of domestic credit to the private sector to GDP. GL is the globalization indicator, measured using the KOF globalization index (Gygli et al., 2019)[4]. GE is government expenditure, measured as the ratio of general government final consumption expenditure to GDP. These underlying variables are selected and measured in accordance with several empirical studies on the EKC hypothesis[5].

### 2.3. Data

The sample countries for our EKC analysis are Egypt, India, Mexico, Pakistan, Thailand, and Turkey. These developing countries were selected due to their global influence, widespread interest in their economic development, and the availability of data. $CO_2$ emissions data were obtained from "$CO_2$ emissions per capita" on "Our World in Data" (Our World in Data, 2023). The KOF globalization index is provided by the KOF Swiss Economic Institute (2023), while data on economic growth, financial development, and government expenditure were retrieved from the World Bank's World Development Indicators (WDI) (World Bank, 2023). The sample period is 1970-2020, that was chosen primarily due to the availability of the KOF globalization index, while covering the first year of the COVID-19 pandemic. We believe that this sample of countries and time period is well-suited for testing the validity of the EKC hypothesis.

## 3. Methodology

### 3.1. Unit Root Tests

Before conducting cointegration analysis, we must check the integration order of each underlying variable using unit root tests. The ARDL approach to cointegration requires that all underlying variables be either integrated of order zero (I(0)) or integrated of order one (I(1)), whereas the VECM approach requires that all underlying variables be I(1). Therefore, we implement two unit root tests: the GLS augmented Dickey–Fuller (ADF-GLS) test (Elliott et al., 1996) and the Phillips-Perron (PP) test (Phillips & Perron, 1988). The ADF-GLS test is a modified version of the Dickey-Fuller unit root test that uses generalized least squares (GLS) to eliminate the problem of autocorrelation in the residuals. The PP test is also developed to be robust to serial correlation.

### 3.2. ARDL Estimation

The ARDL specification is described with the following system equation:

$$\Delta COTWO_t = \alpha_{it}\begin{bmatrix} COTWO_t \\ EG_t \\ EGSQ_t \\ FD_t \\ GL_t \\ GE_t \end{bmatrix} + \sum_{j=1}^{p-1}\theta_{1j}\,\Delta COTWO_{t-j} + \sum_{j=1}^{p-1}\theta_{2j}\,\Delta EG_{t-j} + \sum_{j=1}^{p-1}\theta_{3j}\,\Delta EGSQ_{t-j}$$
$$+ \sum_{j=1}^{p-1}\theta_{4j}\,\Delta FD_{t-j} + \sum_{j=1}^{p-1}\theta_{5j}\,\Delta GL_{t-j} + \sum_{j=1}^{p-1}\theta_{6j}\,\Delta GE_{t-j} + inpt + u_{it} \quad (3)$$

[4] The KOF globalization index is a measure of the degree of globalization of 122 countries. It is published annually by the KOF Swiss Economic Institute at ETH Zurich. The index is based on 24 variables covering three main dimensions of economic, social, and political globalizations.

[5] Although incorporating (non-renewable) energy consumption as one of the underlying variables in the EKC assessment is highly conventional, we opted not to do so due to the following reasons. Firstly, numerous studies have conclusively demonstrated that energy consumption unequivocally increases carbon emissions. Secondly, we empirically confirmed that the policy combination of financial development, globalization, and government expenditure yielded statistically significant estimates. Thirdly, to avoid multicollinearity and preserve the degrees of freedom in estimation, we refrained from including an excessive number of variables.

Equation 3 consists of the dependent variable (COTWO) and the independent variables (EG, EGSQ, FD, GL, GE). The first step in estimating an ARDL model is to perform the bounds test, which is applicable regardless of whether the underlying variables are integrated of order 0 ($I(0)$) or order 1 ($I(1)$). For the bounds test, the estimated F-statistic is compared to critical values that are derived under the assumption of no cointegration. If the *F*-statistic is greater than the upper critical value, the null hypothesis is rejected to conclude that the variables are cointegrated. If the F-statistic is less than the lower critical value, the null hypothesis of no cointegration is accepted. If the *F*-statistic falls between the lower and upper critical values, the test is inconclusive, so that we need to check unit root tests' results. Second, we determine the optimal lag order for each underlying variable using either the Akaike information criterion (AIC) or the Schwartz Bayesian criterion (SBC).

Third, to interpret the ARDL estimation, both the weak and strong exogeneity tests are conducted. The null hypothesis of the weak exogeneity test is that the coefficient on the lagged error correction term (ECT) is equal to zero ($H_0 = \alpha_{it}$). If the null hypothesis is rejected, the ECT is significant so that there is a long-run causal relationship between the variables. On the other hand, the null hypothesis of the strong exogeneity test is that the ECT coefficient and all the coefficients on the lagged independent variables are equal to zero ($H_0 = \alpha_{it} = \theta_{ij}$'s = 0). If the null hypothesis is rejected, a significant overall (long-run + short-run) causality is detected in the ARDL system, irrespective of time spans (Charemza and Deadman, 1997).

## 3.3. VECM Estimation

The VECM specification is given by the following system equation:

$$\begin{bmatrix} \Delta COTWO_t \\ \Delta EG_t \end{bmatrix} = \begin{bmatrix} \alpha_{1j} \\ \alpha_{2j} \end{bmatrix} [\beta_{i1}\ \beta_{i2}\ \beta_{i3}\beta_{i4}\beta_{i5}\ \beta_{i6}] \begin{bmatrix} COTWO_{t-1} \\ EG_{t-1} \\ EGSQ_{t-1} \\ FD_{t-1} \\ GL_{t-1} \\ GE_{t-1} \end{bmatrix} + \Gamma_{ij} \begin{bmatrix} \Delta COTWO_{t-p} \\ \Delta EG_{t-p} \\ \Delta EGSQ_{t-p} \\ \Delta FD_{t-p} \\ \Delta GL_{t-p} \\ \Delta GE_{t-1} \end{bmatrix} + \begin{bmatrix} \hat{u}_{1t} \\ \hat{u}_{2t} \end{bmatrix} \quad (4)$$

Equation 4 treats COTWO as the dependent variable, EG as the endogenous variable, and EGSQ, FD, GL, and GE as the weakly exogenous variables in the cointegrating space. Notably, this study aims to test the EKC hypothesis, so the case in which EG is the dependent variable is not considered.

