




Paper Type: Original Article

The Impact of Green Technology and Industrialization on Environmental Performance in Oil-Producing Countries: A Dynamic ARDL Approach

Seyed Fakhreddin Fakhrosseini^{1*} , Santosh Kumar Sahu²

¹ Department of Management and Accounting, Karaj Branch, Islamic Azad University, Karaj, Iran; sf.fakhrosseini@iau.ac.ir.

² Department of Humanities and Social Sciences, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India; santosh@iitm.ac.in.

Citation:

Received: 12 April 2025
Revised: 29 Jun 2025
Accepted: 12 August 2025

Fakhrosseini, S. F., & Sahu, S. K. (2025). The impact of green technology and industrialization on environmental performance in oil-producing countries: A dynamic ARDL approach. *Innovations in Environmental Economics*, 1(3), 207-221.


Abstract


This study investigates the dynamic effects of industrialization and green technology on environmental performance in 13 oil-producing countries in the Middle East and North Africa (MENA) region over the period 2005–2025. Using panel data and the Autoregressive Distributed Lag (ARDL) approach, both short-run and long-run relationships among the variables are examined. The empirical findings confirm the existence of a long-run equilibrium relationship between the study variables. The results indicate that industrialization exerts a strong, long-term detrimental effect on environmental performance, whereas green technology has a positive but relatively weak effect. Similar patterns are observed in the short run: industrialization negatively affects environmental performance, while green technology positively affects it. In contrast, trade competitiveness, human development, and urbanization do not exhibit statistically significant effects. The error-correction term suggests that approximately 10% of short-run disequilibrium is corrected in each period, indicating a relatively slow adjustment toward long-run equilibrium. The findings imply that industrialization in oil-producing economies remains predominantly pollution-intensive due to the abundance and low cost of fossil fuels. At the same time, the limited penetration of green technologies has constrained their mitigating impact on environmental degradation. Accordingly, the study recommends adopting green industrialization policies, accelerating the transition to renewable energy, attracting environmentally friendly foreign direct investment, strengthening human capital, reforming fossil fuel subsidy systems, and enhancing regional environmental cooperation.


Keywords: Climate change, Oil-producing countries, Industrialization, Green technology, Environmental performance.

1 | Introduction

In recent decades, the paradigm of sustainable development has become a central pillar of global economic and political discourse [1], [2]. The fundamental challenge of this paradigm lies in balancing economic growth, social equity, and environmental protection [3]. Nevertheless, growing evidence suggests that traditional

 Corresponding Author: sf.fakhrosseini@iau.ac.ir

 <https://doi.org/10.48313/iee.v1i3.61>

 Licensee System Analytics. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0>).

patterns of economic growth, primarily dependent on the excessive exploitation of natural resources and fossil fuels, have imposed intolerable pressure on global ecosystems. Climate change, biodiversity loss, and widespread air and water pollution are among the direct consequences of this unsustainable development model, posing serious threats to the long-term survival of human societies [4], [5]. In this context, the transition toward a green, low-carbon economy is no longer merely an option but a strategic necessity for ensuring a secure and prosperous future.

Within this global landscape, oil-producing countries face a unique combination of challenges and opportunities. The economies of these countries have historically and structurally depended on oil and gas exports, which are the primary drivers of greenhouse gas emissions and global warming. This excessive dependence, commonly referred to in the economic literature as the "Resource Curse", has rendered these economies highly vulnerable to fluctuations in global energy prices and has often hindered the development of other productive sectors [6]. Consequently, these countries face a "dual challenge": on the one hand, they urgently need to diversify their economies and reduce reliance on oil revenues; on the other hand, they are expected to fulfill their environmental responsibilities by lowering their carbon footprints and improving environmental performance.

One of the principal pathways toward economic diversification is industrialization. Expanding the industrial sector can contribute to employment generation, growth in non-oil GDP, and technological advancement. However, the process of industrialization in oil-producing countries has frequently followed an environmentally hazardous trajectory. Due to access to inexpensive and heavily subsidized energy, the industries established in these economies, such as petrochemicals, steel, and cement, tend to be highly energy-intensive and polluting. As a result, although industrialization is essential for economic growth, it may simultaneously exacerbate environmental degradation, increase pollutant emissions, and weaken environmental performance indicators [7]. This contradictory relationship has made industrialization a double-edged sword in the pursuit of sustainable development in oil-producing economies.

In response to this potentially destructive force, green technology has emerged as a key solution for decoupling economic growth from environmental degradation. Green technology encompasses a broad spectrum of innovations, including renewable energy sources (such as solar and wind energy), energy-efficiency technologies, waste management systems, and cleaner production processes. Investment in this field not only contributes to reducing greenhouse gas emissions and improving air and water quality but can also serve as a new engine of economic growth, job creation, and international competitiveness [8]. Owing to substantial oil revenues, oil-producing countries possess significant financial capacity to undertake large-scale investments in green technology infrastructure. However, obstacles such as path dependency, extensive fossil fuel subsidies, and the absence of coherent policy frameworks have slowed the transition toward a green economy in these countries [9].

To comprehensively evaluate a country's environmental status, a composite indicator such as the Environmental Performance Index (EPI) is essential. Developed by Yale and Columbia Universities, the EPI is a multidimensional index that assesses environmental health and ecosystem vitality using a wide range of indicators [10]. Unlike one-dimensional measures such as CO₂ emissions, the EPI provides a more comprehensive picture of a country's environmental efforts and policy outcomes, making it a powerful tool for policymakers.

Despite the critical importance of this issue, a clear research gap remains in the existing literature. Many previous studies have examined the relationship between economic growth and environmental degradation within the framework of the Environmental Kuznets Curve (EKC) hypothesis, or have focused solely on the impact of a single variable, such as renewable energy consumption, on CO₂ emissions [11]. However, relatively few studies have investigated the dynamic and interactive effects of two key and opposing forces, namely industrialization (as a source of environmental pressure) and green technology (as a driver of environmental improvement), on a comprehensive performance indicator such as the EPI, particularly within

the unique context of oil-producing countries. Furthermore, the effects of these variables may differ across the short and long runs, thereby necessitating a dynamic econometric framework.

