International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2026, 16(2), 286-295.

Influence of ESG Performance on Shaping the Environmental Kuznets Curve: Evidence from the Expanded Persian Gulf Region

Ines Abdelkafi[1], Aida Smaoui[2]*, Hanene Ezzine[1]

[1]University of Sfax, ESC, LAMEF Laboratory, Sfax, Tunisia, [2]Department of Finance, College of Business, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh, Saudi Arabia. *Email: amsmaoui@imamu.edu.sa

Received: 09 September 2025 **Accepted:** 02 January 2026 **DOI:** https://doi.org/10.32479/ijeep.22440

ABSTRACT

This study investigates the dynamic interplay between economic growth, environmental, social, and governance (ESG) performance, and environmental degradation in the expanded Persian Gulf region. Using a panel ARDL-PMG approach on data from 2018 to 2023 across eight countries, we confirm an inverted U-shaped Environmental Kuznets Curve (EKC), showing that economic growth initially increases CO_2 emissions but eventually leads to reductions beyond a certain income threshold. ESG performance significantly mitigates emissions and moderates the GDP-CO_2 relationship through the interaction term, lowering the EKC turning point and accelerating the stage at which economic growth leads to environmental improvements. The error correction term indicates rapid adjustment toward long-run equilibrium, highlighting the responsiveness of the system to economic and policy changes. These findings emphasize the importance of integrating ESG considerations into national policies, promoting sustainable corporate practices, and supporting green investments to achieve low-carbon and sustainable growth. This study advances the literature by embedding ESG performance within the Environmental Kuznets Curve framework, capturing its moderating role on economic growth, and enabling a more precise estimation of its influence on the EKC turning point. These insights provide both a theoretical contribution and guidance for policymakers, pointing them toward strategies that embed ESG principles, foster green investments, strengthen governance transparency, and accelerate the transition to low-carbon and sustainable growth in strategically important economies.

Keywords: Environmental Kuznets Curve, Environmental, Social, and Governance Performance, CO_2 Emissions, Panel Autoregressive Distributed Lag-Pooled Mean Group, Sustainability, Persian Gulf
JEL Classifications: G3, Q4, Q5

1. INTRODUCTION

The growing urgency of environmental challenges amidst rapid economic growth has reignited both academic and policy interest in the environmental Kuznets curve (EKC) hypothesis (Grossman and Krueger, 1995; Stern, 2004). The EKC suggests an inverted U-shaped relationship between environmental degradation and income per capita, where pollution initially rises with economic expansion before declining after a certain income threshold. While extensively studied across various countries and regions (Dinda, 2004; Józwik et al., 2022), recent research highlights that traditional EKC models often neglect key institutional and governance factors crucial for achieving sustainable development (Jakada et al., 2022; Toufique et al., 2024).

In parallel, Environmental, Social, and Governance (ESG) indicators have gained prominence as essential tools for evaluating sustainability performance at both national and corporate levels (Friede et al., 2015; Zhang et al., 2025). Despite their widespread adoption in investment decisions and regulatory frameworks, the broader macroeconomic impacts of ESG—especially regarding environmental outcomes—remain insufficiently explored, particularly in resource-dependent economies.

The Persian Gulf region, comprising the six gulf cooperation council (GCC) countries—Saudi Arabia, United Arab Emirates, Qatar, Kuwait, Bahrain, and Oman—along with neighboring Iran and Iraq, offers a particularly pertinent setting for investigating these issues. These eight nations are undergoing accelerated economic diversification while facing mounting environmental pressures and increasing global expectations for ESG compliance (Baydoun and Aga, 2021; Saqib, 2018).

This paper provides a novel analysis of the environmental Kuznets curve (EKC) by integrating ESG performance into the framework, using panel data from eight economies spanning 2018 to 2023. To the best of our knowledge, this is the first study to model ESG as a moderating factor through an interaction term with GDP, enabling an examination of how ESG influences the turning point of the EKC. This approach sheds new light on the complex interplay between economic growth, environmental sustainability, and institutional governance, highlighting the role of sustainable practices in accelerating the shift toward lower emissions at earlier stages of economic development.

Our methodology employs advanced Panel ARDL-PMG econometric techniques, allowing us to capture both short-term dynamics and long-term relationships. The remainder of this paper is structured as follows: Section 2 reviews the relevant literature on the EKC and ESG performance; Section 3 outlines the methodology and estimation strategy; section 4 discusses the empirical findings and their implications; and finally, section 5 concludes with policy recommendations.

2. LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

2.1. Theoretical Review

The environmental Kuznets curve (EKC) hypothesis suggests an inverted U-shaped relationship between environmental degradation and economic growth, where pollution levels increase during the early stages of economic development and subsequently decline after surpassing a certain income threshold (Grossman and Krueger, 1995; Stern, 2004). This theory has motivated extensive empirical research across diverse pollutants and regions. For instance, Alsamara et al., 2018 confirm the presence of the EKC for CO_2 emissions in Middle Eastern countries using panel data techniques. Similarly, Ali et al. (2023) highlight the critical role of renewable energy consumption and technological innovation in accelerating the turning point of the EKC in emerging economies. Nevertheless, recent studies underscore that institutional quality and governance factors also play a significant role in shaping the EKC trajectory, influencing the speed and extent of environmental improvements (Jakada, 2022; Toufique, 2024).

In parallel, environmental, social, and governance (ESG) indicators have gained increasing recognition as essential metrics for assessing sustainability performance at both corporate and national levels (Friede et al., 2015; Zhang et al., 2025). The incorporation of ESG factors into economic models has been shown to positively affect environmental outcomes and promote sustainable development (Wang et al., 2023). Within the Gulf region, Alharbi (2024) highlights that ESG reforms make a significant contribution to economic growth in GCC countries, with financial development strengthening this relationship.