The VECM initial condition is that all underlying variables be integrated of order 1 ($I(1)$), as confirmed by the ADF-GL and PP unit root tests; this is different from the ARDL estimation. Next, the Johansen cointegration test is implemented to check for a long-run relationship among the dependent, endogenous, and weakly exogenous variables, through which a single cointegrating relationship ($r$ = 1) is sought. Similar to the ARDL estimation, we conduct two types of Granger causality tests to give VECM interference to the EKC hypothesis in six countries. The weak exogeneity test imposes the null hypothesis of zero restrictions on α ($H_0$: $\alpha_{ij} = 0$). If the null is rejected, there is a long-run causality formed by all the underlying variables in the system (Johansen & Juselius,1992). The strong exogeneity test is done by restricting both α and either of *β*s in the cointegrating space ($H_0$: $\alpha_{ij}\ \beta_{ij} = 0$) (Toda and Phillips, 1993).

## 3.4. Structural Break Dummy

To account for structural breaks in cointegration analysis, we include a level shift dummy variable in both the ARDL and VECM estimations, as suggested by Johansen et al. (2000). One rationale for this is that we believe a structural break in real per capita GDP (EG) is most influential to the EKC estimation. To pinpoint the break dates in the EG series of the six countries, we use the Lee-Strazicich (2003, 2013) (LS) test or the Zivot-Andrew (1992) (ZA) test, both of which use autoregression to determine a break date. Another rationale for including structural breaks in the estimation is that it allows us to better reflect the macroeconomic instability that the six countries experienced over the sample period 1970-2020. This, in turn, allows the underlying variables to collectively explain most variations in $CO_2$ emissions, enabling us to seek a single cointegration ($r$ = 1) and no autocorrelation (Fukuda, 2019).

We estimate the LS test of Models A and AA, which introduce one and two breaks in level with no change in the trend rate, respectively. The estimated breakpoints are used to create level shift dummies for SBONELS (Structural Break, ONE, LS test) and SBTWOLS (Structural Break, TWO, LS test). Similarly, we perform the ZA test, which also autoregressively identifies one break date in level but not in trend, to create a level shift dummy for SBONEZA (Structural Break, ONE, ZA test). The estimated break dates for the sample countries' EG series are given in Table 1.

**Table 1.** Break Dates of LS and ZA Tests.

| | Egypt | India | Mexico | Pakistan | Thailand | Turkey |
|---|---|---|---|---|---|---|
| LS Test (One break) | 1978 | 1978 | 1994 | 1979 | 1998 | 2010 |
| LS Test (Two breaks) | 1978 | 1990 | 1994 | 1979 | 1998 | 1978 |
| | 2001 | 2016 | 2008 | 2001 | 2009 | 2010 |
| ZA test (One break) | 1980 | 1979 | 1978 | 1997 | 1987 | 2011 |

## 4. Empirical Results

We begin with reporting the results of the unit root, ARDL bounds, VECM cointegration, and diagnostic tests for the six countries, followed by a more detailed discussion of each country's ARDL and VECM findings for the EKC hypothesis.

### *4.1. Unit Root Statistics*

To test the stationarity of each variable, we conduct the ADF-GLS and PP tests under two specifications: intercept only and intercept and trend. The unit root statistics are reported in Appendix 2 (A2). We find that all sample countries' COTWO, EG, EGSQ, FD, GL, and GE are nonstationary in levels but stationary in first differences at the 1%, 5%, and 10% significance levels, respectively. Therefore, all underlying variables are statistically suitable (i.e., $I(1)$) for both ARDL and VECM estimations.

### *4.2. Cointegration Tests*

4.2.1. ARDL Bounds Test

The ARDL bounds test is implemented for Egypt, India, Mexico, Pakistan, Thailand, and Turkey, and the results are provided in Table 2. The dependent variable is COTWO, and the endogenous variables are EG, EGSQ, FD, GL, and GE. The maximum lag order is set to 2, 3, or 4, and the lag order for each underlying variable is selected using either the Akaike information criterion (AIC) or the Schwarz Bayesian criterion (SBC). The fourth column of Table 2 shows the structural break dummies included in the ARDL estimation for each country. All of these incorporations are empirically effective in detecting ARDL cointegration at the 5-10% significance level in all the sample countries.

4.2.2. VECM Johansen Cointegration Test

To estimate the VECM, we perform the Johansen (1988) cointegration test, setting the lag order to either 2, 3, or 4 for each country. The results are presented in Table 3. We treat COTWO as the dependent variable, EG as the endogenous variable, and EGSQ, FD, GL, and GE as the weakly exogenous variables. Similar to the ARDL estimation, we also incorporate structural dummies in the VECM estimation for each country. Different from the ARDL estimation, we represent two breaks for India and Mexico by taking two "single-level shift dummies (SB, Structural Break)", and do not include any level shift dummy in Turkey's VECM estimation. Despite the different break representations, we find a single cointegration (r = 1) at the 1-5% significance level in all six countries, shown in Table 3.

