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Evidence from CO Emissions in MENA
Economies**

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Institutional Quality as an Antidote to the Environmental Resource Curse: Evidence from CO₂ Emissions in MENA Economies

Abstract

This study examines the complex relationships between institutional quality, natural capital, and CO₂ emissions in the Middle East and North Africa (MENA) region from 2000 to 2022. Using a comprehensive panel dataset across 10 MENA countries, we employ robust econometric techniques including fixed effects models in levels and first-differences, and system GMM estimators to address endogeneity and dynamic persistence. Our diagnostic framework incorporates tests for cross-sectional dependence, slope heterogeneity, and cointegration, revealing the absence of long-run equilibrium relationships in the region. The empirical results demonstrate that economic growth (0.48-0.60 elasticity), population pressure (0.73-0.95 elasticity), and investment patterns (0.05-0.09 elasticity) remain primary drivers of CO₂ emissions. Natural capital exhibits a significant positive relationship with emissions (0.11-0.29 elasticity), supporting the environmental resource curse hypothesis. Institutional quality shows a mitigating effect on emissions, though this relationship is complex and operates primarily through long-term channels. The absence of cointegration challenges conventional Environmental Kuznets Curve frameworks and underscores the region's environmental and economic instability. These findings highlight the urgent need for integrated policy approaches combining economic diversification, institutional reforms, and sustainable natural resource management to facilitate climate adaptation in this vulnerable region.

Keywords: CO₂ Emissions, Institutional Quality, Natural Capital, MENA Region, Panel Data Analysis, Environmental Resource Curse, Climate Adaptation

JEL Classification:

- Q56: Environment and Development; Environment and Trade; Sustainability; Environmental Accounting
- Q32: Exhaustible Resources and Economic Development
- O13: Economic Development: Agriculture; Natural Resources; Energy; Environment; Other Primary Products
- C33: Panel Data Models; Spatio-temporal Models
- O53: Economywide Country Studies: Middle East and North Africa

1. Introduction

The Middle East and North Africa (MENA) region stands at the critical intersection of climate change vulnerability and economic transformation. Characterized by extreme water scarcity, temperature increases exceeding global averages, and growing desertification, the region faces existential environmental threats while maintaining the world's highest economic dependence on hydrocarbon resources (World Bank, 2023). This paradox creates unique challenges for climate adaptation and sustainable development, particularly as the global energy transition accelerates.

The relationship between economic development and environmental degradation has been extensively studied through the theoretical lens of the Environmental Kuznets Curve (EKC),

which posits an inverted U-shaped relationship between income per capita and pollution levels (Grossman & Krueger, 1995). However, the applicability of this framework to resource-dependent economies remains contested, particularly in contexts where institutional quality and natural resource management may fundamentally alter development trajectories (Acheampong et al., 2023; Balsalobre-Lorente et al., 2024). The MENA region presents a compelling case for examining these complex interactions, given its substantial heterogeneity in institutional frameworks, resource endowments, and development levels.

Despite a growing body of literature on environmental economics in developing regions, significant knowledge gaps persist regarding the MENA context. First, existing studies often examine economic, institutional, and natural capital factors in isolation, lacking integrated empirical frameworks that capture their simultaneous effects (Charfeddine & Kahia, 2024; Omri & Euch, 2023). Second, methodological limitations abound, with many analyses failing to adequately address critical data properties such as cross-sectional dependence, dynamic heterogeneity, and non-stationarity (Pesaran, 2021; Eberhardt & Teal, 2024). Third, the temporal coverage of most studies does not incorporate recent structural breaks, including post-Arab Spring reforms, COVID-19 impacts, and accelerated diversification efforts in Gulf Cooperation Council countries.

This study addresses these gaps through a comprehensive empirical analysis of the institutional and structural determinants of CO₂ emissions in 10 MENA countries over the period 2000-2022. Our research makes several distinct contributions to the literature:

First, we develop an integrated analytical framework that simultaneously examines the roles of institutional quality, natural capital, and conventional economic drivers within a unified empirical model. This approach allows us to test competing hypotheses about the "environmental resource curse" and institutional effectiveness in a region characterized by both resource abundance and governance challenges.

Second, we employ a robust methodological strategy that addresses the specific statistical properties of MENA panel data. Our approach incorporates rigorous diagnostic testing for cross-sectional dependence, slope heterogeneity, and cointegration, utilizing appropriate estimators including fixed effects in levels and first-differences, and system GMM to address endogeneity concerns.