Furthermore, the APCO Worldwide and GCC BDI (2022) report indicates that governments in the region are actively committing to carbon neutrality, encouraging companies to integrate ESG criteria into their strategies. However, the macroeconomic implications of ESG adoption, particularly its influence on environmental quality in resource-dependent countries, remain underexplored.

From a theoretical perspective, institutional quality and environmental regulations often embedded in ESG frameworks—serve as mediators that can shift or flatten the EKC. In resource-rich regions such as the broader Persian Gulf, where oil rents remain central to national economies, ESG adoption may play a decisive role in reshaping development paths and enabling sustainable transitions.

2.2. Empirical Review

This section provides an overview of research on the Environmental Kuznets Curve (EKC) for CO_2 emissions, utilizing both panel and time series data, while highlighting the econometric approaches employed to rigorously test the EKC hypothesis.

Panel regression has historically been the predominant method for estimating the EKC, followed by fully modified ordinary least squares (FMOLS). Holtz-Eakin and Selden (1995) conducted the first panel-based EKC estimation across 130 countries (1951-1986), providing evidence of an inverted U-shaped EKC. Panel regression remains the only method in this review that initially demonstrated all forms of the EKC.

Subsequently, FMOLS became widely applied. Apergis and Payne (2009) applied FMOLS to six Central American countries (1971-2004), confirming an inverted U-shaped EKC. Zhang et al. (2017) extended this analysis to ten newly industrialized countries (1971-2013), using FMOLS, OLS, and DOLS methods, all consistently supporting an inverted U-shaped EKC. Alsamara et al. (2018) applied three econometric techniques—FMOLS, pooled mean group (PMG) estimation, and dynamic common correlated effects (DCCE) regression—to empirically estimate an augmented EKC specification, confirming the EKC hypothesis in the long run for GCC countries. Li et al. (2022) applied FMOLS to a panel of developing countries and confirmed an inverted U-shaped EKC, highlighting the turning points at which economic growth begins to reduce CO_2 emissions. Caporin et al. (2024) employed FMOLS to examine Central Asian economies and found robust evidence of an inverted U-shaped EKC, while demonstrating the influence of heterogeneous country characteristics and regional structural differences on the shape and timing of the EKC.

Roca et al. (2001) conducted the first EKC estimation using time series data for Spain (1973-1996) with OLS, finding no evidence of an EKC. Ang (2007) provided the 1st time series evidence of an EKC in France (1960-2000) using the ARDL bounds testing approach. More recently, Acaroğlu et al. (2023) examined Turkey

(1971-2015) with the ARDL bounds test and identified an inverted U-shaped EKC for CO_2 emissions.

Robust testing of the EKC hypothesis requires econometric frameworks capable of capturing both short- and long-run dynamics while accommodating heterogeneous behavior across countries and mixed orders of integration. Methods such as FMOLS, the generalized method of moments (GMM), and panel autoregressive distributed lag (ARDL) models have been extensively applied (Pesaran et al., 1999; Samargandi et al., 2015). Panel ARDL models are particularly advantageous when variables are integrated of order zero or one, allowing estimation of both short-term adjustments and long-term equilibrium relationships. Recent studies, including Manjengwa et al. (2025), have further highlighted the effectiveness of panel ARDL methodologies in analyzing the impacts of environmental policies and ESG performance on CO_2 emissions, capturing both short- and long-term dynamics while accounting for cross-country heterogeneity.

2.3. Research Gap

While the Environmental Kuznets curve (EKC) has been extensively studied across various regions, there remains a significant gap in research explicitly incorporating ESG metrics into EKC models, particularly within the Persian Gulf region. Most prior studies focus primarily on conventional economic and environmental indicators, often neglecting the role of corporate governance, social responsibility, and sustainability practices in shaping the EKC trajectory. Moreover, very few studies investigate how ESG factors may interact with economic growth to influence the turning point of the EKC.

Addressing this gap, the present study is the first to model ESG as a moderating variable through an interaction term with GDP, enabling a direct assessment of its impact on the EKC turning point. Utilizing advanced Panel ARDL-pooled mean group (PMG) econometric techniques, the study captures both short-term dynamics and long-term relationships, offering a comprehensive framework to understand the complex interplay between economic development, ESG performance, and environmental sustainability in the Persian Gulf region. This approach provides novel insights into how integrating ESG considerations can foster resilient and sustainable growth in the region.

2.4. Hypotheses Development

Based on this integrated theoretical and empirical foundation, the following hypotheses are proposed.

- H_1: There exists an inverted U-shaped relationship between economic growth and environmental degradation (EKC hypothesis) in the Persian Gulf region. This hypothesis is supported by both EKC theory and regional empirical evidence (Alsamara et al., 2018; Ali et al., 2023).
- H_2: Higher ESG performance is associated with lower environmental degradation, controlling for economic growth. This hypothesis aligns with studies demonstrating that ESG adoption contributes to improved environmental outcomes (Wang et al., 2023; Alharbi, 2024).
- H_3: ESG performance moderates the relationship between economic growth and environmental degradation, contributing to an earlier and lower EKC turning point. This hypothesis reflects both theoretical insights and empirical findings that governance quality and institutional frameworks significantly shape EKC dynamics (Li et al., 2022; Jakada, 2022).

These hypotheses will be empirically tested using a Panel ARDL-PMG approach, allowing us to capture both long-run equilibrium relationships and short-term dynamics between the variables across the eight selected countries.