## *4.3. Diagnostic Statistics*

Before proceeding to each country's EKC findings, it is important to check diagnostic statistics of ARDL (autocorrelation, normality, functional form, and heteroskedasticity) and VECM (autocorrelation, normality, and heteroskedasticity) models in Tables 4 and 5. We judge that the twelve ARDL and VECM models are adequate to investigate the EKC validity in all six countries.

**Table 2.** ARDL Bounds Test (*F*-statistics).

| Dependent variable COTWO | | Endogenous variables EG, EGSQ, DCP, KOFECGI, GE | | |
|---|---|---|---|---|
| Country | Maximum lag | Selected lag orders (AIC/SBC) | Det. components | Statistic |
| Egypt | 4 | 4,4,1,2,4,3 (AIC) | SBONELS, Intercept | 6.856** |
| India | 3 | 1,0,0,3,0,2 (SBC) | SBONELS, Intercept | 7.715** |
| Mexico | 4 | 4,2,2,4,4,2 (AIC) | SBTWOLS, Intercept | 5.931** |
| Pakistan | 2 | 2,0,0,0,0,0 (AIC) | SBTWOLS, Intercept | 3.897* |
| Thailand | 4 | 1,3,0,0,3,2 (AIC) | SBONEZA, Intercept | 5.940** |
| Turkey | 4 | 3,3,2,0,3,4 (AIC) | SBONEZA, Intercept | 7.332** |

*Notes: (**) 5% and (*) 10% of significance. The selected lag orders are given as (COTWO, EG, EGSQ, DCP, GL, GE).*

**Table 3.** VECM Johansen Cointegration Test.

| Dep. variables COTWO | End. variable EG | I(1) exo. variables EGSQ; FD; GL; FS | | | |
|---|---|---|---|---|---|
| Country | Lag | Det. components | H0 | H1 | Statistic |
| Egypt | 2 | SBONEZA(1980) | r = 0 | r ≥ 1 | 46.27** |
| | | Intercept | r ≥ 1 | r ≥ 2 | 13.20 |
| India | 4 | SB(1990); SB(2016) | r = 0 | r ≥ 1 | 79.18*** |
| | | Intercept | r ≥ 1 | r ≥ 2 | 16.12 |
| Mexico | 3 | SB(1994); SB(2008) | r = 0 | r ≥ 1 | 56.24*** |
| | | Intercept | r ≥ 1 | r ≥ 2 | 19.79 |
| Pakistan | 4 | SBONEZA (1997) | r = 0 | r ≥ 1 | 51.81*** |
| | | Intercept | r ≥ 1 | r ≥ 2 | 19.09 |
| Thailand | 4 | SBONEZA (1987) | r = 0 | r ≥ 1 | 93.42*** |
| | | Intercept | r ≥ 1 | r ≥ 2 | 19.71 |
| Turkey | 3 | No break dummy | r = 0 | r ≥ 1 | 65.70*** |
| | | Intercept | r ≥ 1 | r ≥ 2 | 17.89 |

*Notes: (***)1% and (**) 5% level of significance. The statistics are based on critical values simulated with 400 random walks and 2500 replications.*

**Table 4.** ARDL Diagnostic Statistics.

| Panel A | Egypt | India | Mexico |
|---|---|---|---|
| Serial correlation | 3.150 [.090] | 1.843 [.184] | 1.708 [.205] |
| Functional form | 0.544 [.469] | 0.069 [.794] | 1.728 [.203] |
| Normality | 2.279 [.320] | 0.909 [.635] | 1.773 [.412] |

| | | | |
|---|---|---|---|
| Heteroscedasticity | 0.315 [.577] | 0.315 [.578] | 0.225 [.637] |
| Panel B | Pakistan | Thailand | Turkey |
| Serial correlation | 1.764 [.192] | 1.920 [.176] | 0.325 [.574] |
| Functional form | 0.173 [.680] | 0.855 [.362] | 0.555 [.463] |
| Normality | 1.318 [.518] | 0.319 [.853] | 0.081 [.960] |
| Heteroscedasticity | 1.899 [.175] | 0.634 [.430] | 0.422 [.519] |

*Notes: The tests of serial correlation, functional form and heteroscedasticity are based on F-version statistics, whereas that of normality is on LM version statistics. In parentheses, p-values are provided.*

**Table 5.** VECM Diagnostic Statistics.

| Panel A | | Egypt | India | Mexico |
|---|---|---|---|---|
| Serial correlation | Ljung-Box | 58.15 [.050] | 51.74 [.008] | 40.06 [.379] |
| | LM(1) | 3.563 [.468] | 7.148 [.128] | 6.000 [.199] |
| | LM(2) | 3.276 [.513] | 1.948 [.745] | 3.502 [.478] |
| Normality | | 4.727 [.316] | 3.763 [.439] | 1.056 [.901] |
| Heteroscedasticity | LM(1) | 15.42 [.080] | 4.815 [.850] | 12.87 [.169] |
| | LM(2) | 25.14 [.121] | 10.57 [.912] | 21.79 [.241] |
| Panel B | | Pakistan | Thailand | Turkey |
| Serial correlation | Ljung-Box | 26.28 [.661] | 58.47 [.001] | 61.54 [.009] |
| | LM(1) | 6.148 [.188] | 4.239 [.375] | 1.437 [.838] |
| | LM(2) | 0.424 [.980] | 4.331 [.363] | 4.547 [.337] |
| Normality | | 6.330 [.176] | 1.274 [.866] | 0.449 [.978] |
| Heteroscedasticity | LM(1) | 11.98 [.214] | 6.049 [.735] | 11.96 [.216] |
| | LM(2) | 15.28 [.642] | 13.05 [.788] | 16.09 [.586] |

*Notes: The results are based on X2 statistics. In parentheses p-values are provided.*

## *4.4. Country Findings*

We present the country-specific findings. For each of ARDL and VECM estimations, we first examine the weak exogeneity statistic to test for the existence of a long-run equilibrium. Then the strong exogeneity statistics are reported, for which the direction of causality is determined by the sign of each variable in the cointegration vector.

