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Testing the Environmental Kuznets Curve Hypothesis Using the Environmental Performance Index: Evidence from Ten Largest High-Income OECD Economies (2006–2022)

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Abstract. *This study aims to analyze the influence of economic growth, renewable energy consumption, and non-renewable energy consumption on the Environmental Performance Index (EPI), as well as to test the Environmental Kuznets Curve (EKC) hypothesis in the 10 largest OECD countries for the period 2006-2022. Using the Panel Vector Error Correction Model (PVECM) analysis technique with the Common Effect Model (CEM) approach, this study provides results that the EKC hypothesis in the 10 countries with the highest economic growth rates in the OECD is not proven. Although GDPPC² is proven to have a positive and significant effect which means indicating a turning point, per capita income and non-renewable energy consumption are proven to have a negative and significant effect both in the short and long term. This indicates that increasing per capita income will actually cause a decline in environmental quality in both the short and long term. This has the impact of policies that sustainable economic growth will be realized if the government pays attention to environmental aspects such as implementing policies prohibiting the use of fossil fuels, imposing carbon taxes to reduce carbon emissions and providing incentives for investment in infrastructure development using renewable energy such as solar or wind energy.*

Keywords:

Environmental
Kuznets Curve;
Renewable
Energy; Non-
Renewable
Energy; P-VECM

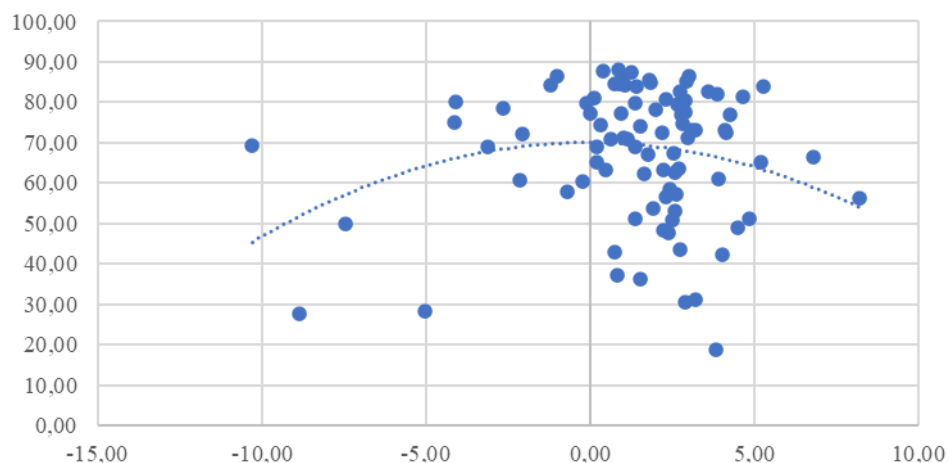
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Pendahuluan

Every nation inevitably endeavors to enhance its economic performance through the pursuit of economic growth. However, the attainment of increased economic growth entails consequences in the form of environmental degradation. According to Shine & Maiti (2025), economic growth is responsible for the escalation of emissions

resulting from energy consumption and industrial expansion. One of the theories that elucidates how economic growth affects environmental degradation is the Environmental Kuznets Curve (EKC) Hypothesis. This hypothesis is a theory introduced by Grossman and Krueger in 1991, as cited in Cahyani & Aminata (2020). The theory applies the Kuznets hypothesis to analyze how economic growth is associated with changes in environmental quality (Cahyani & Aminata, 2020). The Environmental Kuznets Curve (EKC) hypothesis posits that during the initial stages of a country's economic development, environmental pollution increases concurrently with rising per capita income. However, at a certain level of economic development, a turning point in the Kuznets Curve occurs. As per capita income continues to increase, the level of environmental pollution decreases; this can be attributed to the fact that individuals in countries with advanced economies have acquired greater knowledge and understanding of environmental management. Consequently, the Environmental Kuznets Curve (EKC) emerges in the form of an inverted U-shape, which postulates an inverse relationship between pollution and growth. From this theory, it can be inferred that countries with higher incomes tend to exhibit lower levels of environmental degradation compared to countries with lower incomes. The following data presents the economic growth of the ten largest OECD (Organization for Economic Co-operation and Development) countries by income and their corresponding environmental quality conditions, as indicated by the Environmental Performance Index.