3. METHODOLOGY AND ESTIMATION STRATEGY

3.1. Data and Descriptive Statistics

This study investigates the dynamic relationships between environmental degradation, economic growth, energy consumption, and ESG performance in eight countries of the extended Persian Gulf region, including the six GCC member states (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates), as well as Iran and Iraq. The empirical analysis covers the period from 2018 to 2023, depending on data availability. These countries are characterized by their significant reliance on fossil fuel revenues, increasing emphasis on ESG standards, and ongoing structural reforms toward economic diversification and sustainability.

The variables employed are as follows:

- CO_2 emissions per capita (metric tons): A proxy for environmental degradation, sourced from the World Bank's World Development Indicators (WDI).
- Gross domestic product (GDP) per capita (constant 2015 US$): Indicator of economic development, obtained from WDI.
- GDP per capita squared: Included to capture the nonlinear relationship proposed by the Environmental Kuznets Curve (EKC).
- Energy consumption per capita (kg of oil equivalent): serves as a proxy for energy demand and is sourced from the international energy agency (IEA).
- Environmental, social, and governance (ESG) score: Composite index measuring sustainability and governance performance, sourced from Refinitiv and MSCI ESG Direct databases.

Table 1 displays the descriptive statistics of the key variables over the study period (48 observations). The average value of carbon dioxide emissions (LCO_2) is approximately 2.22, with a standard deviation of 0.41, suggesting moderate dispersion around the mean. The distribution is slightly positively skewed (skewness = 0.18), and the Jarque-Bera test confirms the normality of the data with a P = 0.438, which is not statistically significant at the 5% level.

Real GDP per capita (LGDP) and its square ($LGDP^2$) exhibit mean values of 4.32 and 8.64, respectively. Both series are negatively skewed (−0.66) and slightly platykurtic, indicating a flatter distribution than the normal curve. The Jarque-Bera test for these variables gives P-values around 0.093, suggesting marginal deviation from normality, though still acceptable for econometric analysis.

Table 1: Descriptive statistics

Statistics	LCO_2	LGDP	LGDP2	LEC	LESG
Mean	2.223220	4.318716	8.637432	3.944633	1.643788
Median	2.169243	4.440507	8.881015	4.109258	1.641113
Maximum	2.891427	4.947931	9.895862	4.355818	1.810971
Minimum	1.529225	3.475494	6.950988	3.008368	1.492481
Standard deviation	0.407027	0.413086	0.826172	0.400624	0.073409
Skewness	0.187939	−0.666973	−0.666973	−1.116426	0.169278
Kurtosis	2.173241	2.229714	2.229714	2.982610	2.611012
Jarque-Bera	1.649627	4.745503	4.745503	9.971858	0.531862
Probability	0.438317	0.093224	0.093224	0.006833	0.766492
Sum	106.7146	207.2984	414.5967	189.3424	78.90184
Sum Sq. deviation	7.786525	8.020076	32.08030	7.543478	0.253276
Observations	48	48	48	48	48

Source: The authors

Energy consumption (LEC) shows a mean of 3.94, with the highest negative skewness (−1.11) among all variables, indicating a longer left tail. Its Jarque-Bera P-value (0.0068) is below 0.05, indicating a significant deviation from normality, which may require robust estimation methods in further analysis.

Lastly, the share of environmental, social, and governance (LESG) has the lowest dispersion (standard deviation = 0.073) and appears to be the most normally distributed, with a P = 0.766 from the Jarque-Bera test. Overall, the most variables approximately follow a normal distribution.

3.2. Model Specification

Here is how to empirically test each of the three hypotheses using an appropriate econometric specification:

3.2.1. Environmental Kuznets curve (EKC)

Hypothesis: There is an inverted U-shaped relationship between economic growth (GDP) and environmental degradation (e.g., CO_2 emissions).

To test the EKC hypothesis and examine the influence of energy consumption and ESG performance on environmental quality.

Specification:

$$\ln(CO2it) = \alpha i + \beta 1 \ln(GDPit) + \beta 2 [\ln(GDPit)2] + \beta 3 \ln(ECit) + \varepsilon it$$

- αi denotes country-specific fixed effects;
- εit is the error term.

The EKC hypothesis implies $\beta_1>0$ and $\beta_2<0$. Energy consumption is expected to increase emissions ($\beta_3>0$).

3.2.2. Direct effect of ESG performance on pollution

Hypothesis: Better ESG performance is associated with lower pollution levels, regardless of GDP.

Specification:

$$\ln(CO2it) = \alpha i + \beta 1 \ln(GDPit) + \beta 2 [\ln(GDPit)2] + \beta 3 \ln(ECit) + \beta 4\ ESGit + \varepsilon it$$

The better ESG performance is hypothesized to reduce emissions ($\beta 4<0$).

3.2.3. Moderating effect of ESG on the EKC relationship

Hypothesis: ESG performance moderates the relationship between economic growth and pollution. It mitigates the EKC curve (e.g., an earlier turning point).

Specification:

$$\ln(CO2it) = \alpha i + \beta 1 \ln(GDPit) + \beta 2 [\ln(GDPit)2] + \beta 3 \ln(ECit) + \beta 4 \ln ESGit + \beta 5 (\ln(GDPit) \times \ln ESGit) + \beta 6(\ln(GDPit)2 x \ln ESGit) + \varepsilon it$$

β_5 captures how ESG affects the linear impact of GDP, while β_6 reflects whether ESG influences the curvature of the EKC. If β_6 is negative and statistically significant, then a higher ESG score leads to an earlier turning point (i.e., at a lower GDP level).

3.3. Estimation Technique

The empirical model involves dynamic relationships with potential endogeneity and mixed integration orders among variables. To address these challenges, we apply the panel autoregressive distributed lag (Panel ARDL) model estimated via the pooled mean group (PMG) estimator developed by Pesaran et al. (1999).