### 4.4.1. Egypt Findings

Egypt's ARDL and VECM findings on the EKC hypothesis are given in Table 6. Both of the ARDL and VECM weak exogeneity statistics indicate that the ECT coefficient is statistically significant at the 1% level, with a negative sign and an acceptable magnitude[6]. This suggests the existence of a long-run equilibrium relationship between the variables. According to the ARDL and VECM strong exogeneity statistics and the signs of the underlying variables in the cointegration vector, both economic growth (EG) and its squared term (EGSQ) are positive at the 1% level, suggesting that the EKC hypothesis is not validated in Egypt. The other variables show mixed results. Financial development (FD) is negative at the 1% level, while globalization (GL) is positive at the 1% level. Government expenditure (GE) is positive in the ARDL estimation, but the VECM model does not converge for GE. The ARDL and VECM estimations reveal a long-run equilibrium relationship between Egypt's carbon emissions, economic growth, and other relevant variables. However, the EKC hypothesis is not supported by the findings, as both economic growth and its squared term exhibit positive coefficients. This suggests that environmental pollution increases monotonically with economic growth in Egypt.

[6] In general, an ECT coefficient that is between -1 and -2 is considered to be good. However, this is just a general guideline. The optimal size of the ECT will vary depending on the specific data set and model being used (see Enders, 2014; Greene, 2011).

### 4.4.2. India Findings

Table 7 reports India's ARDL and VECM findings. Both the ARDL and VECM weak exogeneity statistics show that the ECT coefficient is statistically significant at the 1% level, with a negative sign and an acceptable size. Thus, the existence of a long-run equilibrium relationship is detected between the variables. We then look at the ARDL and VECM strong exogeneity statistics and the signs of the underlying variables in the cointegration vector. Both estimations show that economic growth (EG) is positive at the 1% level, while its squared term (EGSQ) is negative. This unanimously confirms the EKC hypothesis in India. The two estimations also agree on the directions of two other variables, with financial development (FD) being positive and globalization (GL) being negative for environmental pollution. However, the two estimations differ on the sign of government expenditure (GE), with it having a positive and statistically significant impact in the ARDL estimation, but a negative and statistically significant impact in the VECM estimation. Overall, the ARDL and VECM estimations provide evidence for the validity of the EKC hypothesis in India. This implies that India has been on a good path to ameliorating the environment, with economic growth and globalization playing a key role.

### 4.4.3. Mexico Findings

We provide Mexico's findings for the ARDL and VECM estimations in Table 8. Both estimations yield weak exogeneity statistics that indicate a negative and statistically significant ECT coefficient whose size is also adequate, supporting the existence of a long-run steady relationship between the underlying variables at the 1% level of significance. However, the two estimations' strong exogeneity results are different. The ARDL estimation indicates that economic growth (EG) is negative at the 5% level, while its squared term (EGSQ) is positive at the 5% level, suggesting a U-shaped carbon-growth relationship. On the other hand, the VECM estimation detects that EG is positive and EGSQ is negative at the 1% level, supporting the EKC hypothesis. Therefore, the ARDL and VECM findings contradict each other regarding Mexico's EKC validity. As far as other variables are concerned, financial development (FD) exhibits a negative relationship with economic growth in the ARDL estimation, while no VECM estimate is available. For globalization (GL) and government expenditure (GE), both estimations yield consistent results: GL exerts a positive influence on economic growth, while GE exerts a negative influence at the 1% level. These mixed results for Mexico's EKC hypothesis suggest a complex interplay between Mexico's policies and carbon emissions. Further investigation is warranted to disentangle these intricate dynamics and reconcile the seemingly contradictory results.

### 4.4.4. Pakistan Findings

In Table 9, we present Pakistan's ARDL and VECM findings for the EKC hypothesis. The weak exogeneity statistics corroborate a statistically significant long-run steady-state relationship between the underlying variables in both estimations. Each ECT exhibits an appropriate magnitude as well. However, the VECM significance is borderline, falling at the 10% level. Next, examining the strong exogeneity statistics and the signs of the underlying variables in the cointegration vector, we find that economic growth (EG) is positive, while its squared term (EGSQ) is negative. The ARDL significance level for these findings is 1%, whereas the VECM significance level is 5%. This evidence supports the presence of an EKC relationship in Pakistan. For other underlying variables, Pakistan's ARDL and VECM estimations are less powerful to deduce definitive results. The ARDL estimation has detected that financial development (FD) is positive, globalization (GL) is also positive, and government expenditure (GE) is negative at the 1% level. On the other hand, the VECM estimation does not provide any significant estimates for these variables. While the presence of an EKC relationship in Pakistan is supported by both estimations, the impacts of financial development, globalization, and government expenditure remain inconclusive. Further research is needed to clarify the complex relationship between economic growth and environmental sustainability in Pakistan.

4.4.5. Thailand Findings

Thailand's ARDL and VECM findings for the EKC hypothesis are summarized in Table 10. We begin by examining the ARDL and VECM weak exogeneity statistics, which validate the presence of long-run steady-state relationships among the underlying variables at the 1% significance level, accompanied by an acceptable ECT size. Next, we investigate the strong exogeneity statistics and the direction of each variable. These results indicate that Thailand's economic growth (EG) has a negative impact on carbon emissions, while its squared term (EGSQ) has a positive impact. This pattern suggests a U-shaped carbon-growth relationship, contradicting the EKC hypothesis. The remaining underlying variables, financial development (FD), globalization (GL), and government expenditure (GE), exhibit consistent and straightforward effects: all three variables positively correlate with carbon emissions at the 1% level. Through the ARDL and VECM estimations, we uncover a long-term association between economic growth and carbon emissions in Thailand, failing to corroborate the EKC hypothesis. Financial development, globalization, and government spending demonstrate positive correlations with carbon emissions, indicating that these factors may hinder the achievement of sustainable growth.