Accordingly, this study seeks to address this research gap. The central research question is as follows: Given the distinctive economic structures of oil-producing countries, what are the dynamic short- and long-run effects of industrialization and green technology investment on the EPI?

2 | Literature Review and Research Background

The relationship between industrialization, technology, and the environment is highly complex and multidimensional, and has been examined through various economic, managerial, and sociological perspectives. Historically, industrialization has largely been regarded as a primary driver of environmental degradation. However, with the emergence of green technologies, this paradigm has gradually evolved. The following section outlines the major theoretical frameworks that explain this relationship.

2.1 | Environmental Kuznets Curve

The EKC hypothesis is among the most prominent theories in environmental economics. According to this framework, the relationship between economic growth, of which industrialization is a major engine, and environmental degradation follows an inverted U-shaped pattern. In the early stages of economic development and industrialization, environmental pollution intensifies as production growth is prioritized and environmental externalities are neglected. However, once a certain income threshold is reached, countries and industries gain greater capacity and willingness to invest in cleaner technologies and implement stricter environmental regulations, leading to improved environmental performance and declining pollution levels [12]. Within this framework, green technology acts as a catalyst. The adoption of green technologies can shift the turning point of the EKC to the left, enabling countries to achieve sustainable development with lower levels of environmental degradation.

2.2 | The Porter Hypothesis

The Porter Hypothesis, proposed by Michael Porter, challenges the traditional view that environmental regulations necessarily impose costs and reduce competitiveness. According to this hypothesis, stringent yet well-designed environmental regulations can stimulate innovation within firms. Such innovations, often manifested as green technologies, not only reduce pollution but may also increase productivity, lower production costs through resource and energy efficiency, and create competitive advantages [13]. Accordingly, industrialization accompanied by effective environmental regulations can become a driving force behind the adoption of green technology. In turn, green technology enhances both environmental and economic performance.

2.3 | Resource-Based View

The Resource-Based View (RBV) argues that sustainable competitive advantage stems from a firm's valuable, rare, inimitable, and non-substitutable resources and capabilities. Hart [14] extended this perspective into the environmental domain through the concept of the "Natural-RBV." From this standpoint, capabilities related to green technology, such as proactive pollution management, sustainable product design, and life-cycle monitoring, can be regarded as strategic resources. Firms that invest in developing these capabilities during the industrialization process are more likely to improve their environmental performance while simultaneously gaining competitive advantages through market differentiation, enhanced brand reputation, and reduced legal and regulatory risks.

2.4 | Institutional Theory

Institutional Theory explains why organizations operating within a common institutional environment gradually become similar over time, a phenomenon known as "isomorphism" [15]. According to this Theory,

organizations are subject to institutional pressures that encourage them to adopt specific structures and practices to gain legitimacy and social acceptance. These pressures can be categorized into three types:

- I. Coercive pressures: arising from governmental laws and regulations that require firms to comply with environmental standards and adopt cleaner technologies.
- II. Mimetic pressures: whereby firms imitate the strategies and technologies of successful industry leaders to reduce uncertainty. If leading firms successfully implement green technologies, others are likely to follow.
- III. Normative pressures: originating from professional norms, social expectations, customers, Non-Governmental Organizations (NGOs), and public opinion, all of which encourage firms to adopt environmentally responsible practices and green technologies.

Institutional Theory effectively explains how industrialization in the contemporary world is increasingly evolving toward "green industrialization" under the influence of these institutional pressures. Collectively, these theoretical frameworks demonstrate that the relationship between industrialization and environmental performance is neither linear nor exclusively negative. While conventional industrialization may intensify environmental degradation, as suggested by the upward phase of the EKC, the emergence of green technology as a key mediating factor has the potential to fundamentally transform this relationship. The Porter Hypothesis and the RBV provide economic and strategic rationales for adopting green technologies, whereas Institutional Theory highlights the social and regulatory forces shaping this transition.

Recent empirical studies further support these theoretical arguments. Ullah and Ozturk [16], in a study investigating the role of green finance in accelerating environmental sustainability with emphasis on industrial structure and green innovation, employed panel econometric models and found that green finance significantly reduces pollutant emissions by financing green innovation projects and facilitating the transition toward sustainable industrial structures. Their findings identified green financial institutions and instruments as essential complements to technological and industrial policies. Similarly, Zhang and Liu [17] used advanced data analysis techniques and case-study approaches in their study on the nexus between artificial intelligence, green technological innovation, and industrial environmental performance. Their results demonstrated that artificial intelligence can substantially improve environmental performance through optimizing production processes, reducing energy consumption, and accelerating green innovation cycles. They concluded that AI functions as a transformative general-purpose technology capable of supporting low-carbon industrialization. Mushi [18] examined how green technological innovation affects the environmental performance of industrial firms. The results indicate a strong positive association between sustainability strategies and firm performance, emphasizing the value of embedding sustainable practices within organizational operations. Although green innovation has a direct and positive effect on firm performance, it does not play a significant moderating role in the relationship between sustainability strategies and organizational performance.

Likewise, Ahmed et al. [19] showed that green innovation plays a central and transformative role in enhancing both environmental and organizational performance. Green product and process innovations significantly drive overall green innovation, which in turn leads to improved sustainability outcomes and firm performance. While human resource practices do not show a strong moderating effect, management commitment significantly strengthens the impact of green innovation on organizational performance. Overall, the study underscores that institutionalizing green innovation, supported by strong managerial commitment, is key to achieving sustainable organizational success. Li and Shafique [20] conducted a cross-country panel-data analysis to examine the impact of green industrial policies on technological innovation and sustainable development. Their findings suggested that policies such as clean technology subsidies and pollution standards are strong drivers of green innovation and environmental improvement. Nevertheless, the effectiveness of such policies depends heavily on institutional quality and technological absorptive capacity.