The PMG estimator offers flexibility by allowing short-run coefficients, error variances, and speed of adjustment to differ across countries, while imposing homogeneity on the long-run coefficients. This approach is particularly appropriate for panels where variables are integrated of order zero or one (I[0] or I[1]) and for capturing both short- and long-term dynamics.

The Panel ARDL model in error-correction form is specified as follows:

$$\Delta\ln(CO2_{it}) = \phi_i\ [\ln(CO2_{it-1}) - \beta_1 \ln(GDP_{it}) + \beta_2 \ln(GDP_{it}) + \beta_3 \ln(EC_{it}) + \beta_4 \ln ESG_{it} + \beta_5 (\ln(GDP_{it} \times \ln ESG_{it}) + \beta_6 (\ln(GDP_{it})^2 \times \ln ESG_{it})]$$

$$+\sum_{j=1}^{p-1}\gamma_{ij}\Delta ln(CO2_{it-j})+\sum_{j=0}^{q-1}\delta_{1ij}\Delta ln(GDP_{it-j})+$$
$$\sum_{j=0}^{q-1}\delta_{2ij}\Delta ln(GDP_{it-j})^2+\sum_{j=0}^{q-1}\delta_{3ij}\Delta ln(EC_{it-j})+$$
$$\sum_{j=0}^{q-1}\delta_{3ij}\Delta ln(EC_{it-j})+\sum_{j=0}^{q-1}\delta_{4ij}\Delta ln(ESG_{it-j})$$
$$+\mu_i+\varepsilon_{it}$$

Where:
- ϕ_i is the error correction speed of adjustment coefficient (expected negative and significant);
- The expression in brackets captures the long-run relationship. The coefficients β_1, β_2, β_3, β_4, β_5, and β_6 represent long-run elasticities and are assumed to be identical across all countries, consistent with the long-run homogeneity assumption.
- δ_{ij} coefficients represent short-run dynamics;
- The constants μ_i are country-specific, capturing fixed effects unique to each country.
- ε_{it} is the error term.

Before estimation, panel unit root tests (e.g., Levin-Lin-Chu, Im-Pesaran-Shin) will be conducted to determine the order of integration. Panel cointegration tests (Pedroni, Kao) will verify the existence of long-run relationships.

3.3.1. Turning point calculation

3.3.1.1. Standard EKC model (without interaction)

In a standard EKC model (without interaction), the level of GDP at which environmental degradation begins to decline, is calculated by deriving the first-order condition and solving for GDP.

$$\text{Turning point} = -\beta_1/(2\cdot\beta_2)$$

3.3.1.2. Log-linear specification

When the EKC is specified in a log-linear form, with all variables expressed in natural logarithms, the turning point is obtained by differentiating the equation with respect to ln(GDP) and solving the resulting first-order condition.

$$d\ln(CO_2)/d\ln(GDP) = \beta_1 + 2\cdot\beta_2\cdot\ln(GDP) = 0$$

$$\ln(GDP) = -\beta_1/(2\cdot\beta_2)^*$$

Thus, the GDP turning point is given by:

$$GDP = \exp(-\beta_1/(2\cdot\beta_2))^*$$

3.3.1.3. Panel ARDL-PMG with ESG interaction

In this extended specification, ESG (environmental, social, and governance) performance is introduced as a moderating variable by interacting it with the squared GDP term. This interaction enables the model to capture how enhanced sustainability practices influence the shape and curvature of the Environmental Kuznets Curve (EKC).

By including ESG as a moderator, the model integrates interaction terms that allow for an examination of how ESG modifies the relationship between GDP and CO_2 emissions. Consequently, the turning point of the EKC becomes conditional on the level of ESG performance.

Within the Panel ARDL framework estimated via the PMG approach, the turning point is calculated based on the long-run equilibrium relationship, which is extracted from the error correction term (specifically, the expression within brackets in the equation). This long-run relationship forms the foundation for determining the turning point, following the same principle as in static models.

Accordingly, the partial derivative of CO_2 emissions with respect to the logarithm of GDP can be expressed as:

$$\partial\ln(CO_2)/\partial\ln(GDP) = \beta_1 + 2\cdot\beta_2\cdot\ln(GDP) + \beta5\cdot\ln(ESG) + 2\cdot\beta6\cdot\ln(GDP)\cdot\ln(ESG)$$

Solving for the turning point gives:

$$\ln(GDP) = -(\beta_1 + \beta_5\cdot\ln(ESG))/[2\cdot(\beta_2 + \beta_6\cdot\ln(ESG))]^*$$

$$GDP = \exp(-(\beta_1 + \beta_5\cdot\ln(ESG))/[2\cdot(\beta_2 + \beta_6\cdot\ln(ESG))])^*$$

This expression shows that the turning point is no longer fixed, but varies with the ESG score.

If $\beta_6 < 0$ and statistically significant, it indicates that higher ESG performance leads to an earlier turning point, meaning that countries with better ESG practices begin to reduce emissions at lower levels of income. This result supports the hypothesis that ESG contributes positively to the environmental transition by accelerating the decoupling between growth and emissions. This confirms the moderating role of ESG in accelerating the environmental transition process.

3.4. Estimation Strategy

To capture both short-run dynamics and long-run relationships, this study employs the Panel Autoregressive distributed lag (panel ARDL) model using the pooled mean group (PMG) estimator. This method accommodates heterogeneity in short-run coefficients and error variances across countries while imposing homogeneity on long-run coefficients, making it suitable for variables integrated of order I(0) and I(1). The PMG-ARDL approach estimates both short-term adjustments and long-term elasticities, with the error correction term capturing the speed of convergence to equilibrium.