Source: U.S. Energy Information Administration (2023); Energy Institute – Statistical Review of World Energy (2024), World Development Indicators (2025), processed

Figure 1. Environmental Performance Index (EPI) vs. GDP Growth

The Environmental Kuznets Curve (EKC) hypothesis postulates that an inverted U-shaped relationship exists between economic growth and environmental quality. As illustrated in the graph presented in Figure 1, the relationship between the EPI and GDP growth during the period 2006–2022 does not exhibit a clear inverted U-shaped pattern as assumed by the EKC hypothesis. The data distribution appears random, and although a polynomial trend line is present, its shape demonstrates only a weak curvature that is not visually significant. This suggests that economic growth does not consistently align with improvements in environmental quality, even in countries with high economic and technological capacity. In fact, there is a tendency for EPI scores to decline as GDP growth increases, albeit in a pattern that is not entirely linear. This indicates that increased economic growth is not necessarily accompanied by improvements in environmental quality in countries with substantial economic capacity. The incongruity between changes in the Environmental Performance Index

and the Kuznets Curve hypothesis can be attributed to various factors, both from the calculation of the Environmental Performance Index itself and from environmental conditions. The random fluctuations observed in EPI values across countries may also result from the increasing number of indicators used to calculate the Environmental Performance Index each year; specifically, in 2018, only 24 indicators were employed, whereas by 2020, this number had expanded to 32 indicators. The addition of these indicators can cause significant changes in a country's index score even when its policies have not substantially changed. This condition thus raises an important question: is the EKC hypothesis still relevant in the context of large economies that possess more complex environmental policies and more advanced economic capacities?

Several recent studies have demonstrated that the form of this relationship can vary, exhibiting not only an inverted U-shape but also a U-shape. In the literature by Destek & Sinha (2020) and Zoundi (2017), the curve formed is U-shaped, occurring in the respective countries studied, namely 24 OECD countries and 25 African countries. An N-shaped curve has also been identified; Beck & Joshi (2015) found that OECD countries exhibit an N-shaped curve pattern in the relationship between economic growth and CO₂ emissions. Similarly, in the study by Bisset (2022), an N-shaped curve was observed in Sub-Saharan African (SSA) countries with upper-middle income. Özokcu & Özdemir (2017) identified another form of the EKC, namely the inverted N-curve, which was observed in 26 OECD countries. Likewise, the study by Pradhan et al. (2022) confirmed that the EKC hypothesis is valid and assumes an inverted N-shape in BRICS countries. Factors such as trade openness, human capital, renewable energy consumption, institutions, technology, environmental policy, and natural resource revenues also influence the shape and validity of the EKC.

Studies examining the relationship between economic growth and environmental degradation have been extensively conducted. These studies have demonstrated that the EKC hypothesis is supported, whereby GDP exerts a positive influence on environmental degradation; however, at a certain income level, a turning point occurs wherein GDP exerts a negative influence on environmental degradation, as reported by Adzim et al. (2024), Alzgool et al. (2020), Chopra et al. (2024), Mohamed et al. (2024), Ojaghlou et al. (2023), Soeharjoto et al. (2022), Voumik et al. (2023), and Yunita et al. (2023b). Nevertheless, other research has demonstrated that the EKC hypothesis is not supported, as GDP was found to have no significant effect on environmental degradation (Ginting et al., 2023). Furthermore, environmental quality is not solely determined by GDP or economic growth; other factors, such as non-renewable energy consumption and renewable energy consumption, also exert influence on environmental degradation or environmental quality. The study by Cahyani & Aminata (2020b) demonstrated that renewable energy consumption has a positive effect on environmental degradation. Conversely, the studies by Chopra et al. (2024), Coşkun & Eygü (2025a), Hasan et al. (2023), Mohamed et al. (2024), Sahputra et al. (2025a), and Voumik et al. (2023) demonstrated that renewable energy consumption has a negative effect. In contrast to these studies, research by Cahyani & Aminata (2020b), Coşkun & Eygü (2025a), Hasan et al. (2023), Sahputra et al. (2025a), and Voumik et al. (2023) demonstrated that non-renewable energy consumption has a significant effect on CO₂ emissions.