Among studies conducted in 2023, Awan et al. [21] explored the role of digitalization as a modern dimension of industrialization in promoting green industrialization. Drawing on the Technology Acceptance Model (TAM), they demonstrated that digitalization can enhance resource efficiency and reduce waste, thereby facilitating low-carbon industrialization. Similarly, Yi et al. [22] showed that the introduction of FDI has a

significant positive effect on green technology progress, while the moderating effect of trade openness weakens the positive effect, which has a negative impact on green technology progress. Ren et al. [23] analyzed the role of green technology in the relationship between industrial agglomeration and eco-efficiency using spatial and panel-data methods. Their results revealed that while industrial agglomeration may initially increase pollution, the presence of green technology can reverse this relationship and improve eco-efficiency. Green technology was therefore identified as a crucial moderating variable capable of offsetting the adverse environmental effects of industrial concentration. Wang and Chen [24] examined the effects of the digital economy and industrial upgrading on green total factor productivity through spatial econometric analysis. Their study concluded that the digital economy contributes to green productivity by facilitating industrial upgrading and reducing informational inefficiencies. Sarfraz et al. [25], focusing on the manufacturing sector, investigated the role of Corporate Social Responsibility (CSR) and green technology in environmental performance using firm-level panel data. Their findings indicated that CSR alone has a limited influence on environmental improvement; however, when combined with investments in green technology, it creates significant synergistic effects in reducing emissions and enhancing resource efficiency. They argued that manufacturing firms seeking green competitive advantages should integrate CSR strategies with green technological innovation.

AppiahTwum and Long [26], in a study of Asia-Pacific countries, demonstrated that human capital contributes positively to environmental performance convergence. In contrast, trade competitiveness has mixed effects, depending on scale, composition, and technological impacts. Their conclusions emphasized the importance of strengthening human capital, enforcing stricter environmental regulations within international competition, and pursuing continuous green industrialization. Hao [18], through a panel-data analysis of selected countries, found that the impact of economic variables on climate change varies according to countries' income levels. In high-income economies, industrialization increases pollution while foreign direct investment reduces it, supporting the "Pollution Halo" hypothesis.

In contrast, both factors intensify pollution in low-income countries. The study also found that renewable energy generally reduces environmental pollution, although this effect is weaker in low-income economies. Within the domestic literature, Niroomand et al. [27] examined the effect of environmental orientation on sustainable performance, considering the mediating roles of green supply chain management and green innovation as well as the moderating role of institutional pressure. Using structural equation modeling and data collected from employees of Sepahan Battery Industrial Complex, they found that environmental orientation significantly improves sustainable performance. At the same time, institutional pressures strengthen the relationships between environmental orientation, green supply chain practices, and green innovation.

Similarly, Heidari Ayneh et al. [28] investigated the effect of production agglomeration on the green economic efficiency of industrial workshops with 10 or more employees across 11 industrial sectors during 2011–2021. Using the SBM approach to measure green efficiency, they found that the beverage industry had the highest efficiency, whereas the clothing and metal industries performed poorly. Production agglomeration negatively affected green efficiency, while human capital and infrastructure development had positive impacts. Their findings also indicated that environmental regulations were ineffective and technological innovation had no statistically significant impact. Furthermore, Fathi et al. [29] examined the effect of CSR on environmental performance with emphasis on the mediating roles of green transformational leadership and green capability. Using SmartPLS and survey data from industrial firms in Qom Industrial Town, they found that CSR positively and significantly influences environmental performance through green leadership and green capabilities. Their study highlighted the importance of strengthening CSR practices and promoting green transformational leadership to improve firms' environmental outcomes. Overall, the reviewed literature emphasizes the critical roles of human capital, green capabilities, CSR, and institutional frameworks in achieving green efficiency and sustainable performance. However, several research gaps remain.

A systematic review of prior studies reveals that most existing research has focused on the role of macroeconomic variables, renewable energy consumption, and green technological innovation in improving environmental performance. Nevertheless, the present study contributes to the literature in several important ways. First, most international studies [16–18] primarily examine green innovation and environmental performance at the level of large firms or developed economies. In contrast, this study focuses specifically on oil-producing countries within the MENA region, offering a context-sensitive analysis that remains underexplored in the literature. Second, although some domestic studies, such as Heidari Ayneh et al. [28], have investigated production agglomeration and green efficiency, their findings regarding the insignificant role of technological innovation contradict many international studies [20]. This inconsistency suggests that structural and institutional characteristics specific to oil-dependent economies, such as ineffective environmental regulations, technological constraints, and fossil-fuel-based industrial structures, may hinder the successful implementation of internationally recognized green development pathways. Therefore, the primary research gap addressed by this study is the limited number of investigations that simultaneously examine industrialization and green technology within a unified dynamic framework, while considering both short- and long-run effects on environmental performance in oil-producing countries. This study seeks to fill this gap by providing empirical evidence from a dynamic ARDL framework tailored to the specific economic structure of oil-producing economies in the MENA region. Based on the theoretical foundations and findings of previous studies, the conceptual model of the present study is schematically illustrated in Fig. 1, showing the impact of industrialization and green technology on environmental performance in oil-producing countries.