4.4.6. Turkey Findings

Table 11 shows Turkey’s ARDL and VECM findings for the EKC hypothesis. As mentioned above, different from other countries’ estimations, Turkey’s VECM specification does not incorporate a structural break dummy as it provides more significant results. Both the ARDL and VECM estimations yield the weak exogeneity statistics that indicate a negative and statistically significant ECT coefficient whose size is acceptable, supporting the existence of a long-run steady relationship between the underlying variables at the 1% level of significance. Subsequently, we proceed with an examination of the strong exogeneity statistics and the direction of each variable. Both ARDL and VECM estimations show that Turkey’s economic growth (EG) has a positive impact, while its squared term (EGSQ) has a negative impact. These results provide strong support for the EKC hypothesis. For the remaining underlying variables, both estimations yield consistent and straightforward results: all of financial development (FD), globalization (GL), and government expenditure (GE) are positive for carbon emissions at the 1% level. Utilizing ARDL and VECM models, we establish a long-run relationship between carbon emissions and economic growth in Turkey, which provides empirical support for the EKC hypothesis. Financial development, globalization, and government expenditure exhibit positive associations with carbon emissions, suggesting that these factors may play crucial roles in achieving sustainable growth.

**Table 6.** Egypt’s Findings.

| | | |
|---|---|---|
| I. ARDL estimation (k =4) | | |
| A. Cointegrating vector | | |
| $COTWO = 0.305EG + 0.036EGSQ - 0.0126FD + 0.148GL + 0.215GE - 0.018SBONELS - 2.809$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -2.317 | CHSQR(1) = 33.49 [.000]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| ΔEGs & ECT(-1) | CHSQR(5) = 42.04 [.000]*** | Positive |
| ΔEGSQ & ECT(-1) | CHSQR(2) = 37.30 [.000]*** | Positive |
| ΔFDs & ECT(-1) | CHSQR(2) = 36.53 [.000]*** | Negative |
| ΔGLs & ECT(-1) | CHSQR(5) = 47.84 [.000]*** | Positive |
| ΔGEs & ECT(-1) | CHSQR(4) = 35.27 [.000]*** | Positive |
| II. VECM estimation (k =2) | | |
| A. Cointegrating vector | | |
| $COTWO = 0.528EG + 0.019EGSQ - 0.042FD + 0.219GL + 0.304GE - 0.012SBONEZA - 3.898$ | | |
| B. Weakly exogenous test | | |

| | | |
|---|---|---|
| ECT coefficient | Result | |
| α = -0.775 | CHSQR(1) = 9.095 [.003]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| EG & ECT(-1) | CHSQR(2) = 9.584 [.008]*** | Positive |
| EGSQ & ECT(-1) | CHSQR(2) = 10.49 [.005]*** | Positive |
| FD & ECT(-1) | CHSQR(2) = 10.57 [.005]*** | Negative |
| GL & ECT(-1) | CHSQR(2) = 19.67 [.000]*** | Positive |
| GE & ECT(-1) | — | — |

*Notes: (***) 1% level of significance.*

**Table 7.** India Findings.

| I. ARDL estimation (k = 3) | | |
|---|---|---|
| A. Cointegrating vector | | |
| $COTWO = 5.843EG - 0.405EGSQ + 0.171FD - 0.106GL - 0.240GE - 0.049SBONELS + 20.08$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -0.438 | CHSQR(1) = 29.12 [.000]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| ΔEG & ECT(-1) | CHSQR(2) = 39.75 [.000]*** | Positive |
| ΔEGSQ & ECT(-1) | CHSQR(2) = 43.23 [.000]*** | Negative |
| ΔFDs & ECT(-1) | CHSQR(4) = 37.81 [.000]*** | Positive |
| ΔGL & ECT(-1) | CHSQR(2) = 29.48 [.000]*** | Negative |
| ΔGEs & ECT(-1) | CHSQR(3) = 43.88 [.000]*** | Positive |
| II. VECM estimation (k =4) | | |
| A. Cointegrating vector | | |
| $COTWO = 3.995EG - 0.245EGSQ + 0.165FD - 0.318GL - 0.168GE + 0.019SB(1990) - 0.162SB(2016) - 14.41$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -0.927 | CHSQR(1) = 45.96 [.000]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| EG & ECT(-1) | CHSQR(2) = 45.99 [.000]*** | Positive |
| EGSQ & ECT(-1) | CHSQR(2) = 45.97 [.000]*** | Negative |
| FD & ECT(-1) | CHSQR(2) = 46.13 [.000]*** | Positive |
| GL & ECT(-1) | CHSQR(2) = 45.97 [.000]*** | Negative |
| GE & ECT(-1) | CHSQR(2) = 46.38 [.000]*** | Negative |