Based on the aforementioned phenomena and the persistent discrepancies in the findings of previous studies, this research aims to examine the relationship between the Environmental Performance Index (EPI) and economic growth, renewable energy consumption, and non-renewable energy consumption. The distinction of this study from previous research, which constitutes its novelty, lies in the utilization of the Environmental Performance Index (EPI) as a measure for assessing environmental quality in the context of economic growth, particularly in the ten largest economies

in the world. In prior studies, researchers focused exclusively on the relationship between GDP per capita, renewable energy consumption, and non-renewable energy consumption with CO₂ gas emissions.

Research Methodology

This study employs a quantitative data analysis approach (*quantitative research*), utilizing secondary data in the form of panel data spanning the period from 2006 to 2022 across ten countries, namely the United States, Australia, Russia, the United Kingdom, Italy, Japan, Germany, Canada, South Korea, and France. These ten countries were selected based on their having the highest levels of economic growth among OECD member countries. The data were obtained from several sources, including the World Bank, Our World in Data, and the Yale Center for Environmental Law & Policy – Environmental Performance Index (EPI). The data utilized comprise the Environmental Performance Index, GDP per capita in local currency, renewable energy consumption, and non-renewable energy consumption. The dependent variable in this study is the Environmental Performance Index (EPI), while the independent variables employed are GDP per Capita, Renewable Energy Consumption, and Non-Renewable Energy Consumption.

The analytical technique employed in this study is the Panel Vector Error Correction Model (PVECM). The PVECM model was selected because it aligns with the objectives of this study, which seek to examine both short-run and long-run relationships. Furthermore, the PVECM model illustrates the mechanism of adjustment from the occurrence of shocks toward equilibrium. The Error Correction Term (ECT) component in the VECM model indicates the speed at which short-run disequilibrium is corrected toward long-run equilibrium. This method is based on the Vector Autoregression (VAR) framework, derived from the VAR model. VECM requires stationarity at the first difference level. PVECM is utilized to model the interrelationships among variables and to analyze the long-run and short-run relationships between these variables (Sari, 2017). This approach represents an extension of the VAR model adapted for panel data, taking into account the heterogeneous characteristics across observational units (Susilo & Fatmawati, 2024). Mathematically, the baseline model in this study is expressed as follows:

$$EPI_{it} = \beta_0 + \beta_1 GDPPC_{it} + \beta_2 GDPPC_{it}^2 + \beta_3 RENEPC_{it} + \beta_4 FFECPC_{it} + \varepsilon_{it} \quad (1)$$

where EPI denotes the environmental performance index of country i in period t , and ε represents the error term. The squared GDP per capita variable ($GDPPC^2$) is incorporated into the model to test the non-linear hypothesis between environmental quality and economic growth, thereby testing the Environmental Kuznets Curve (EKC) hypothesis.

To mitigate issues arising from differing data scales in the model, certain variables in this study are transformed into natural logarithmic (ln) form. This transformation is applied to the economic growth variable, namely $GDPPC$ and $GDPPC^2$, as well as to the energy consumption variables, namely $RENEPC$ and $FFECPC$. Meanwhile, the EPI variable is not transformed into natural logarithmic form because it is already expressed as an index with a relatively stable scale. Accordingly, the research model following logarithmic transformation can be expressed as follows:

$$EPI_{it} = \beta_0 + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC_{it}^2 + \beta_3 \ln RENEPC_{it} + \beta_4 \ln FFECPC_{it} + \varepsilon_{it} \quad (2)$$

This study employs the Vector Error Correction Model (VECM) approach to analyze the long-run and short-run relationships between the dependent and

independent variables utilized. Through the VECM model, the dynamic relationships among variables can be observed through changes in variables from the previous period (lag) affecting changes in variables in the current period. The VECM model in this study can be formulated as follows:

$$\begin{aligned} \Delta EPI_{it} = & \beta_0 + \sum_{k=1}^p \beta_1 \Delta EPI_{it-k} + \sum_{k=1}^p \beta_2 \Delta \ln GDP PC_{it-k} + \sum_{k=1}^p \beta_3 \Delta \ln GDP PC_{it-k}^2 \\ & + \sum_{k=1}^p \beta_4 \Delta \ln RENE CPC_{it-k} + \sum_{k=1}^p \beta_5 \Delta \ln FFEC PC_{it-k} + \lambda ECT_{it-1} + \varepsilon_{it} \end{aligned} \quad (3)$$