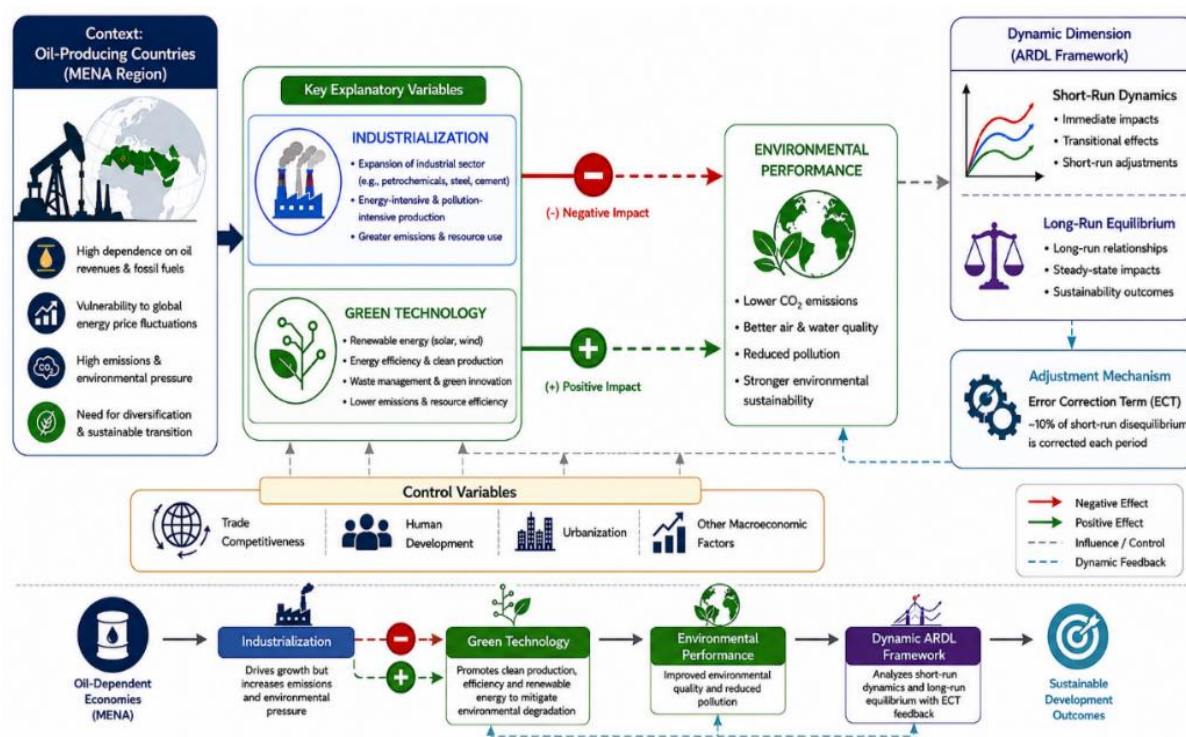


Fig. 1. Conceptual model of the study.

3 | Research Methodology

This study is conducted quantitatively, employing panel data analysis. The statistical population consists of oil-producing countries in the Middle East and North Africa (MENA) region. Using a systematic elimination approach based on data availability, the final sample includes 13 countries: the United Arab Emirates, Bahrain, Algeria, Iraq, Iran, Jordan, Kuwait, Morocco, Egypt, Oman, Saudi Arabia, Syria, and Tunisia. The study covers the period from 2005 to 2025. The required data were collected through documentary and library-based methods from reliable international databases. The primary data sources include the World Bank for the

variables CE, RE, IND, FDI, TRO, and GDP, and the United Nations Development Programme (UNDP) for the Human Development Index (HDI). All variables were compiled into a balanced panel of 13 countries over the study period. Based on the model developed by Appiah Twum and Long [26], the study's dependent variable is environmental performance (EE), measured by carbon dioxide emissions. The independent variables include trade competitiveness (Trade), green technology (Green), human development (Human Capital), industrialization (Industry), and urbanization (Urb).

To examine both the short-run and long-run relationships among the variables, the Autoregressive Distributed Lag (ARDL) approach was employed. The baseline model of the study is specified as follows:

$$\Delta EE_t = \alpha_i + \sum_{j=0}^p \beta_{1j} \Delta EE_{t-j} + \sum_{j=0}^q \beta_{2j} \Delta Trade_{t-j} + \sum_{j=0}^q \beta_{3j} \Delta Green_{t-j} + \sum_{j=0}^q \beta_{4j} \Delta HumanCapital_{t-j} + \sum_{j=0}^q \beta_{5j} \Delta Industry_{t-j} + \sum_{j=0}^q \beta_{6j} \Delta Urb_{t-j} + \varepsilon_{it} \quad (1)$$

Following confirmation of a long-run relationship through the Bounds Test, the short-run and long-run coefficients were estimated. Furthermore, the Error Correction Model (ECM) was applied to determine the speed of adjustment toward the long-run equilibrium.

4 | Data and Results

4.1 | Descriptive Statistics

The descriptive statistics of the research variables are presented in *Table 1*. The findings indicate that the environmental performance variable (E), with a mean of 0.44 and a standard deviation of 0.22, exhibits relatively moderate dispersion. Trade competitiveness (TRAD), with a mean of 0.38 and a minimum value of 0.001, demonstrates the largest relative range of variation among the variables. Green technology (GREEN), with a mean of 4.66 and a standard deviation of 0.76, shows a relatively symmetric distribution. Human development (HUMAN), with a mean of 3.35 and a standard deviation of 0.39, exhibits the lowest degree of dispersion. Meanwhile, industrialization (INDUSTRY), with a mean of 8.04 and a standard deviation of 2.67, and Urbanization (URB), with a mean of 8.13 and a standard deviation of 3.58, display the highest degree of heterogeneity across the oil-producing countries, reflecting substantial structural differences in industrial development and population distribution patterns among these economies.

Table 1. Descriptive statistics of variables in oil-producing countries

Variable	Symbol	Mean	Median	Maximum	Minimum	Std. Dev.
Environmental Performance	E	0.44	0.36	0.98	0.17	0.22
Trade Competitiveness	TRAD	0.38	0.35	0.83	0.001	0.21
Green Technology	GREEN	4.66	4.45	6.86	3.46	0.76
Human Development	HUMAN	3.35	3.25	3.94	2.66	0.39
Industrialization	INDUSTRY	8.04	7.63	9.43	6.33	2.67
Urbanization	URB	8.13	7.18	16.98	3.27	3.58

Source: Research Findings

4.2 | Unit Root Test

To examine the stationarity properties of the variables and determine the appropriate estimation approach, the Fisher unit root test, which combines the p-values from individual ADF tests across cross-sections, was employed. The null hypothesis of the test assumes the presence of a unit root (non-stationarity). The results reported in *Table 2* indicate that the variables GDP, FDI, and IND are stationary at the 5% significance level, as their probability values are below 0.05. In contrast, CE, RE, HDI, and TRO are found to be non-stationary, as their p-values exceed the 0.05 threshold. Therefore, the model contains a mixture of I(0) and I(1) variables. This condition justifies the use of estimation techniques such as the ARDL model or Fully Modified Ordinary

Least Squares (FMOLS), as these methods can accommodate variables integrated at different orders of integration.

Table 2. Results of the unit root test.

Variables	Fisher Test	Probability	Result
E	354.07	0.0000	Stationary
TRAD	234.683	0.0015	Stationary
GREEN	607.855	0.0000	Stationary
HUMAN	629.021	0.0000	Stationary
INDUSTRY	541.083	0.0000	Stationary
URB	310.112	0.0002	Stationary

Source: Research Findings

4.3 | Short-Run and Long-Run Effects Using the ARDL Approach

In this section, the ARDL (1,0,1,1,0) model is employed to analyze the short-run and long-run dynamics of environmental performance (EE), trade competitiveness (TRAD), green technology (GREENT), human development (HDI), industrialization (INDUSTRY), and urbanization (URB).