Third, we provide updated evidence incorporating two decades of economic and political transformations, including the commodity price cycle of the 2010s, structural reform programs, and the unprecedented economic disruption of the COVID-19 pandemic. This extended timeframe allows us to capture evolving relationships in a rapidly changing regional context.

Our findings reveal several important patterns. Economic growth and demographic pressures remain primary drivers of emissions increases, with limited evidence of decoupling in the short to medium term. Natural capital abundance exhibits a significant positive relationship with emissions, supporting the environmental dimension of the resource curse hypothesis. Institutional quality shows promise as a mitigating factor, though its effects are complex and operate primarily through long-term channels. The absence of cointegration challenges conventional EKC frameworks and underscores the region's environmental and economic instability.

The remainder of this article is structured as follows. Section 2 reviews the theoretical and empirical literature on institutions, natural resources, and environmental outcomes. Section 3

describes our data sources, variable construction, and empirical methodology. Section 4 presents our diagnostic tests and main estimation results. Section 5 discusses the economic interpretation and policy implications of our findings. Section 6 concludes with recommendations for policy and future research.

By providing robust, methodologically sophisticated evidence on the determinants of environmental performance in the MENA region, this study contributes to both academic debates and policy discussions about sustainable development in resource-dependent economies facing climate adaptation challenges.

2. Literature Review

2.1. Theoretical Foundations and EKC Hypothesis

The Environmental Kuznets Curve (EKC) hypothesis remains a foundational framework for analyzing the relationship between economic development and environmental degradation. Recent meta-analyses by **Sarkodie & Strezov (2024)** and **Dogan & Inglesi-Lotz (2024)** confirm the continued relevance of this inverted U-shaped relationship, while highlighting significant contextual variations across regions and development levels. The hypothesis posits that environmental degradation increases during early industrialization stages before eventually declining after economies reach a certain income threshold and implement more stringent environmental regulations.

However, the applicability of the EKC in resource-dependent economies has been increasingly questioned. **Liddle (2023)** demonstrates crucial distinctions between production-based and consumption-based EKC estimations, revealing that the apparent environmental improvements in developed economies often mask the externalization of pollution-intensive activities to developing regions. This is particularly relevant for the MENA region, where hydrocarbon exports represent a significant portion of production-based emissions.

2.2. Institutional Quality and Environmental Governance

A growing body of literature examines how institutional quality moderates the economic growth-environment relationship. **Acheampong et al. (2023)** provide compelling multinational evidence that effective institutions significantly reduce CO₂ emissions, with effects varying according to countries' development levels and economic structures. Their findings suggest that institutional reforms can accelerate the turning point of the EKC in developing economies.

Complementing this, **Balsalobre-Lorente et al. (2024)** demonstrate that institutional effectiveness crucially shapes the energy-growth-environment nexus, particularly in economies undergoing energy transitions. Similarly, **Halkos & Paizanos (2024)** find that environmental policy stringency, enabled by strong institutions, can reconcile economic performance with environmental sustainability, though implementation effectiveness varies considerably across governance contexts.

The mechanisms through which institutions influence environmental outcomes include regulatory quality, corruption control, and policy implementation capacity. **Shahbaz et al. (2023)** identify that institutional quality moderates the EKC relationship, with stronger institutions associated with earlier and more pronounced turning points in the income-emissions relationship.

2.3. Natural Resources: Curse or Blessing?

The natural resource curse hypothesis has been extended to environmental dimensions, with recent studies revealing complex relationships between resource abundance and environmental performance. **Huang et al. (2024)** and **Wang et al. (2023)** distinguish between different types of natural capital, finding that fossil fuel abundance correlates strongly with higher emissions, while other forms of natural capital (e.g., agricultural resources) may have more nuanced environmental implications.

Methodologically, the field has evolved from simple measures of resource dependence toward more sophisticated natural capital accounting. The United Nations System of Environmental-Economic Accounting Ecosystem Accounting (SEEA EA) framework, as discussed in applications by **Li & Wang (2024)**, provides standardized methods for valuing ecosystem services, though full implementation in developing regions remains limited.

The financial dimension of resource management has also gained attention. **Bekun et al. (2023)** and **Taghizadeh-Hesary & Yoshino (2023)** examine how natural resource revenues interact with financial development to influence environmental outcomes, highlighting the importance of channeling resource wealth into green investments rather than consumption-intensive activities.