Note:

EPI: Environmental Performance Index

lnGDPPC: Natural logarithm of GDP per Capita

*lnGDPPC*²: Natural logarithm of the square of GDP per Capita

lnRENECPC: Natural logarithm of Renewable Energy Consumption per Capita

lnFFECPC: Natural logarithm of Non-Renewable Energy Consumption per Capita

α : Constant

β : Coefficients of the independent variables

ECT: Error Correction Term

Δ : First difference operator

λ : Speed of adjustment coefficient toward long-run equilibrium

ε : Error Term

i: Country

t: Year

p: Lag length in the model

k: Optimal lag obtained from the optimal lag test

Results and Discussion

Stationarity Test

The stationarity test is conducted to ensure that the fundamental assumptions of the VECM model are satisfied. The stationarity test results in this study were obtained from the unit root test using the Phillips-Perron (PP) method.

Table 1. Unit Root Stationarity Test Results

Panel Unit Root Test				
Variable	Unit Root Test	Test Statistics	Probability	Non-Stationary
EPI	Level	21.6704	0.3587	Stationary
	1st Difference	43.8071	0.0016	Non-Stationary
lnGDPPC	Level	21.6177	0.3616	Stationary
	1st Difference	103.848	0.0000	Non-Stationary
lnGDPPC ²	Level	20.5952	0.4213	Stationary
	1st Difference	104.306	0.0000	Non-Stationary
lnRENECPC	Level	34.9646	0.0203	Stationary
	1st Difference	83.9495	0.0000	Non-Stationary
lnFFECPC	Level	28.0811	0.1075	Stationary
	1st Difference	107.853	0.0000	Stasioner

Source: processed data

Based on the results presented in Table 1, the unit root test at the level indicates that all variables are non-stationary at the level, with probability values exceeding α at 5 percent. This serves as the basis for selecting the PVECM estimation method. VECM is a specialized form of the VAR (Vector Autoregressive) model designed for data that

are non-stationary at the level but possess long-run cointegration relationships. Nevertheless, the PVECM model requires that the data exhibit the same level of stationarity, specifically at the first difference level (Sari, 2017). At the first difference level, the results indicate that all five variables have probabilities below 5 percent, signifying that they are stationary. This finding is consistent with the fundamental premise of the VECM model, which requires stationarity at the first difference level. Subsequently, prior to conducting the cointegration test to confirm the existence of long-run equilibrium relationships among the variables in the model, it is necessary to determine the optimal lag length.

Table 2. Optimal Lag Test Results

Lag	LogL	LR	FPE	AIC	SC	HQ
0	- 463.2556	NA	0.444571	13.37873	13.53934	13.44253
1	187.5681	1190.078	7.64E-09	-4.501945	-3.538305	-4.119176
2	247.4980	101.0247*	2.85E-09*	- 5.499942*	- 3.733267*	- 4.798197*

Source: processed data

The optimal lag value can be observed in Table 2 using the criteria of the Akaike Information Criterion (AIC), Schwarz Information Criterion (SC), or Hannan-Quinn (HQ). The results obtained from the lag test indicate that the smallest values across all criteria are located at lag 2. Therefore, the model in this study is considered optimal when utilizing lag 2. Consequently, the cointegration test is conducted using lag 2.

Cointegration Test

In this study, the cointegration test is conducted using Johansen's Cointegration Test at a 5 percent significance level.

Table 3. Cointegration Test Results

Maximum Eigenvalue				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	Nilai Kritis (5%)	Prob.
None*	0.584952	52.76165	33.87687	0.0001
At most 1*	0.425693	33.27542	27.58434	0.0083
At most 2*	0.336451	24.60919	21.13162	0.0155
Trace Statistic				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	Critical Value (5%)	Prob.
None*	0.584952	124.2953	69.81889	0.0000
At most 1*	0.425693	71.53363	47.85613	0.0001
At most 2*	0.336451	38.2582	29.79707	0.0042

As presented in Table 3, the Maximum Eigenvalue results indicate that for the hypotheses None, At Most 1, and At Most 2, the max-eigen statistic values are each greater than the critical values at 5%. Furthermore, the probability of each hypothesis is less than 0.05. Therefore, it can be concluded that three cointegration relationships exist within this model. The presence of these cointegration relationships confirms that the variables employed in this study possess long-run equilibrium relationships.