Before estimating the dynamic relationships among the variables, it is essential to verify their statistical properties and ensure the appropriateness of the econometric techniques used. This subsection presents the results of the panel unit root tests, including Levin, Lin and Chu (LLC) and Im, Pesaran and Shin (IPS) tests, which examine the stationarity properties of the variables across countries. Ensuring stationarity or identifying the order of integration is crucial to avoid spurious regression results.

Following the unit root tests, the cointegration tests (Pedroni and Kao) are conducted to assess the existence of a long-run equilibrium relationship among the variables. The interpretation of the cointegration test results will guide the choice of the suitable estimation model in the subsequent analysis.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Preliminary Tests

4.1.1. Panel unit root tests

Table 2 presents the results of various panel unit root tests, including Levin, Lin and Chu (LLC), Augmented Dickey-Fuller (ADF), and Phillips-Perron (PP) tests. These tests help determine whether the series are stationary or contain a unit root, thereby establishing the order of integration of the variables.

The unit root tests conducted on the variables LCO_2, LGDP, LEC, and LESG reveal that none of these series are stationary at their levels. While the LLC test often rejects the null hypothesis of a unit root at level, the ADF-Fisher and PP-Fisher tests generally fail to reject it, indicating non-stationarity. However, after taking the first difference of each variable, all three tests consistently reject the presence of a unit root, confirming that the differenced series are stationary. These results suggest that the variables are integrated of order one, I(1). The tests were performed under different model specifications, including individual effects, individual linear trends, and no deterministic components, with the findings remaining robust across these variations.

4.1.2. Cointegration tests

Table 3 presents the results of panel cointegration analyses, including the Kao and Pedroni tests. These procedures assess whether a long-run equilibrium relationship exists among the variables by examining the residuals of the estimated models, thereby confirming the presence of cointegration across the panel.

The ADF statistic on the residuals is −3.7888 with a very low P-value (0.0001), which leads us to reject the null hypothesis of no cointegration. This indicates that there is a cointegrating relationship among the variables, meaning they share a stable long-term equilibrium despite being non-stationary at levels.

The Panel PP and Panel ADF statistics under the "within-dimension" (common AR coefficients) show very low P-values (below 5%), also confirming the presence of cointegration.

Similarly, the "between-dimension" statistics, Group PP and Group ADF, are highly significant with P-values close to zero.

Some statistics like Panel v-Statistic or rho-Statistic are not significant, which is common due to differences in test sensitivities.

Overall, the majority of test statistics indicate that the variables are cointegrated.

The results from the Kao and Pedroni tests provide strong evidence of a long-run equilibrium relationship among LCO_2, LGDP, LEC, and LESG. This supports the use of econometric models that account for cointegration (such as error correction models) to analyze their dynamic interactions.

Cointegration tests assess whether there exists a long-run equilibrium relationship among the studied variables (here LCO_2, LGDP, LEC, and LESG).

Table 2: Panel unit root tests (LLC, ADF, PP)

Variable	Model specification	LLC statistic	LLC P- value	ADF-fisher statistic	ADF-fisher P-value	PP-fisher statistic	PP-fisher P-value
LCO_2	Individual effects and trends	−8.967	0.000	18.249	0.310	36.440	0.003
LCO_2	Individual effects	−3.460	0.000	17.295	0.367	31.084	0.013
LCO_2	None	6.780	1.000	1.521	1.000	0.951	1.000
$D(LCO_2)$	Individual effects and trends	−15.047	0.000	17.983	0.325	31.001	0.014
$D(LCO_2)$	Individual effects	−10.511	0.000	30.775	0.014	41.115	0.001
$D(LCO_2)$	None	−5.402	0.000	45.960	0.000	50.809	0.000
LGDP	Individual effects and trends	−3.434	0.000	4.588	0.998	3.496	1.000
LGDP	Individual effects	−3.453	0.000	15.531	0.486	15.994	0.453
LGDP	None	−6.161	0.000	45.584	0.000	46.443	0.000
D(LGDP)	Individual effects and trends	−3.434	0.000	4.588	0.998	3.496	1.000
D(LGDP)	Individual effects	−3.453	0.000	15.531	0.486	15.994	0.453
D(LGDP)	None	−6.161	0.000	45.584	0.000	46.443	0.000
LEC	Individual effects and trends	−7.541	0.000	19.227	0.257	37.980	0.002
LEC	Individual effects	−4.226	0.000	22.499	0.128	33.167	0.007
LEC	None	4.345	1.000	3.455	1.000	3.113	1.000
D(LEC)	Individual effects and trends	−9.042	0.000	13.376	0.645	24.623	0.077
D(LEC)	Individual effects	−8.571	0.000	32.442	0.009	44.235	0.000
D(LEC)	None	−4.749	0.000	52.603	0.000	53.036	0.000
LESG	Individual effects and trends	−6.777	0.000	16.155	0.442	29.435	0.021
LESG	Individual effects	−2.568	0.005	18.317	0.306	22.825	0.119
LESG	None	1.035	0.850	8.899	0.918	14.107	0.591
D(LESG)	Individual effects and trends	−20.647	0.000	40.026	0.001	53.932	0.000
D(LESG)	Individual effects	−10.793	0.000	36.822	0.002	40.305	0.001
D(LESG)	None	−8.651	0.000	67.210	0.000	65.642	0.000

Source: The authors

4.2. Interpretation of the Panel ARDL Estimation Results

Table 4 provides the long-run and short-run coefficients estimated from the ARDL model. The objective is to analyze the determinants of CO_2 emissions in relation to economic growth, energy use, and sustainability-related governance indicators.

The long-run coefficients provide insightful evidence regarding the drivers of CO_2 emissions in the panel of countries.