4.3.1 | Short-run effects

Table 3 presents the estimated short-run coefficients. The lagged environmental performance variable exhibits a negative and statistically significant coefficient (-0.10), suggesting that improvements in environmental performance reduce the dependent variable in the short run. Green technology with one lag has a positive and significant coefficient (0.17), indicating a favorable short-run effect. Conversely, industrialization with a one-year lag shows a negative, statistically significant coefficient (-1.94), suggesting that increased industrialization reduces environmental performance in the short term. The first differences in green technology and industrialization both display strong negative, highly significant coefficients (-4.99 and -6.88 , respectively), indicating substantial short-run adjustment effects. In contrast, TRAD, HDI, and URB do not exhibit statistically significant short-run impacts, as their probability values exceed the 0.05 significance level. The adjusted coefficient of determination (Adjusted $R^2 = 0.36$) indicates that approximately 36% of the variation in the dependent variable is explained by the model's explanatory variables. Furthermore, the Durbin–Watson statistic (2.05) confirms the absence of autocorrelation in the residuals.

Table 3. Short-run estimation results.

Variable	Coefficient	t-Statistic	Probability
EE(-1)*	-0.10	-3.09	0.03
TRAD**	0.03	0.83	0.04
GREENT(-1)	0.17	2.44	0.07
HDI**	0.001	0.28	0.01
INDUSTRY(-1)	-1.94	-2.38	0.81
URB**	0.10	0.50	0.19
D(GREENT)	-4.99	-3.40	1.47
D(INDUSTRY)	-6.88	-8.98	0.77
Akaike Information Criterion = 2.96		$R^2 = 0.38$	
Schwarz Criterion = 3.08		Adjusted $R^2 = 0.36$	
Hannan–Quinn Criterion = 3.01		F-statistic = 17.7	
Durbin–Watson Statistic = 2.05		Prob(F-statistic) = 0.0000	

Source: Research Findings

4.3.2 | Long-run effects

Table 4 reports the results of the Bounds Test used to determine the existence of a long-run equilibrium relationship among the variables. The calculated F-statistic is 5.81, which exceeds the upper critical bound at the 1% significance level (4.21). Therefore, the null hypothesis of no long-run relationship is rejected, confirming the presence of a stable long-run equilibrium relationship among the study variables.

Table 4. Bounds test results.

Significance Level	Lower Bound	Upper Bound	F-statistic
10%	2.81	2.93	5.81
5%	2.14	3.34	
1%	2.82	4.21	

Source: Research Findings

The long-run estimation results reported in *Table 5* indicate that green technology has a positive, statistically significant coefficient (1.62), suggesting that increases in green technology improve environmental performance in the long run. In contrast, industrialization has a strong, highly significant negative coefficient (-18.99), indicating a substantial adverse effect on environmental performance over time. Meanwhile, trade competitiveness (TRAD), human development (HDI), and urbanization (URB) do not exert statistically significant long-run effects, as their p-values remain above the conventional 0.05 significance threshold.

Table 5. Long-Run Estimation Results

Variable	Coefficient	t-Statistic	Probability
TRAD	0.29	0.82	0.41
GREENT(-1)	1.62	2.23	0.03
HDI	0.03	0.28	0.78
INDUSTRY(-1)	-18.99	-3.48	0.00
URB	0.95	0.54	0.59

Source: Research Findings

4.4 | Error Correction Model

Table 6 reports the error correction coefficient, which measures the speed of adjustment toward the long-run equilibrium. The coefficient of the error correction term, $\text{CointEq}(-1)$, is -0.10 and statistically significant. The negative sign confirms the presence of a valid error-correction mechanism. Specifically, approximately 10% of short-run disequilibrium is corrected during each period, indicating that the system gradually converges toward its long-run equilibrium path.

Table 6. ECM Results

Variable	Coefficient	t-Statistic	Probability
$\text{CointEq}(-1)^*$	-0.10	-4.98	0.000

Source: Research Findings

4.5 | Diagnostic Tests

The diagnostic test results indicate that the estimated model does not suffer from econometric problems. In the LM autocorrelation test, the probability values associated with both the F-statistic (0.09) and Obs*R-squared statistic (0.09) exceed the 0.05 significance level. Therefore, the null hypothesis of no serial correlation cannot be rejected, implying that the residuals are uncorrelated. Similarly, the ARCH heteroskedasticity test reports probability values of 0.55 for both statistics, confirming the null hypothesis of homoskedasticity. Thus, the residuals' variance remains constant over time, and no heteroskedasticity problem arises. Overall, these findings confirm the statistical validity and reliability of the estimated model.

Table 7. Diagnostic test results.

Test	Criterion	Statistic	Probability	Result
LM Autocorrelation Test	F-statistic	2.36	0.09	No Autocorrelation
	Obs*R-squared	4.84	0.09	No Autocorrelation
ARCH Heteroskedasticity Test	F-statistic	0.34	0.55	No Heteroskedasticity
	Obs*R-squared	0.34	0.55	No Heteroskedasticity

Source: Research Findings

4.6 | Structural Stability Tests

To assess the stability of the estimated coefficients over the study period and ensure the absence of structural changes in the model, the CUSUM (Cumulative Sum of Recursive Residuals) and CUSUMSQ (Cumulative Sum of Squares of Recursive Residuals) tests were applied. These tests identify systematic changes in regression coefficients over time. The CUSUM test results indicate that the blue line representing the cumulative statistic remains within the 95% confidence bounds throughout the entire study period. Therefore, the null hypothesis of coefficient stability cannot be rejected, indicating that the estimated model parameters remain stable over time. Similarly, the CUSUMSQ test, which is more sensitive to sudden changes in residual variance, indicates that the cumulative squared residuals remain within the critical bounds throughout the period. Consequently, no evidence of structural instability or variance inconsistency is observed, further supporting the robustness and stability of the estimated model. The main empirical findings of the study are visually summarized in Fig. 2.