Consequently, subsequent estimation can proceed using the Panel Vector Error Correction Model (PVECM).

PVECM Model Determination Test

The prerequisites for employing the VECM analytical technique have been fulfilled. Subsequently, given that the observations in this study encompass ten countries over the period 2006–2022 (a combination of cross-sectional and time-series data), the analytical technique employed is Panel VECM. The initial step in panel regression is to determine the best model through sequential Chow, Hausman, and LM tests (Table 4).

Table 4. Model Determination Test Results

Test	Effect Test	Prob.	Model Tested	Result
Chow	Cross Section F	0.9923	CEM vs FEM	p-value > 0.05; CEM
Hausman	Cross Section Random	0.9131	REM vs FEM	p-value > 0.05; REM
LM	Breusch-Pagan	0.0578	CEM vs REM	p-value > 0.05; CEM

The initial step in determining the best panel regression model is by conducting the Chow Test. The Chow Test is conducted to determine whether the Common Effect Model (CEM) or the Fixed Effect Model (FEM) is superior, by examining the probability value. If the obtained probability value is greater than the significance level ($> \alpha$) and H_0 is accepted, then the accepted model is the Common Effect Model (CEM). Conversely, if the probability value is smaller than the significance level ($< \alpha$), then H_0 is rejected, indicating that the superior model is the Fixed Effect Model (FEM). The Chow Test results in Table 4 indicate a probability value of 0.9923, which exceeds the 5% significance level; thus, the selected model is CEM. Subsequently, the Hausman Test is conducted to determine the superior model between FEM and the Random Effect Model (REM). The Hausman Test yields a probability value of 0.9131, indicating that the superior model is REM; therefore, it is necessary to proceed with the LM Test. The LM Test results indicate a probability value of 0.0578, which exceeds the 5% alpha level; thus, the superior model selected is CEM. This result signifies that each observational unit exhibits uniform behavior throughout the observation period. Consequently, the PVECM estimation in this study employs the PVECM Common Effect Model.

PVECM Model Estimation

Based on the cointegration test results, which confirm the existence of cointegration in the research model, the model estimation can proceed in accordance with the fundamental concept of PVECM. The results of the VECM model estimation reveal the existence of long-run and short-run relationships among the variables, taking into account the values of the t-statistic and the t-table. If the t-statistic value exceeds the t-table value of 1.987934 at a 5 percent significance level, the variable can be deemed to exert a significant influence. The results of the PVECM model estimation are as follows:

Table 5. Long-Run and Short-Run VECM Model Estimation

Long Run				
Variable	Coefficient t	Standar Error	t-Statistic	Prob

lnGDPPC(-1)	-1982.093	-647.868	-3.05941	0.0033*
lnGDPPC ² (-1)	105.3999	-32.4237	3.25070	0.0019*
lnRENECPC(-1)	45.58100	-10.4365	4.36747	0.00005*
lnFFECPC(-1)	-110.7197	-24.6662	-4.48873	0.00003*
C	9907.424			

Short Run

Variable	Coefficient	Standar Error	t-Statistic	Prob
CointEq1	-0.075342	-0.02858	-2.63596*	0.0106*
D(EPI(-1))	-0.187916	-0.12601	-1.49132	0,1409
D(lnGDPPC(-1))	-2184.425	-959.363	-2.27695	0.0262*
D(lnGDPPC ² (-1))	114.8478	-48.6721	2.35962	0.0214*
D(lnRENECPC(-1))	-21.11019	-20.5661	-1.02646	0.3086
D(lnFFECPC(-1))	-195.2672	-65.4809	-2.98205	0.0041*
C	-9.488945	-3.39104	-2.79824	0.0048*

R² = 0.198904

Adj. R² = 0.122609

F-statistic = 2.607046

Note : * = significant at α 5% (t-table = 1.987934)