*Notes: (***) 1% level of significance.*

**Table 8.** Mexico Findings.

| I. ARDL estimation (k =4) | | |
|---|---|---|
| A. Cointegrating vector | | |
| $COTWO = -1.970EG + 0.206EGSQ - 0.355FD - 1.085\, GL + 0.290GE + 0.140SBTWOLS + 9.256$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -0.705 | CHSQR(1) = 6.793 [.009]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| ΔEGs & ECT(-1) | CHSQR(3) = 9.308 [.025]** | Negative |
| ΔEGSQs & ECT(-1) | CHSQR(3) = 9.241 [.026]** | Positive |
| ΔFD & ECT(-1) | CHSQR(5) = 9.399 [.094]* | Negative |
| ΔGLs & ECT(-1) | CHSQR(5) = 19.52 [.002]*** | Negative |

| | | |
|---|---|---|
| ΔGEs & ECT(-1) | CHSQR(3) = 22.61[.000]*** | Positive |
| II. VECM estimation (k =3) | | |
| A. Cointegrating vector | | |
| $COTWO = 7.424EG - 0.481EGSQ - 0.317FD - 0.952GL + 0.233GE + 0.184SB(1994) + 0.143SB(2008) - 23.29$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -0.550 | CHSQR(1) = 13.57 [.000]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| EG & ECT(-1) | CHSQR(2) = 15.14 [.001]*** | Positive |
| EGSQ & ECT(-1) | CHSQR(2) = 15.03 [.001]*** | Negative |
| FD & ECT(-1) | — | — |
| GL & ECT(-1) | CHSQR(2) = 15.58 [.000]*** | Negative |
| GE & ECT(-1) | CHSQR(2) = 14.61 [.001]*** | Positive |

*Notes: (***) 1%, (**) 5%, and (*) 10% level of significance.*

**Table 9.** Pakistan Findings.

| | | |
|---|---|---|
| I. ARDL estimation (k =2) | | |
| A. Cointegrating vector | | |
| $COTWO = 8.888EG - 0.545EGSQ + 0.105FD + 0.094GL - 0.157GE - 0.047SBTWOLS - 36.15$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -0.628 | CHSQR(1) =32.58 [.000]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| ΔEG & ECT(-1) | CHSQR(2) = 33.74 [.000]*** | Positive |
| ΔEGSQ & ECT(-1) | CHSQR(2) = 33.83 [.000]*** | Negative |
| ΔFD & ECT(-1) | CHSQR(2) = 33.03 [.000]*** | Positive |
| ΔGL & ECT(-1) | CHSQR(2) = 32.84 [.000]*** | Positive |
| ΔGE & ECT(-1) | CHSQR(2) = 32.63 [.000]*** | Negative |
| II. VECM estimation (k =4) | | |
| A. Cointegrating vector | | |
| $COTWO = 16.56EG - 1.119EGSQ + 0.135FD + 0.030GL - 0.143GE + 0.025SBONEZA - 61.69$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -0.361 | CHSQR(1) = 3.050 [.081]* | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| EG & ECT(-1) | CHSQR(2) = 7.343 [.025]** | Positive |
| EGSQ & ECT(-1) | CHSQR(2) = 7.704 [.021]** | Negative |
| FD & ECT(-1) | CHSQR(2) = 3.265 [.195] | Positive |
| GL & ECT(-1) | — | — |
| GE & ECT(-1) | — | — |

*Notes: (***) 1%, (**) 5%, and (*) 10% level of significance.*

**Table 10.** Thailand Findings.

| | | |
|---|---|---|
| I. ARDL estimation (k =4) | | |
| A. Cointegrating vector | | |
| $COTWO = -6.744EG + 0.485EGSQ + 0.493FD + 1.712GL + 0.297GE + 0.529SBONEZ + 13.80$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -0.276 | CHSQR(1) = 11.75 [.001]*** | |
| C. Strong exogeneity test | | |

| Regressor | Result | Direction |
|---|---|---|
| ΔEGs & ECT(-1) | CHSQR(4) = 18.93 [.001]*** | Negative |
| ΔEGSQ & ECT(-1) | CHSQR(2) = 12.51 [.002]*** | Positive |
| ΔFD & ECT(-1) | CHSQR(2) = 17.75 [.000]*** | Positive |
| ΔGLs & ECT(-1) | CHSQR(4) = 23.87 [.000]*** | Positive |
| ΔGEs & ECT(-1) | CHSQR(3) = 20.45 [.000]*** | Positive |
| II. VECM estimation (k =4) | | |
| A. Cointegrating vector | | |
| $COTWO = -7.588EG + 0.531EGSQ + 0.246FD + 1.997GL + 0.576GE + 0.766SBONEZ + 16.48$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -0.356 | CHSQR(1) = 11.87 [.001]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| EG & ECT(-1) | CHSQR(2) = 36.70 [.000]*** | Negative |
| EGSQ & ECT(-1) | CHSQR(2) = 35.53 [.000]*** | Positive |
| FD & ECT(-1) | CHSQR(2) = 30.26 [.000]*** | Positive |
| GL & ECT(-1) | CHSQR(2) = 22.57 [.000]*** | Positive |
| GE & ECT(-1) | CHSQR(2) = 27.01 [.000]*** | Positive |

*Notes: (***) 1% level of significance.*

**Table 11.** Turkey's Findings.

| | | |
|---|---|---|
| I. ARDL estimation (k =4) | | |
| A. Cointegrating vector | | |
| $COTWO = 6.078EG - 0.553EGSQ + 0.050FD + 0.299GL + 0.006GE - 0.017SBONEZA - 16.48$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -1.778 | CHSQR(1) = 42.24 [.000]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| ΔEGs & ECT(-1) | CHSQR(4) = 42.52 [.000]*** | Positive |
| ΔEGSQs & ECT(-1) | CHSQR(3) = 42.30 [.000]*** | Negative |
| ΔFD & ECT(-1) | CHSQR(2) = 46.94 [.000]*** | Positive |
| ΔGL & ECT(-1) | CHSQR(4) = 44.57 [.000]*** | Positive |
| ΔGE & ECT(-1) | CHSQR(5) = 53.55 [.000]*** | Positive |
| II. VECM estimation (k =3) | | |
| A. Cointegrating vector | | |
| $COTWO = 6.626EG - 0.609EGSQ + 0.042FD + 0.271GL + 0.074GE - 17.86$ | | |
| B. Weakly exogenous test | | |
| ECT coefficient | Result | |
| α = -1.212 | CHSQR(1) = 13.93 [.000]*** | |
| C. Strong exogeneity test | | |
| Regressor | Result | Direction |
| EG & ECT(-1) | CHSQR(2) = 39.70 [.000]*** | Positive |
| EGSQ & ECT(-1) | CHSQR(2) = 39.79 [.000]*** | Negative |
| FD & ECT(-1) | CHSQR(2) = 20.38 [.000]*** | Positive |
| GL & ECT(-1) | CHSQR(2) = 19.72 [.000]*** | Positive |
| GE & ECT(-1) | CHSQR(2) = 23.39 [.000]*** | Positive |