- LGDP (Log of GDP per capita) is positive and statistically significant at the 1% level (coefficient = 0.2755; $P < 0.001$), suggesting that economic growth is associated with an increase in CO_2 emissions in the long run.
- $LGDP^2$ (squared log of GDP per capita) is negative and significant at the 5% level (coefficient = −0.4131; P = 0.0122), confirming the existence of an inverted U-shaped Environmental Kuznets Curve (EKC). This implies that after a certain income threshold, further economic growth leads to a reduction in CO_2 emissions.
- LEC (log of energy consumption) is positively associated with CO_2 emissions and highly significant (coefficient = 0.836; $P < 0.001$), which reflects the strong contribution of energy use to environmental degradation in the region.
- LESG (log of ESG index) shows a negative and statistically significant coefficient (coefficient = −1.2887; $P < 0.001$), indicating that stronger environmental, social, and governance (ESG) performance is associated with lower CO_2 emissions. This supports the role of sustainability-oriented governance in mitigating environmental impacts.

Table 3: Panel cointegration tests

Test	Statistic	Value	P-value
Kao residual cointegration test	ADF t-statistic	−3.7888***	0.0001
	Residual variance	0.000288	
	HAC variance	0.000252	
Pedroni residual cointegration test (within-dimension)	Panel v-statistic	−0.1795	0.5712
	Weighted Panel v-statistic	−1.4915	0.9321
	Panel rho-statistic	1.1745	0.8799
	Weighted Panel rho-statistic	0.3634	0.6418
	Panel PP-statistic	−2.5857**	0.0049
	Weighted Panel PP- statistic	−6.8449***	0.0000
	Panel ADF-statistic	−1.9670*	0.0246
	Weighted Panel ADF-statistic	−5.3489***	0.0000
Pedroni residual cointegration test (between-dimension)			
	Group rho-statistic	2.3898	0.9916
	Group PP-statistic	−15.3115***	0.0000
	Group ADF-statistic	−9.0497***	0.0000

Source: The authors

4.2.1. Interaction terms

- lnGDP * lnESG: Negative and significant (−0.078), indicating that the effect of GDP on the dependent variable diminishes when ESG improves.
  For each 1% increase in ESG, the marginal effect of GDP on CO_2 emissions decreases by 0.078% points. Example: If GDP's direct effect on CO_2 is +0.5 (i.e., 1% GDP growth increases CO_2 by 0.5%), then increasing ESG by 10% would reduce that effect by 0.78% points, bringing it down to 0.5 −0.78 = negative effect (net reduction).
- $\ln GDP^2$ * lnESG: The coefficient is also negative (−0.0054) and statistically significant, further confirming the moderating role of ESG in the GDP-CO_2 emissions relationship. In the case of the quadratic term ($\ln GDP^2$), the interpretation focuses on changes in the curvature of the relationship rather than on a direct percentage change in CO_2 emissions. The value −0.0054 indicates that for every 1% increase in ESG, the coefficient of GDP^2 becomes more negative by 0.0054, causing the curve to bend downward more sharply. In practical terms, this accelerates the point at which the GDP-CO_2 trajectory changes direction, thereby lowering the GDP turning point by a measurable margin.

Then, we calculate the turning points corresponding to different ESG values and present them in Table 5, alongside Graph 1, which illustrates how the turning point shifts with varying ESG levels. Table 5 reveals a clear trend: As ESG scores rise, the GDP turning point expressed both in logarithmic and absolute terms significantly decreases. This indicates that better ESG performance lowers the GDP threshold at which environmental degradation begins to decline. In other words, higher ESG levels

Table 4: Panel ARDL-PMG estimation

Variable	Coefficient	Standard error	t-statistic	P-value	Significance
Long-run coefficients					
lnGDP	0.2755	0.1203	2.2901	0.0004	***
$\ln GDP^2$	−0.0306	0.0115	−2.6431	0.0122	***
lnEC	0.836	0.1847	4.5264	0.0001	***
lnESG	−1.2887	0.3033	−4.2489	0.0002	***
lnGDP * InESG	−0.078			0.0341	***
$\ln GDP^2$ * InESG	−0.0054			0.0262	***
Constant (C)	−1.5844	0.398	−3.9812	0.0003	***
Short-run coefficients					
COINTEQ (ECT)	−0.4514	0.1656	−2.72576	0.0001	***

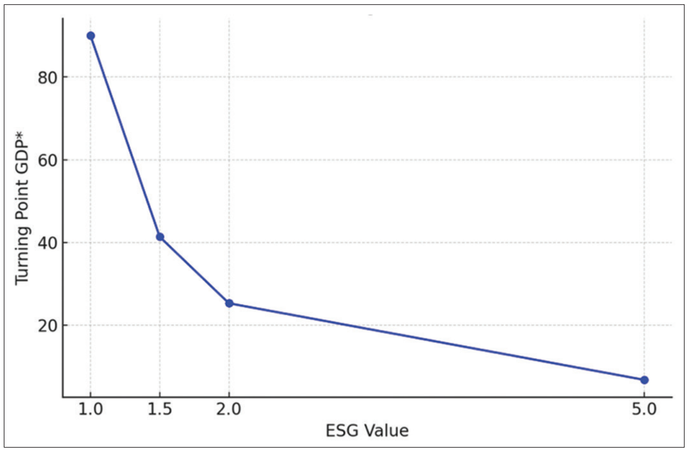
Source: The authors

Table 5: GDP turning point values at different levels of ESG

ESG value	ln (ESG)	Turning point ln (GDP)*	Turning point GDP*
1	0	4.50	90.02
1.5	0.405	3.72	41.35
2	0.693	3.23	25.28
5	1.609	1.91	6.75

Source: The authors

Graph 1: Variation of turning point with environmental, social, and governance values



Source: The authors

bring forward the point where the effect of GDP on the dependent variable changes from positive to negative, occurring at a lower GDP level once ESG is accounted for.