Table 5 presents the PVECM model estimation results, indicating that the CointEq1 parameter coefficient (Error Correction Term) is -0.075342, with a t-statistic of -2.63596*, which is greater than the t-table value at the significance level (< 0.05), indicating the presence of a long-run adjustment process. The R² value of 0.198904 is relatively low, indicating that the independent variables (renewable energy consumption, non-renewable energy consumption, and per capita income) are capable of explaining only 19.89 percent of the variation occurring in the environmental quality index, while the remaining 80.11 percent is explained by other variables outside the model, such as population density, institutional factors, and low public literacy.

The Effect of GDP per Capita (GDPPC) on Environmental Performance

The VECM estimation results indicate that the GDP per capita (GDPPC) variable exerts a negative and significant influence on the environmental quality index in both the short run and the long run. This finding is consistent with the discoveries of Alzgool et al. (2020) and Soeharjoto et al. (2022), who identified a negative effect of GDP per capita on the environmental quality index (EPI). This finding is contrary to the results reported by Cahyani & Aminata (2020), who stated that GDP per capita does not exert a significant influence on environmental quality.

GDP per capita exerts a negative influence on the Environmental Performance Index (EPI), which implies that when a country's GDP per capita increases, the purchasing power of its citizens also increases. Consequently, the demand for resources that compromise the environment also escalates, leading to a decline in environmental quality. The direction of the influence of GDP per capita is negative in both the short run and the long run; therefore, this finding is inconsistent with the Environmental Kuznets Curve (EKC), which posits that in the short run, increases in income will exacerbate environmental degradation, whereas in the long run, improvements in welfare will lead to reductions in environmental degradation.

The Effect of Renewable Energy Consumption (RENECPC) on Environmental Performance (EPI)

The renewable energy consumption (RENECPC) variable in the long-run PVECM estimation model yields a significant result, with a t-statistic value of 4.36747, which is greater than the t-table value of 1.987934 ($4.36747 > 1.987934$). Furthermore, with a coefficient value of 45.58100, renewable energy consumption exhibits a positive relationship with the Environmental Performance Index (EPI). In other words, renewable energy consumption in the long run is capable of improving environmental quality. This finding is consistent with the research findings of Iqbal et al. (2021), Mata et al. (2024), Musa et al. (2021), and Saudi et al. (2019), who stated that renewable energy consumption is capable of reducing CO₂ emissions and exerts a positive impact on the Environmental Performance Index (EPI).

Meanwhile, in the short-run PVECM model, renewable energy consumption yields a result that differs from the long-run model. In the short-run PVECM estimation, RENEPC yields a non-significant result, with a t-statistic value of -1.02646, which is smaller than the t-table value of 1.987934 ($1.02646 < 1.987934$). This indicates that renewable energy consumption in the short run is unable to improve environmental performance. This finding suggests that the utilization or consumption of renewable energy requires a longer time horizon, with effects on environmental quality materializing only in the long run, owing to the need for infrastructure development, investment, and technology adoption that cannot be implemented instantaneously.

The Effect of Non-Renewable Energy Consumption (FFECPC) on Environmental Performance (EPI)

The long-run VECM model estimation demonstrates that the non-renewable energy consumption (FFECPC) variable exerts a significant influence on environmental performance (EPI), with a t-statistic value of -4.48873, which is greater than the t-table value of 1.987934 ($4.48873 > 1.987934$). This variable also possesses a negative coefficient of -110.7197. Meanwhile, in the short run, the FFECPC variable is also proven to exert a negative and significant influence on EPI. These results indicate that the consumption of non-renewable energy, such as fossil fuels, increases carbon emissions in both the short run and the long run, thereby exerting adverse effects on the environment and consequently reducing environmental performance (EPI). This finding supports the findings from previous research, such as those of Cahyani & Aminata (2020), Coşkun & Eygü (2025), Hasan et al. (2023), Sahputra et al. (2025), Shokravi et al. (2025), and Voumik et al. (2023), who stated that non-renewable energy consumption is capable of increasing CO₂ emissions, thereby exerting a negative impact on the Environmental Performance Index (EPI).