*Notes: (***) 1% level of significance.*

## 5. Policy Implications and Conclusion

The relationship between carbon emissions and economic growth is complex and multifaceted, to which the EKC hypothesis suggests that as a country develops, environmental pollution will initially increase but eventually decline. However, the findings of this study suggest that the EKC hypothesis is not universally valid. In Egypt and Thailand, carbon emissions increase monotonically with economic growth. In India, the EKC hypothesis is supported, suggesting that the country is on a good path to ameliorating the environment. In Mexico, the findings are mixed, with the ARDL estimation suggesting a U-shaped carbon-growth relationship and the VECM estimation supporting the EKC hypothesis. In Pakistan, the EKC hypothesis is supported, but the impacts of financial development, globalization, and government expenditure remain inconclusive. In Turkey, the EKC hypothesis is supported, but financial development, globalization, and government expenditure exhibit positive associations with carbon emissions.

Our ARDL and VECM findings provide valuable policy implications for the EKC hypothesis in six countries. Firstly, countries should adopt comprehensive policy strategies that integrate these goals and fully consider the long-term environmental and societal impacts of their decisions. These strategies can foster economic growth while simultaneously enhancing environmental outcomes, making them crucial for fulfilling international obligations under SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). In particular, policymakers in Egypt, Mexico, and Thailand, where the EKC hypothesis is not (fully) supported by the present study, should reevaluate their policy designs to achieve sustainable development.

Secondly, countries should invest heavily in research and development to accelerate the creation of new technologies that can effectively reduce carbon emissions. To attract the necessary funding and human capital, countries must cultivate a strong economic and academic foundation. Financial development and globalization play crucial roles in achieving this, enabling countries to tap into global knowledge and capital markets. Notably, policymakers in countries with positive financial development (FD) (India, Pakistan, Thailand, and Turkey) and/or positive globalization (GL) (Egypt, Pakistan, Thailand, and Turkey) should carefully evaluate the impact of each policy on carbon emissions.

Thirdly, countries must actively raise awareness about the environmental repercussions of economic growth. Governments should encourage individuals and businesses to adopt environmentally responsible practices and reduce their environmental impact. To achieve this, governments must establish a comprehensive framework for efficient budget allocation that drives measurable results. In this regard, government expenditure plays a crucial role. This implication holds particular significance for Egypt, India, Mexico, Thailand, and Turkey, where our findings have demonstrated that government expenditure (GE) increases carbon emissions.

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## Conflict of interest

The author claims that the manuscript is completely original. The author also declares no confliction.

## Appendix

**A1.** Egypt, India, Mexico, Pakistan, Thailand, and Turkey's EKC Results.

| Country | The EKC is validated | The EKC is not validated |
|---|---|---|
| Egypt | Mahmood et al. (2019) | The present study ARDL & VECM<br>Bese & Kalayci (2019)<br>El-Aasar & Hanafy (2018) |

| | | |
|---|---|---|
| India | The present study ARDL & VECM<br>Rana & Sharma (2019)<br>Sultan et al. (2019) | Villanthenkodath et al. (2021) |
| Mexico | The present study VECM<br>Seri & Fernandez (2021)<br>Adebayo et al. (2023); Miranda et al. (2020) | The present study ARDL |
| Pakistan | The present study ARDL & VECM<br>Arif et al. (2022)<br>Hashmi et al. (2020); Khan et al. (2023) | |
| Thailand | Fukuda (2023)<br>Hussain et al. (2021)<br>Paweenawat & Plyngam (2017) | The present study ARDL & VECM |
| Turkey | The present study ARDL & VECM<br>Genç et al. (2022); Kilavuz & Dogan (2021)<br>Adebayo et al. (2023) | Alola & Donve (2021)<br>Bese & Kalayci (2019) |

**A2.** Unit Root Test Results (ADF-GLS and PP Tests, $k = 4$).

(a) Egypt

| | ADF-GLS Test | | PP Test | |
|---|---|---|---|---|
| | Inpt. only | Inpt.. & Trend | Inpt. only | Inpt. & Trend |
| COTWO | 0.121 | -1.426 | -1.988 | -1.905 |
| ΔCOTWO | -2.824*** | -3.214** | -9.362*** | -10.045*** |
| EG | -0.305 | -2.327 | -1.871 | -1.491 |
| ΔEG | -2.410** | -2.752 | -4.189*** | -4.402*** |
| EGSQ | -0.178 | -2.518 | -1.371 | -1.661 |
| ΔEGSQ | -2.594** | -2.925* | -4.285*** | -4.371*** |
| FD | -1.031 | -1.533 | -1.989 | -1.246 |
| ΔFD | -2.340** | -2.723 | -7.360*** | -7.692*** |
| GL | -0.724 | -0.859 | -2.715* | -1.749 |
| ΔGL | -3.224*** | -3.882*** | -6.095*** | -6.604*** |
| GE | -0.392 | -2.019 | -0.909 | -1.780 |
| ΔGE | -1.561 | -2.395 | -4.855*** | -4.793*** |