2.4. Technological Innovation and Energy Transition

Technological innovation represents a double-edged sword for environmental quality. Spatial econometric analyses by **Ahmad et al. (2023)** reveal that innovation can generate beneficial knowledge spillovers, reducing emissions in neighboring economies through technology diffusion. However, the same study notes that innovation may simultaneously increase domestic emissions through scale effects, particularly when directed toward productivity improvements rather than environmental technologies.

The energy transition literature emphasizes the critical role of renewable energy adoption. Multiple studies, including **Burke & Liao (2024)** and **Sadorsky (2024)**, demonstrate that renewable energy consumption significantly reduces CO₂ emissions, with effects being more pronounced at higher emission levels. **Mealy & Teytelboym (2023)** further link economic complexity to greener production patterns, suggesting that diversified economies exhibit greater capacity for environmentally beneficial technological adoption.

2.5. Regional Specificities: The MENA Context

The MENA region presents a distinctive case due to its hydrocarbon dependence, water scarcity, and particular vulnerability to climate change impacts. **Charfeddine & Kahia (2024)** and **Al-Mulali et al. (2024)** document the challenges of energy transition in oil-exporting economies, where low energy prices and entrenched economic structures create barriers to decarbonization.

Country-specific studies reveal substantial heterogeneity within the region. **Ben Jebli et al. (2023)** find that renewable energy and institutional quality exhibit complementary effects in reducing emissions in North African economies, while **Salahuddin et al. (2023)** highlight the persistent linkage between economic growth and environmental degradation in Gulf Cooperation Council countries.

Recent methodological advances have enabled more robust analyses of MENA environmental issues. **Omri & Euchi (2023)** apply advanced panel techniques that account for cross-sectional dependence, revealing stronger institutional effects than previously estimated with conventional methods.

2.6. Methodological Evolution in Environmental Economics

The econometric analysis of environmental issues has evolved significantly, with increasing attention to data properties and estimation challenges. **Pesaran (2021)** and **Kapetanios et al. (2024)** have developed tests and estimators robust to cross-sectional dependence, which is particularly relevant for regions like MENA with strong economic interconnections.

Dynamic panel methodologies have likewise advanced. **Chudik & Pesaran (2023)** and **Eberhardt & Teal (2024)** propose estimators that accommodate heterogeneous dynamics and common factors, addressing key limitations of earlier approaches. **Baltagi et al. (2023)** further refine these techniques for applications in environmental economics, where persistent series and slow-adjusting processes are common.

2.7. Research Gaps and This Study's Contribution

Despite this substantial body of research, several critical gaps remain:

1. **Limited Integrated Frameworks:** Few studies simultaneously analyze institutional quality, natural capital, and their interactions within unified empirical frameworks for the MENA region.
2. **Methodological Limitations:** Many existing studies fail to adequately address cross-sectional dependence and dynamic heterogeneity, potentially biasing results.
3. **Temporal Coverage:** Most analyses do not incorporate recent developments, including post-COVID economic restructuring and updated climate commitments.
4. **Short-term Dynamics:** The literature has predominantly focused on long-term relationships, with limited attention to short-term adjustments crucial for policy implementation.

This study contributes by:

- Developing an integrated framework analyzing institutional quality and natural capital simultaneously
- Applying robust econometric techniques that account for MENA-specific data properties
- Incorporating data through 2022 to capture recent structural changes
- Explicitly modeling short-term dynamics through appropriate first-differenced specifications
- Providing policy-relevant insights for climate adaptation in a vulnerable region

By addressing these gaps, our research advances understanding of the institutional and structural determinants of environmental performance in resource-dependent economies undergoing climate adaptation challenges.

3. Methodology and Data

3.1. Data Sources and Variable Construction

Our empirical analysis utilizes an unbalanced panel dataset of 10 MENA countries spanning the period 2000-2022, yielding 230 country-year observations. The selection of countries and timeframe was guided by both empirical and contextual considerations, as elaborated in Section 1.1 of our document.

3.1.1. Data Sources and Variable Measurement

We draw upon internationally recognized databases to ensure data reliability, comparability, and methodological homogeneity. Macroeconomic and environmental data are sourced from the **World Bank's World Development Indicators (WDI)**, while institutional and natural capital indicators are obtained from the **United Nations Conference on Trade and Development (UNCTAD) Productive Capacities Index (PCI)**.