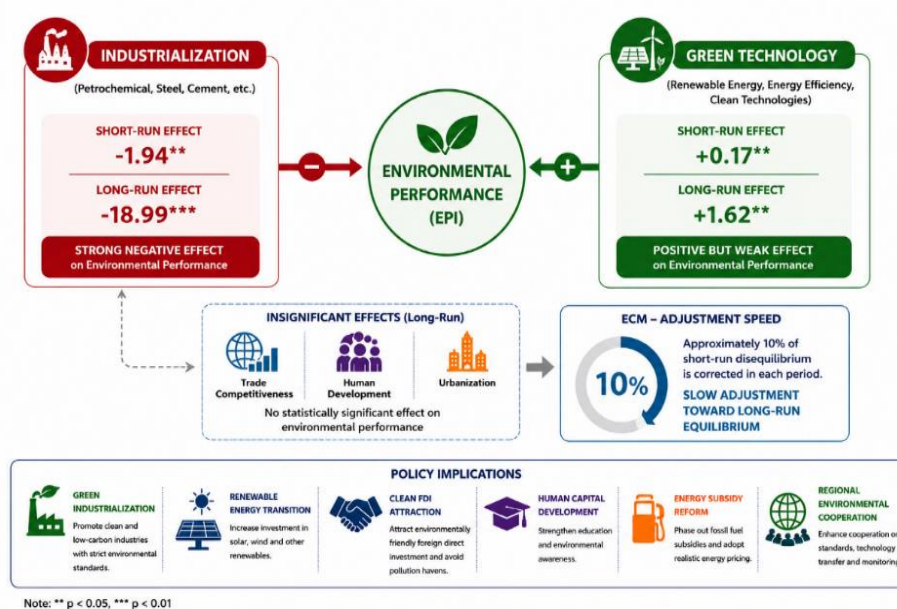


Fig. 2. Graphical summary of the findings.

4.7 | Structural Stability Tests

To evaluate the stability of the estimated coefficients throughout the study period and to ensure the absence of structural changes in the model, the CUSUM (Cumulative Sum of Recursive Residuals) and CUSUMSQ (Cumulative Sum of Squares of Recursive Residuals) tests were employed. These tests are widely used to detect systematic changes in regression coefficients over time. The results of the CUSUM test, illustrated in Fig. 3, indicate that the blue line representing the cumulative CUSUM statistic remains entirely within the 95% confidence bounds represented by the two red lines. As long as the CUSUM curve remains within these critical boundaries, the null hypothesis of coefficient stability cannot be rejected. Accordingly, the findings confirm that the estimated coefficients are structurally stable at the 95% confidence level. This result suggests that the model's underlying structure did not change significantly during the study period and that the estimated coefficients are stable over time. The CUSUMSQ test operates similarly to the CUSUM test; however, instead of cumulative residuals, it examines the cumulative squared residuals. This test is more sensitive to sudden changes in the variance of the residuals and potential instability in the estimated parameters. In Fig. 4, the blue line again remains within the 95% confidence intervals throughout the entire sample period. Therefore, the null hypothesis of parameter stability is accepted, and no evidence of structural breaks or instability in the residual variance is observed. Overall, the results of both the CUSUM and CUSUMSQ tests confirm the robustness and stability of the estimated ARDL model over the study period.

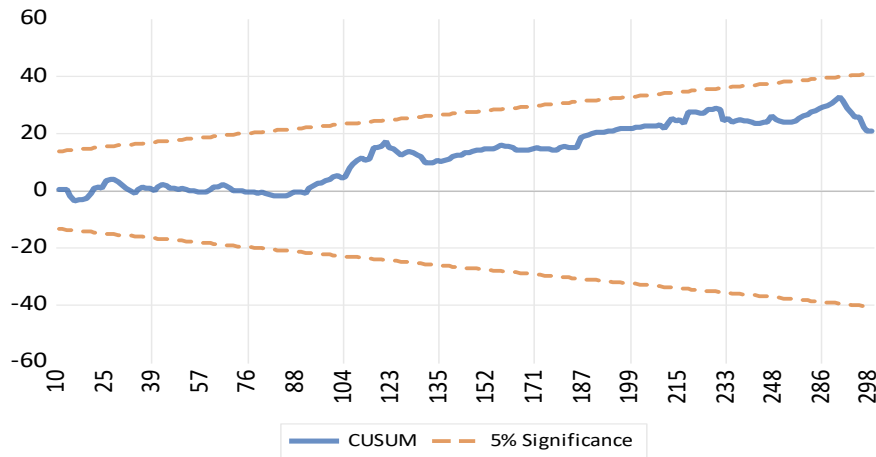


Fig. 3. Results of the CUSUM stability test.

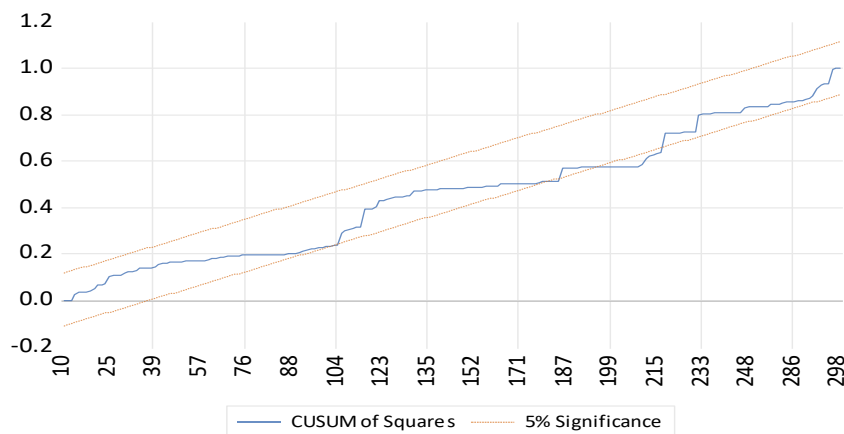


Fig. 4. Results of the CUSUMSQ stability test.