Therefore, ESG acts as a moderating factor on GDP's impact by shifting this turning point, suggesting that improvements in ESG accelerate the onset of beneficial environmental effects relative to economic growth.

Graph 1 visually confirms this relationship, showing a steep decline in the GDP turning point as ESG increases, meaning that enhanced ESG quality causes the GDP level at which adverse effects emerge to drop significantly.

4.2.2. Short-run coefficient

Regarding the short-run dynamics, the error correction term (COINTEQ) is negative and statistically significant (coefficient = −0.4514; $P < 0.001$), confirming the existence of a stable long-run relationship among the variables. The magnitude of this coefficient indicates that approximately 45.14% of any deviation from the long-run equilibrium is corrected within 1 year, implying a relatively rapid adjustment toward equilibrium.

Based on the histogram of the residuals (Graph 2), the distribution appears approximately symmetric and bell-shaped, suggesting normality. This visual impression is confirmed by the Jarque-Bera test, which yields a test statistic of 0.067 and a corresponding $P = 0.967$. Since the P-value exceeds the 5% significance level, we fail to reject the null hypothesis of normality. Additionally, the residuals exhibit minimal skewness (0.095) and a kurtosis value close to 3 (3.06), further supporting the assumption of normality. These findings indicate that the model residuals are normally distributed, validating the appropriateness of the model's specification.

4.3. Discussion and Policy Implications

The empirical findings provide strong evidence supporting the Environmental Kuznets Curve (EKC) hypothesis (H_1) in the expanded Persian Gulf region. The positive and statistically significant coefficient on economic growth (LGDP), along with the negative and significant coefficient on its squared term ($LGDP^2$), confirm the presence of an inverted U-shaped relationship between economic growth and environmental degradation. This validates H_1 and is consistent with prior research, such as Alsamara et al. (2018), Li et al. (2022), Acaroğlu et al. (2023) Caporin et al. (2024) and Toufique, (2024), which documented similar EKC patterns in various contexts.

Regarding Hypothesis 2 (H_2), which posits that higher ESG performance reduces environmental degradation, the results support this assumption. The ESG index (LESG) has a negative and highly significant effect on CO_2 emissions, indicating that stronger ESG practices are associated with lower emissions, even after controlling for economic growth. This finding aligns with recent studies (Wang et al., 2023; Zhang et al., 2025 and Manjengwa et al., 2025) highlighting the positive environmental impact of robust ESG commitments.

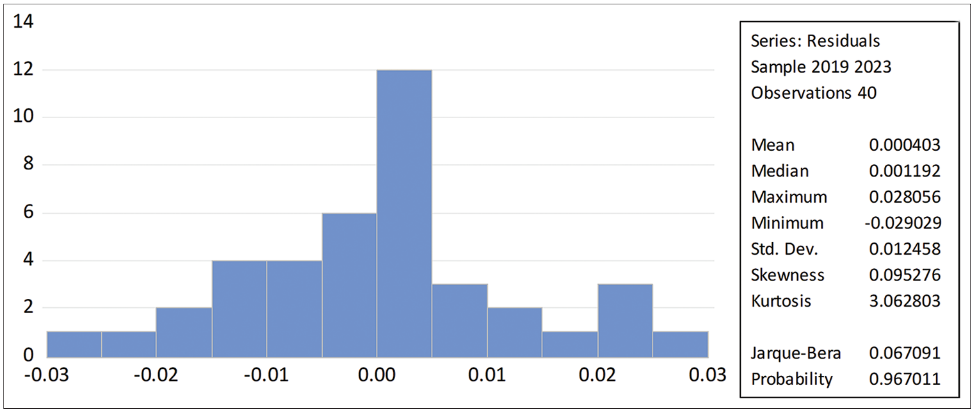
Hypothesis 3 (H_3) proposes that ESG performance moderates the relationship between economic growth and environmental degradation, leading to an earlier and lower EKC turning point. The ARDL results confirm this moderation effect through the significant and negative interaction term between $\ln GDP^2$ and ln ESG (−0.0054). This indicates that higher ESG performance steepens the downward curvature of the GDP–CO_2 relationship, thereby accelerating the point at which CO_2 emissions begin to decline. In practical terms, improvements in ESG lower the GDP level required to reach the EKC turning point.

Furthermore, the significantly negative error correction term (ECT = –0.4514) demonstrates a stable long-run equilibrium relationship. The system corrects nearly 45% of any disequilibrium annually, implying a relatively rapid adjustment, with full convergence expected within approximately 2.2 years.

In summary, all three hypotheses are supported by the empirical evidence. The results not only confirm theoretical expectations but also align closely with contemporary empirical studies, reinforcing the importance of economic growth dynamics and ESG performance in addressing environmental challenges in the Persian Gulf region.

These findings carry important policy implications. Policymakers should integrate ESG principles into national strategies, promote sustainable corporate practices, and invest in green technologies to accelerate emissions reductions and shift the EKC turning point to earlier stages of economic development. Enhancing governance quality and transparency in ESG reporting will strengthen investor

Graph 2: Hystogram of residuals



Source: The authors

confidence and facilitate a transition toward a greener and more sustainable economy.

Overall, the results confirm that embedding ESG considerations within economic and environmental policies is essential for guiding the Persian Gulf region toward a low-carbon, socially responsible, and sustainable growth trajectory.

5. CONCLUSION

This study provides novel empirical evidence on the interplay between economic growth, ESG performance, and environmental degradation in the expanded Persian Gulf region. The results confirm the existence of an Environmental Kuznets Curve (EKC), showing that economic growth initially increases CO_2 emissions but eventually leads to reductions after a certain income threshold (H1). Moreover, higher ESG performance directly mitigates environmental degradation (H_2) and moderates the GDP–CO_2 relationship, accelerating the turning point of the EKC to lower GDP levels (H_3).