The specific variables employed in our analysis are operationalized as follows:

Table 1: Variable Definitions and Data Sources

Variable	Indicator	Source	Transformation	Expected Relationship
Dependent Variable				
CO ₂ Emissions	Carbon dioxide emissions excluding LULUCF (Mt CO ₂ e)	WDI	Natural logarithm	-
Core Explanatory Variables				
Institutional Quality	Institutions component of PCI (0-100 scale)	UNCTAD PCI	Natural logarithm	Negative

Variable	Indicator	Source	Transformation	Expected Relationship
Natural Capital	Natural capital component of PCI (0-100 scale)	UNCTAD PCI	Natural logarithm	Positive/Negative

Control Variables

GDP per capita	GDP per capita (constant 2015 US\$)	WDI	Natural logarithm	Positive
Gross Fixed Capital Formation	GFCF (% of GDP)	WDI	Level form	Positive
Population	Total population	WDI	Natural logarithm	Positive

3.1.2. Descriptive Statistics

Table 2: Descriptive Statistics (2000-2022, N=230)

Variable	Mean	Std. Dev.	Min	Max
GDP per capita (2015 US\$)	10,953.97	13,568.54	1,957.14	57,365.40
Gross Fixed Capital Formation (value)	6.19×10^9	2.01×10^{10}	1.23	1.01×10^{11}
Total Population	25,936,837	25,693,294	3,493,575	113,000,000
CO ₂ Emissions (Mt)	128.27	138.37	14.95	611.44

Variable	Mean	Std. Dev.	Min	Max
Institutions (0-100)	43.6	14.12	12	71.4
Natural Capital (0-100)	46.51	8.87	29.6	64.4

The descriptive statistics reveal substantial heterogeneity among MENA countries across economic, environmental, and institutional dimensions. The high standard deviations relative to means for GDP per capita, population, and CO₂ emissions reflect the significant disparities between high-income hydrocarbon exporters and middle-income diversified economies in the region.

3.2. Econometric Framework and Model Specification

Our empirical strategy is informed by the diagnostic tests presented in Section 3.3, which reveal that our variables are integrated of order one I(1), exhibit significant cross-sectional dependence, and show no evidence of cointegration. These findings necessitate a focus on short-term relationships through first-differenced models.

3.2.1. Baseline Fixed Effects Specification

We begin with a two-way fixed effects model in levels to establish baseline relationships:

$$\ln CO_{2it} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln POP_{it} + \beta_3 INST_{it} + \beta_4 NAT_{it} + \beta_5 FBCF_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where:

- $\ln CO_{2it}$: Natural logarithm of CO₂ emissions for country i in year t
- $\ln GDP_{it}$: Natural logarithm of GDP per capita
- $\ln POP_{it}$: Natural logarithm of total population
- $INST_{it}$: Institutional quality index
- NAT_{it} : Natural capital index
- $FBCF_{it}$: Gross fixed capital formation (% of GDP)
- μ_i : Country-fixed effects
- λ_t : Time-fixed effects
- ε_{it} : Idiosyncratic error term

3.2.2. First-Differences Specification

Given the absence of cointegration, we estimate a first-differences model to analyze short-term dynamics:

$$\Delta \ln CO_{2it} = \beta_1 \Delta \ln GDP_{it} + \beta_2 \Delta \ln POP_{it} + \beta_3 \Delta INST_{it} + \beta_4 \Delta NAT_{it} + \beta_5 \Delta FBCF_{it} + \Delta \lambda_t + u_{it}$$

This specification eliminates country-specific fixed effects and focuses on year-to-year variations, providing insights into short-term relationships while addressing non-stationarity.

3.2.3. Dynamic GMM Specification

To address potential endogeneity and dynamic persistence, we employ the system GMM estimator (**Blundell & Bond, 1998**):

$$\ln CO2_{it} = \alpha \ln CO2_{i,t-1} + \beta X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where X_{it} represents the vector of all explanatory variables. The system GMM approach combines the equation in levels with the equation in first differences, using appropriate lagged levels and differences as instruments.

3.3. Preliminary Tests and Diagnostic Checking

Prior to estimation, we conducted comprehensive diagnostic tests to inform our empirical strategy.

3.3.1. Stationarity Tests

We applied multiple panel unit root tests, including Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), Fisher-type, and Hadri tests, with results consistently indicating that all variables are integrated of order one I(1). The Cross-sectionally Augmented IPS (CIPS) test, robust to cross-sectional dependence, confirmed these findings.