6 | Conclusion and Policy Recommendations

The primary objective of this study was to investigate the dynamic effects of industrialization and green technology on environmental performance across 13 oil-producing countries in the MENA region during 2005–2025. The ARDL model estimates indicate that, in the short run, industrialization has a negative, statistically significant effect on environmental performance. In contrast, green technology exerts a positive, statistically significant effect. These findings confirm that industrialization in oil-producing countries, enabled by easy, inexpensive access to fossil fuels, largely follows a pollution-intensive development path that imposes additional pressure on the environment. In the long run, the results reveal that the coefficient of industrialization (-18.99) is substantially stronger than in the short run and remains statistically significant.

In contrast, green technology, with a coefficient of 1.62, continues to exert a positive but relatively weak effect on environmental performance. This important finding suggests that, within oil-producing countries, the environmentally destructive force of industrialization is considerably stronger than the mitigating influence of green technology. In other words, a substantial gap exists between the rapid expansion of pollution-intensive industries and the development and diffusion of clean technologies.

Moreover, trade competitiveness, human development, and urbanization do not exhibit statistically significant long-run effects on environmental performance. This outcome may be attributed to the distinctive structural characteristics of oil-dependent economies, including excessive reliance on oil-export revenues, limited economic diversification, and the weakness of regulatory and educational institutions in these countries. The estimated error correction coefficient (-0.10) indicates that approximately 10% of short-run disequilibrium is corrected in each period, implying that the model gradually converges toward long-run equilibrium. However, the relatively low adjustment speed reflects the strong inertia embedded within the industrial and environmental structures of oil-producing economies, suggesting that meaningful reforms will require sustained policy efforts and long-term commitment.

Based on the empirical findings of this study, the following policy recommendations are proposed for policymakers and planners in oil-producing countries:

- I. **Fundamental Revision of the Industrialization Model:** Given the strong negative effect of industrialization on environmental performance in the long run, oil-producing countries should move toward a model of "green industrialization." This transition requires implementing stricter environmental standards for pollution-intensive industries, particularly the petrochemical, steel, and cement industries, as well as providing tax incentives and financial support for low-carbon, environmentally friendly industries.
- II. **Accelerating the Transition toward Renewable Energy:** Since the positive effect of green technology remains considerably weaker than the negative effect of industrialization, oil-producing economies should significantly increase investment in renewable energy projects such as solar and wind power. Utilizing oil revenues to finance this transition, as initiated in countries such as the United Arab Emirates and Saudi Arabia, could facilitate the shift toward sustainable energy systems.
- III. **Attracting Environmentally Friendly Foreign Direct Investment (FDI):** Although FDI was not statistically significant in the present model, policymakers should adopt strict environmental regulations and provide incentives for investors to use green technologies to prevent oil-producing countries from becoming "pollution havens."
- IV. **Strengthening Human Capital and Environmental Education:** Despite the statistical insignificance of the human development variable in the long run, this finding should not be interpreted as diminishing the importance of education and environmental awareness. Rather, it may indicate that the current level of human capital in the sampled countries has not yet reached the threshold necessary to significantly influence environmental performance. Therefore, comprehensive environmental education programs at both academic and public levels remain essential.
- V. **Reforming Energy Subsidy Systems:** Gradually removing fossil fuel subsidies and implementing realistic energy pricing mechanisms can increase economic incentives for efficient energy consumption and investment in energy-efficient technologies.
- VI. **Enhancing Regional Environmental Cooperation:** Given the transboundary nature of air pollution and climate change, oil-producing countries in the MENA region should strengthen regional cooperation by establishing joint environmental institutions to coordinate environmental standards, facilitate green technology transfer, and monitor environmental commitments.

Authors' Contributions

S. F. F.: Writing-original draft, Methodology, Data Curation, Conceptualization, Software, Formal Analysis, and Visualization, and Validation. S. K. S.: Validation, Writing-Review & Editing, and Formal Analysis. The authors have read and agreed to the published version of the manuscript.

Data Availability

The data is available on request from the corresponding author.

Funding

No external funding was received for this research.

Conflict of Interest

There are no competing interests to declare.

Consent for Publication

The authors have given consent for the publication of this manuscript.

Ethics Approval and Consent to Participate

The authors confirm that this research did not involve human participants or animal subjects.

References

- [1] Fakher, H. A., & others. (2023). The impact of gross domestic product, financial development, energy consumption on environmental quality: With emphasis on six environmental indicators. *Journal of natural environment*, 76(2), 345–363. (In Persian). <https://www.sid.ir/filesserver/jf/721-285046-x-1370621.pdf>
- [2] Fakher, H. A. (2022). Threshold impact of financial development on the composite environmental quality index with emphasis on the role of research and development: using multi-criteria decision makin and principal component analysis. *Journal of decisions and operations research*, 6(Special Issue), 1–25. (In Persian). <https://doi.org/10.22105/dmor.2021.272043.1321>
- [3] Sachs, J. D. (2015). The age of sustainable development. In *The age of sustainable development*. Columbia University Press.
http://www.earthinstitute.columbia.edu/sitefiles/file/Sachs%20Writing/2014/%E2%80%9CThe%20Age%20of%20Sustainable%20Development%20by%20Jeffrey%20D_%20Sachs%20-%20Project%20Syndicate%E2%80%9D.pdf
- [4] Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P. W., Trisos, C., ... & Orendain, D. J. (2023). IPCC, 2023: Climate Change 2023: Synthesis report. contribution of working groups I, II and III to the Sixth assessment report of the intergovernmental panel on climate change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.
<https://biblio.ugent.be/publication/01KAV2B3ZQ47W8ZHHDZ81WAMNM>
- [5] Fakher, H.-A., Abedi, Z., Ahmadian, M., & Shaygani, B. (2018). Comparative examine the impact of financial development (based on money market and capital market) in the intensity of economic growth effects on the environmental performance. *Environmental researches*, 9(17), 133–146.
<https://dor.isc.ac/dor/20.1001.1.20089597.1397.9.17.17.4>
- [6] Ross, M. L. (2013). *The oil curse: How petroleum wealth shapes the development of nations*. Princeton University Press.
- [7] Zeb, K., Ali, S. M., Khan, B., Mehmood, C. A., Tareen, N., Din, W., ... Haider, A. (2017). A survey on waste heat recovery: Electric power generation and potential prospects within Pakistan. *Renewable and sustainable energy reviews*, 75, 1142–1155. <https://doi.org/10.1016/j.rser.2016.11.096>
- [8] Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *American economic review*, 102(1), 131–166. <https://doi.org/10.1257/aer.102.1.131>
- [9] Toczyłowska-Mamińska, R. (2017). Limits and perspectives of pulp and paper industry wastewater treatment--A review. *Renewable and sustainable energy reviews*, 78, 764–772.
<https://doi.org/10.1016/j.rser.2017.05.021>
- [10] Wolf, M. J., Emerson, J. W., Esty, D. C., Sherbinin, A. D., & Wendling, Z. A. (2022). 2022 Environmental Performance Index: ranking country performance on sustainability issues [full report].
<https://bvear.mb.do/handle/123456789/2830>