By incorporating ESG interactions into a dynamic panel ARDL framework, this study extends the existing literature on sustainable development and environmental governance in the region. The significant error correction term further demonstrates that the system adjusts rapidly toward long-run equilibrium, emphasizing the robustness of the findings.

Overall, the study highlights the critical role of ESG considerations in shaping the environmental outcomes of economic growth, providing a clear analytical basis for both future research and strategic decision-making. It contributes methodologically by modeling ESG as a moderating factor in the EKC, and practically by offering insights into how sustainable governance can accelerate the decoupling of economic growth from environmental degradation.

REFERENCES

Acaroğlu, H., Kartal, H.M., García Márquez, F.P. (2023), Testing the environmental Kuznets curve hypothesis in terms of ecological footprint and CO_2 emissions through energy diversification for Turkey. Environmental Science and Pollution Research International Environ, 30, 63289-63304.

Alharbi, F. (2024), The impact of ESG reforms on economic growth in GCC countries: The role of financial development. Sustainability, 16(24), 11067.

Ali, A., Radulescu, M., Balsalobre-Lorente, D. (2023), A dynamic relationship between renewable energy consumption, nonrenewable energy consumption, economic growth, and carbon dioxide emissions: Evidence from Asian emerging economies. Energy and Environment, 34(8), 3529-3552.

Alsamara, M., Mrabet, Z., Saleh, A.S., Anwar, S. (2018), The environmental Kuznets curve relationship: A case study of the gulf cooperation council region. Environmental Science and Pollution Research International, 25(33), 33183-33195.

Ang, J.B. (2007), CO_2 emissions, energy consumption, and output in France. Energy Policy, 35(10), 4772-4778.

APCO Worldwide GCC Board Directors Institute. (2022), ESG in the GCC Region: Accelerating Integration. Available from: https://gccbdi.org

Apergis, N., Payne, J.E. (2009), CO_2 emissions, energy usage, and output in Central America. Energy Policy, 37(8), 3282-3286.

Baydoun, H., Aga, M. (2021), The effect of energy consumption and economic growth on environmental sustainability in the GCC Countries: Does financial development matter? Energies, 14(18), 1-17.

Caporin, M., Cooray, A., Kuziboev, B., Yusubov, I. (2024), New insights on the environmental Kuznets curve (EKC) for Central Asia. Empirical Economics, 66, 2335-2354.

Dinda, S. (2004), Environmental Kuznets curve hypothesis: A survey. Ecological Economics, 49(4), 431-455.

Friede, G., Busch, T., Bassen, A. (2015), ESG and financial performance: Aggregated evidence from more than 2000 empirical studies. Journal of Sustainable Finance and Investment, 5(4), 210-233.

Grossman, G.M., Krueger, A.B. (1995), Economic growth and the environment. The Quarterly Journal of Economics, 110(2), 353-377.

Holtz-Eakin, D., Selden, T.M. (1995), Stoking the fires? CO_2 emissions and economic growth. Journal of Public Economics, 57(1), 85-101.

Jakada, A.H., Mahmoud, S., Haron, N.F., Danmaraya, I.A. (2022), Revisiting the environmental Kuznet curve in Africa: The interactive role of financial development in sustainable environment. Journal of Sustainability Science and Management, 17(4), 1-20.

Józwik, B., Kyophilavong, P., Dash, A.K., Gavryshkiv, A.V. (2022), Revisiting the environmental Kuznets curve hypothesis in South Asian Countries: The role of energy consumption and trade openness.

Energies, 15(22), 1-20.

Li, W., Qiao, Y., Li, X., Wang, Y. (2022), Energy consumption, pollution haven hypothesis, and environmental Kuznets curve: Examining the environment-economy link in belt and road initiative countries. Energy, 239, 122559.

Manjengwa, E., Dunga, S.H., Mncayi-Makhanya, P., Makhalima, J. (2025), ESG performance and economic growth in BRICS countries: A dynamic ARDL panel approach. Sustainability, 17(14), 6334.

Pesaran, M.H., Shin, Y., Smith, R.J. (1999), Pooled mean group estimation of dynamic heterogeneous panels. Journal of the American Statistical Association, 94(446), 621-634.

Roca, J., Padilla, E., Farré, M., Galletto, V. (2001), Economic growth and atmospheric pollution in Spain: Discussing the environmental Kuznets curve hypothesis. Ecological Economics, 39(1), 85-99.

Samargandi, N., Fidrmuc, J., Ghosh, S. (2015), Is the environmental Kuznets curve hypothesis valid? A review of the literature and empirical evidence. Energy Economics, 51, 434-446.

Saqib, N. (2018), Greenhouse gas emissions, energy consumption and economic growth: Empirical evidence from gulf cooperation council countries. International Journal of Energy Economics and Policy, 8(6), 392-400.

Stern, D. I. (2004), The rise and fall of the environmental Kuznets curve. World Development, 32(8), 1419-1439.

Toufique, M.M.K. (2024), The relationship between institutional quality, industry, energy sources and environmental quality in Bangladesh: Insights from ARDL analysis. Asian Journal of Empirical Research, 14(4), 84-95.

Wang, J., Yu, J., Zhong, R. (2023), Country environmental, social and governance performance and economic growth: The international evidence. Accounting and Finance, 63, 3911-3941.

Zhang, S., Liu, X., Bae, J. (2017), Does trade openness affect CO_2 emissions: Evidence from ten newly industrialized countries? Environmental Science and Pollution Research, 24, 17616-17625.

Zhang, Y., Ban, Q., Li, J. (2025), Navigating environmental uncertainty: The role of ESG performance in driving firm-level high-quality development. Sustainability, 17, 1947.