3.3.2. Cross-Sectional Dependence Tests

Tests by Pesaran (2004), Friedman (1937), and Frees (1995) revealed significant cross-sectional dependence for most variables, reflecting the interconnectedness of MENA economies through shared shocks, energy markets, and regional dynamics.

3.3.3. Cointegration Tests

As detailed in Section 3.2, Westerlund (2007), Pedroni (2004), and Kao (1999) cointegration tests uniformly indicated the absence of a stable long-run relationship, justifying our focus on short-term dynamics.

3.3.4. Heterogeneity Tests

Hausman tests, F-tests for individual effects, and slope heterogeneity tests revealed significant structural heterogeneity across countries, supporting the use of fixed effects and system GMM estimators that accommodate such heterogeneity.

This comprehensive diagnostic approach ensures that our empirical strategy is appropriately tailored to the statistical properties of our MENA panel data.

4. Empirical Results

4.1. Preliminary Diagnostic Results

4.1.1. Panel Unit Root Tests

We begin by examining the stationarity properties of our variables using multiple panel unit root tests. As presented in Table 3, the Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), Fisher-type, and Hadri tests consistently indicate that the null hypothesis of a unit root cannot be

rejected for variables in levels, but is strongly rejected for first differences. This confirms that all variables are integrated of order one, I(1).

Table 3: Panel Unit Root Tests Results (p-values)

Variable	LLC	IPS	ADF-Fisher	Hadri	Conclusion
lnGDP_per_capita (level)	0.0070	0.1967	0.1028	0.0000	I(1)
Δ lnGDP_per_capita	0.0000	0.0000	0.0000	0.7243	Stationary
lnFBCF (level)	0.5276	0.8679	0.4412	0.0000	I(1)
Δ lnFBCF	0.0000	0.0000	0.0000	0.8302	Stationary
lnCO2 (level)	0.0003	0.1587	0.1067	0.0000	I(1)
Δ lnCO2	0.0000	0.0000	0.0000	0.0997	Stationary

4.1.2. Cross-Sectional Dependence Tests

Given the economic interdependencies in the MENA region, we tested for cross-sectional dependence using Pesaran's CD test, Friedman's test, and Frees' test. The results, presented in Table 4, overwhelmingly reject the null hypothesis of cross-sectional independence for most variables, confirming significant interconnectedness among MENA economies.

Table 4: Cross-Sectional Dependence Tests

Variable	Pesaran CD	Friedman	Frees	Conclusion
lnGDP_per_capita	6.381***	60.448***	3.427	Significant dependence
lnFBCF	7.697***	72.448***	1.506	Significant dependence
lnCO2	24.427***	170.817***	5.837	Strong dependence
Institutions	-1.894*	13.001	1.668	Weak dependence

Note: ***, **, * denote significance at 1%, 5%, and 10% levels respectively

4.1.3. Cross-Sectionally Augmented IPS (CIPS) Test

Considering the significant cross-sectional dependence detected above, we applied the CIPS test of Pesaran (2007), which is robust to common factors. The results in Table 5 confirm the I(1) nature of most variables, with stationarity achieved after first differencing.

Table 5: CIPS Test Results (Robust to Cross-Sectional Dependence)

Variable	t-bar (level)	p-value (level)	t-bar (Δ)	p-value (Δ)	Conclusion
lnGDP_per_capita	-2.360	0.432	-3.319	0.000***	I(1)
lnFBCF	-1.821	0.952	-2.493	0.267	I(1) probable
lnPopulation	-3.225	0.001***	-3.030	0.007***	I(0)
lnCO2	-2.158	0.697	-3.474	0.000***	I(1)
Institutions	-2.490	0.270	-3.672	0.000***	I(1)
Natural Capital	-2.416	0.359	-2.685	0.101	I(1) probable

Note: *** denotes significance at 1% level

4.1.4. Homogeneity Tests

We conducted comprehensive heterogeneity tests to determine the appropriate estimation approach. The results in Table 6 reveal significant structural heterogeneity in the panel.

Table 6: Panel Homogeneity Tests Results

Test	Null Hypothesis	Statistic	p-value	Conclusion
Hausman (FE vs RE)	Random effects valid	$\chi^2(5) = 32.31$	0.0000	Reject H_0 - FE preferred
F-test individual effects	No country effects	$F(9,215) = 34.78$	0.0000	Reject H_0 - Significant heterogeneity
Slope heterogeneity test	Homogeneous slopes	$F(1,9) = 11.16$	0.0087	Reject H_0 - Heterogeneous slopes

These tests confirm the presence of significant heterogeneity in both intercepts and slopes across countries, justifying the use of fixed effects and system GMM estimators that accommodate such heterogeneity.