Evidence of a U-Shaped Relationship Between Economic Growth (GDPPC, GDPPC²) and Environmental Quality (EPI)

The long-run PVECM model estimation demonstrates that the squared GDP per capita variable (GDPPC²) exerts a significant influence on environmental performance (EPI), with a t-statistic value of 3.25070, which is greater than the t-table value of 1.987934 ($3.25070 > 1.987934$). This variable also possesses a positive coefficient of 105.3999. Meanwhile, in the short run, the GDPPC² variable is also proven to exert a positive and significant influence on EPI. Although GDPPC² is proven to exert a positive and significant effect, indicating the existence of a turning point, this finding is not consistent with the Environmental Kuznets Curve (EKC) hypothesis, as per capita income exerts a negative and significant influence in both the short run and the long run. This indicates that in these ten countries, increases in welfare, as reflected by increases in per capita income, actually lead to a decline in environmental

quality. This condition necessitates the adoption of more environmentally friendly technologies, more stringent environmental regulations, and increased investment in environmental management, so that environmental quality can ultimately be improved.

Impulse Response Function (IRF) Analysis

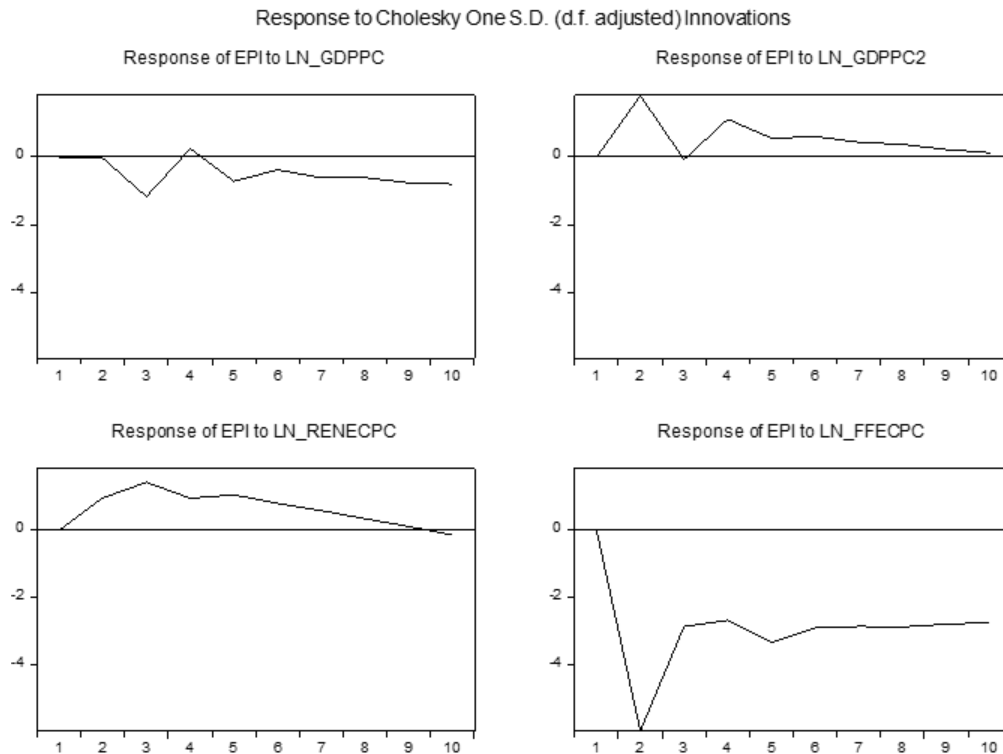


Figure 2. Impulse Response Function (IRF)

The Impulse Response Function graph presented in Figure 2 aims to illustrate how the EPI variable responds to shocks from other variables, namely $\ln\text{GDPPC}$, $\ln\text{GDPPC}^2$, $\ln\text{RENECPC}$, and $\ln\text{FFECPC}$, over the subsequent ten periods. The graph depicting the EPI response to $\ln\text{GDPPC}$ reveals a negative reaction in the initial periods, particularly in the third period, which gradually stabilizes while remaining in the negative region. This further suggests that an increase in GDP per capita leads to a decline in environmental quality in the short run.