(b) India

| | ADF-GLS Test | | PP Test | |
|---|---|---|---|---|
| | Inpt. only | Inpt.. & Trend | Inpt. only | Inpt. & Trend |
| COTWO | -0.958 | -3.328** | -0.009 | -2.562 |
| ΔCOTWO | -1.847 | -1.481 | -7.231*** | -7.151*** |
| EG | -0.428 | -0.742 | 2.450 | -2.891 |
| ΔEG | -1.420 | -2.748 | -6.639*** | -7.556*** |
| EGSQ | -0.498 | -0.839 | 2.880** | -2.426 |
| ΔEGSQ | -1.425 | -3.255** | -6.294*** | -7.448*** |
| FD | -0.217 | -3.125** | -1.508 | -2.089 |
| ΔFD | -1.361 | -2.010 | -6.224*** | -6.221*** |
| GL | -0.662 | -2.116 | -0.420 | -1.554 |
| ΔGL | -1.617 | -1.629 | -3.797*** | -3.755** |
| GE | -1.350 | -2.225 | -2.402 | -2.512 |
| ΔGE | -1.831 | -2.934* | -6.223*** | -6.155*** |

(c) Mexico

| | ADF-GLS Test | | PP Test | |
|---|---|---|---|---|
| | Inpt. only | Inpt.. & Trend | Inpt. only | Inpt. & Trend |
| COTWO | -0.990 | -0.858 | -3.194** | -1.372 |
| ΔCOTWO | 0.391 | -2.531 | -6.447*** | -7.736*** |
| EG | 0.131 | -1.671 | -2.543* | -2.563 |
| ΔEG | -3.871*** | -3.997*** | -6.079*** | -6.346*** |

| | | | | |
|---|---|---|---|---|
| EGSQ | 0.133 | -1.733 | -2.456 | -2.568 |
| ΔEGSQ | -3.918*** | -4.019*** | -6.138*** | -6.386*** |
| FD | -1.447 | -1.764 | -2.131 | -1.863 |
| ΔFD | -2.071* | -2.219 | -7.404*** | -7.700*** |
| GL | 0.782 | -1.796 | -0.045 | -2.920 |
| ΔGL | -2.997*** | -3.230** | -6.312*** | -6.260*** |
| GE | -0.575 | -2.470 | -2.196 | -2.573 |
| ΔGE | -3.095*** | -3.181** | -6.856*** | -6.810*** |

(d) Pakistan

| | ADF-GLS Test | | PP Test | |
|---|---|---|---|---|
| | Inpt. only | Inpt.. & Trend | Inpt. only | Inpt. & Trend |
| COTWO | 0.216 | -1.916 | -0.412 | -2.101 |
| ΔCOTWO | -1.042 | -1.725 | -6.392*** | -6.366*** |
| EG | 0.235 | -2.744* | 0.099 | -2.314 |
| ΔEG | -1.433 | -2.065 | -5.985*** | -5.919*** |
| EGSQ | 0.304 | -2.795* | 0.300 | -2.417 |
| ΔEGSQ | -1.517 | -2.189 | -5.877*** | -5.823*** |
| FD | -1.134 | -2.406 | -1.362 | -1.993 |
| ΔFD | -3.881*** | -4.164*** | -5.595*** | -5.583*** |
| GL | -0.085 | -0.819 | -2.526 | -1.987 |
| ΔGL | -2.772** | -3.081* | -6.219*** | -6.576*** |
| GE | -2.169** | -2.283 | -2.098 | -2.193 |
| ΔGE | -2.859*** | -2.823* | -6.551*** | -6.481*** |

(e) Thailand

| | ADF-GLS Test | | PP Test | |
|---|---|---|---|---|
| | Inpt. only | Inpt. & Trend | Inpt. only | Inpt. & Trend |
| COTWO | -0.222 | -1.062 | -2.446 | -0.500 |
| ΔCOTWO | -0.643 | -2.671 | -5.097*** | -5.376*** |
| EG | -0.183 | -1.430 | -1.728 | -0.683 |
| ΔEG | -2.318** | -2.740 | -4.290*** | -4.564*** |
| EGSQ | -0.137 | -1.680 | -1.342 | -1.027 |
| ΔEGSQ | -2.402** | -2.769 | -4.493*** | -4.635*** |
| FD | -0.234 | -1.273 | -2.381 | -1.622 |
| ΔFD | -2.032* | -2.392* | -3.335** | -3.537* |
| GL | 0.127 | -0.651 | -2.107 | -0.246 |
| ΔGL | -2.429** | -3.178** | -5.967*** | -6.471*** |
| GE | -1.088 | -2.468 | -0.691 | -2.229 |
| ΔGE | -3.040*** | -3.152** | -4.226*** | -4.293** |

(f) Turkey

| | ADF-GLS Test | | PP Test | |
|---|---|---|---|---|
| | Inpt. only | Inpt. & Trend | Inpt. only | Inpt. & Trend |
| COTWO | 0.753 | -1.507 | -2.164 | -2.887 |
| ΔCOTWO | -1.219 | -2.533 | -6.362*** | -6.464*** |
| EG | 1.774 | -1.297 | 0.886 | -1.740 |
| ΔEG | -3.550*** | -4.046*** | -6.711*** | -6.802*** |
| EGSQ | 1.878* | -0.918 | 1.477 | -1.129 |
| ΔEGSQ | -3.427*** | -3.986*** | -6.503*** | -6.754*** |
| FD | -0.434 | -1.372 | 0.204 | -1.266 |
| ΔFD | -2.028* | -3.179** | -5.211*** | -5.361*** |
| GL | -0.251 | -0.988 | -1.688 | -0.782 |
| ΔGL | -2.787** | -3.576** | -7.811*** | -8.135*** |
| GE | -1.819 | -2.694 | -1.789 | -2.405 |
| ΔGE | -3.143*** | -3.299** | -6.421*** | -6.358*** |

*Notes: (***) 1%, (**) 5%, and (*) 10% level of significance.*

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