- [11] Fakher, H. A., & Idroes, G. M. (2025). Room for improving the ecological sustainability gap in g20 economies through the lens of load capacity factor: The role of green energy initiatives as moderators. *Innovations in environmental economics*, 1(1), 1–18. <https://doi.org/10.48313/iee.v1i1.33>
- [12] Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The quarterly journal of economics*, 110(2), 353–377. https://www.nber.org/system/files/working_papers/w4634/w4634.pdf
- [13] Porter, M. E., & Linde, C. van der. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of economic perspectives*, 9(4), 97–118. <https://doi.org/10.1257/jep.9.4.97>
- [14] Hart, S. L. (1995). A Natural-Resource-Based View of the Firm. *The academy of management review*, 20(4), 986–1014. <https://doi.org/10.2307/258963>
- [15] DiMaggio, P. J., Powell, W. W., & others. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American sociological review*, 48(2), 147–160. https://lms.academyofhrd.org/wp-content/uploads/2023/01/The_Iron_Cage_Revisited_Institutional_Isomorphism_a.pdf
- [16] Sæther, B., & Neumann, A. (2024). The effect of the 2022 energy crisis on electricity markets ashore the North Sea. *Energy economics*, 131, 107380. <https://doi.org/10.1016/j.eneco.2024.107380>
- [17] Liu, Y., Liu, B., Yang, H., & Luo, K. (2025). Optimal production and maintenance strategies for manufacturing/remanufacturing leasing system considering uncertain quality and carbon emission. *International journal of production economics*, 280, 109489. <https://doi.org/10.1016/j.ijpe.2024.109489>
- [18] Hao, Y. (2022). Effect of economic indicators, renewable energy consumption and human development on climate change: An empirical analysis based on panel data of selected countries. *Frontiers in energy research*, 10, 841497. <https://doi.org/10.3389/fenrg.2022.841497>
- [19] Ahmed, R. R., Akbar, W., Aijaz, M., Channar, Z. A., Ahmed, F., & Parmar, V. (2023). The role of green innovation on environmental and organizational performance: Moderation of human resource practices and management commitment. *Heliyon*, 9(1). [https://www.cell.com/heliyon/pdf/S2405-8440\(22\)03967-6.pdf](https://www.cell.com/heliyon/pdf/S2405-8440(22)03967-6.pdf)
- [20] D'Adamo, I., Dell'Aguzzo, A., & Pruckner, M. (2024). Residential photovoltaic and energy storage systems for sustainable development: An economic analysis applied to incentive mechanisms. *Sustainable development*, 32(1), 84–100. <https://doi.org/10.1002/sd.2652>
- [21] Xiong, L., Jing, B., Chen, M., Zheng, X., & Wu, W. (2023). Comprehensive environmental impact assessment of plastic film mulching with emphasis on waste disposal of discarded plastic film in sunflower production. *Journal of cleaner production*, 404, 136979. <https://doi.org/10.1016/j.jclepro.2023.136979>
- [22] Yi, M., Xu, L., Zhang, T., Ao, L., & Sun, M. (2025). The impact of foreign direct investment on green technology progress in China on two-carbon background: taking trade openness into consideration. *Frontiers in environmental science*, 12, 1533146. <https://doi.org/10.3389/fenvs.2024.1533146>
- [23] Wang, H. Y., Li, Y., Jiao, S. Q., Chou, K. C., & Zhang, G. H. (2023). Recovery of Ni matte from Ni-bearing electroplating sludge. *Journal of environmental management*, 326, 116744. <https://doi.org/10.1016/j.jenvman.2022.116744>
- [24] Cheng, Z., & Meng, X. (2023). Can carbon emissions trading improve corporate total factor productivity? *Technological forecasting and social change*, 195, 122791. <https://doi.org/10.1016/j.techfore.2023.122791>
- [25] Cao, H. W., Pei, Q. M., Yu, X., Santosh, M., Li, G. M., Zhang, L. K., ... & Cao, A. B. (2023). Discovery of the large-scale Eocene Xiwu Pb–Zn–Ag deposit in the Tethyan Himalaya: Geochronology, geochemistry, and C–H–O–S–Pb–Sr–Nd isotopes. *Gondwana research*, 124, 165–187. <https://doi.org/10.1016/j.gr.2023.07.001>
- [26] Appiah-Twum, F., & Long, X. (2023). Human capital, trade competitiveness and environmental efficiency convergence across Asia Pacific countries. *Environmental and resource economics*, 85(1), 109–132. <https://doi.org/10.1007/s10640-023-00758-6>
- [27] Niromand, M., Ahmadzadeh, S., & Bahrami, Z. (2025). Investigating the effect of environmental orientation on sustainable performance with the mediating role of green supply chain management and green innovation and the moderating role of institutional pressure. *Research in production and operations management*, 16(1), 25–48. (In Persian). <https://doi.org/10.22108/pom.2025.143545.1600>

-
- [28] HeydriA Aineh, Z., Abedin, S. Z. Al, & Majid, J. S. A. (2025). Investigating the effect of production aggregation on the green economic efficiency of industrial workshops with ten or more employees. *Quarterly journal of industrial economics research*, 8(29), 20–38. **(In Persian)**. <https://doi.org/10.30473/jier.2025.73645.1490>
- [29] Fathia, M. R., Mokariana, P., & Ghadimib, H. (2024). Investigating the impact of corporate social responsibility on environmental performance with emphasis on the mediating role of green transformational leadership and green capability. *Journal of industrial innovations*, 2(4), 424–435. **(In Persian)**. <https://doi.org/10.61882/jii.2.4.424>