Meanwhile, the graph depicting the EPI response to the $\ln\text{GDPPC}^2$ shock reveals a response that is the inverse of the $\ln\text{GDPPC}$ shock. During the initial to mid-period, the $\ln\text{GDPPC}^2$ shock elicits a positive response in EPI before gradually declining and approaching the equilibrium point. This positive response indicates that at higher income levels (the quadratic effect), economic growth exerts a positive impact on the environment. A positive response is also observed in the EPI's reaction to the $\ln\text{RENECPC}$ shock during the initial period, which subsequently diminishes gradually toward the equilibrium point. This graph demonstrates that renewable energy consumption contributes positively to the environment in the short run.

Finally, the graph depicting the EPI response to the $\ln\text{FFECPC}$ shock reveals a negative response during the initial period, which persists in the negative region through the final period, albeit with diminishing fluctuations. This indicates that the continuous consumption of non-renewable energy, in this case fossil fuels, persistently degrades environmental quality and performance. Overall, all EPI responses to the shocks from the independent variables tend to revert to the

equilibrium line in the final periods, indicating the presence of long-run equilibrium adjustment.

Forecast Error Variance Decomposition (FEVD) Analysis

The Forecast Error Variance Decomposition (FEVD) analysis aims to determine the extent to which each variable contributes to explaining the fluctuations occurring in the EPI variable over several future periods

Table 6. Forecast Error Variance Decomposition (FEVD) Results

Period	S.E.	EPI	lnGDPPC	lnGDPPC ²	lnRENECPC	lnFFECPC
1	16.90601	100.0000	0.000000	0.000000	0.000000	0.000000
2	22.77953	92.41855	0.000251	0.628922	0.175412	6.776864
3	25.77269	92.35247	0.206851	0.492282	0.437040	6.511353
4	29.02188	92.86369	0.170380	0.535135	0.450772	5.980020
5	31.83278	92.79495	0.192453	0.475027	0.481906	6.055661
6	34.15902	92.93127	0.179247	0.443376	0.471923	5.974187
7	36.32768	93.06816	0.187804	0.406437	0.442392	5.895206
8	38.27609	93.15421	0.194840	0.375575	0.406268	5.869105
9	40.05021	93.22568	0.214907	0.345905	0.371785	5.841725
10	41.68376	93.27752	0.235740	0.320216	0.344393	5.822134

Source: processed data

Based on the variance decomposition presented in Table 6, the variation occurring in environmental quality in both the short run and up to period 10 is determined by shocks occurring in the environmental quality variable itself, with a contribution of 93.28 percent in period 10. The second-largest contributor to the variation in environmental quality is non-renewable energy consumption, at 6.78 percent in the second period, which remains at 5.84 percent by period 10. This finding suggests that the dynamics occurring in the environmental quality index are determined by internal factors of environmental quality itself and also by non-renewable energy consumption.

Conclusions and Recommendations

This study concludes that the Environmental Kuznets Curve (EKC) hypothesis is not supported in countries with the highest levels of economic growth among OECD member nations. Although GDPPC² is proven to exert a positive and significant effect, indicating the existence of a turning point, this finding is inconsistent with the Environmental Kuznets Curve (EKC) hypothesis, as per capita income exerts a negative and significant influence in both the short run and the long run. This indicates that in these ten countries, increases in welfare, as reflected by increases in per capita income, lead to a decline in environmental quality in both the short run and the long run. This condition is further reinforced by the finding that non-renewable energy consumption exerts a negative and significant influence on environmental quality in both the short run and the long run.

The policy implications arising from the finding that increases in per capita income lead to a decline in environmental quality in both the short run and the long run suggest that sustainable economic growth can only be realized if the government gives due consideration to environmental sustainability aspects. Policies pertaining to rewards and penalties for businesses that have implemented environmental protection measures in their operations must be optimized. Given the finding that non-renewable energy consumption exerts the strongest influence on the EPI in the ten countries with the highest economic growth rates in the OECD, these ten countries should

implement policies involving the gradual restriction or prohibition of fossil fuel usage, the establishment of carbon pricing or the imposition of carbon taxes to suppress carbon emissions, and the provision of incentives for investment in the construction of renewable energy infrastructure, such as solar and wind energy.

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