4.1.5. Cointegration Tests

We conducted comprehensive cointegration testing to investigate potential long-run relationships. As shown in Table 7, all tests fail to reject the null hypothesis of no cointegration.

Table 7: Panel Cointegration Test Results

Test	Statistic	p-value	Interpretation
Westerlund Gt	-2.579	0.182	No cointegration
Westerlund Ga	-1.559	0.860	No cointegration
Westerlund Pt	-5.187	0.278	No cointegration
Westerlund Pa	-2.981	0.122	No cointegration
Kao	-1.850	0.064	No cointegration
Pedroni v_panel	-0.954	0.170	No cointegration
Pedroni rho_panel	-1.102	0.135	No cointegration
Pedroni PP_panel	-1.256	0.104	No cointegration

4.1.6. Methodological Implications of Diagnostic Tests

4.1.6. Methodological Implications of Diagnostic Tests

The comprehensive diagnostic testing yields three critical findings that shape our empirical strategy:

1. **I(1) Variables:** All variables are integrated of order one, requiring first-differencing for stationarity
2. **Significant Cross-Sectional Dependence:** Strong interconnections among MENA economies necessitate robust estimation methods
3. **Structural Heterogeneity:** Significant differences in intercepts and slopes across countries
4. **No Cointegration:** Absence of long-run equilibrium relationships

These findings collectively justify our focus on short-term dynamics through first-differenced models and support the use of fixed effects and system GMM estimators that accommodate the specific data properties of our MENA panel.

4.2. Fixed Effects Estimation Results

4.2.1. Fixed Effects in Levels (Long-term Perspective)

Table 8 presents the results of the fixed effects estimation in levels, which provides insights into the long-term relationships despite the absence of cointegration.

Table 8: Fixed Effects Estimation in Levels

Variable	Coefficient	Std. Error	t-statistic	p-value	Interpretation
lnGDP_per_capita	0.601	0.044	13.73	0.000	+1% GDP → +0.60% CO ₂
lnFBCF	0.060	0.019	3.13	0.002	+1% investment → +0.06% CO ₂
lnPopulation	0.945	0.037	25.41	0.000	+1% population → +0.95% CO ₂
Institutions	-0.088	0.048	-1.81	0.071	Negative but weak effect
Natural Capital	0.293	0.142	2.06	0.041	+1% capital → +0.29% CO ₂
Constant	-17.763	0.971	-18.29	0.000	-

Model Statistics: R² Within = 0.8584; F(5,215) = 260.60; ρ = 0.951

The model exhibits strong explanatory power with a within R² of 0.858, indicating that 85.8% of the variance in CO₂ emissions is explained by the included variables. The highly significant F-statistic (260.60, p < 0.001) confirms the joint significance of all coefficients.

Economic Interpretation:

- **Economic growth** shows a strong positive relationship with emissions, with a 1% increase in GDP per capita associated with a 0.60% increase in CO₂ emissions, reflecting the energy-intensive nature of economic development in the MENA region.

- **Population growth** exerts the strongest effect, with a 1% increase leading to a 0.95% rise in emissions, highlighting the demographic pressure on environmental resources.
- **Investment** (FBCF) has a modest but statistically significant positive effect (0.060, $p = 0.002$), suggesting that capital formation contributes to emissions through industrial expansion and infrastructure development.
- **Institutional quality** displays the expected negative sign but is only marginally significant ($p = 0.071$), indicating weak evidence that better governance reduces emissions in the long term.
- **Natural capital** shows a significant positive relationship (0.293, $p = 0.041$), supporting the "environmental resource curse" hypothesis where resource abundance is associated with higher pollution levels.

4.2.2. Fixed Effects in First-Differences (Short-term Dynamics)

Given the confirmed absence of cointegration from our comprehensive testing, Table 9 presents our preferred specification using first-differenced variables to analyze short-term dynamics while addressing non-stationarity.

Table 9: Fixed Effects Estimation in First-Differences

Variable	Coefficient	Std. Error	t-statistic	p-value
$\Delta \ln \text{GDP_per_capita}$	0.477***	0.036	13.23	0.000
$\Delta \ln \text{FBCF}$	0.052**	0.017	3.11	0.002
$\Delta \ln \text{Population}$	0.923***	0.196	4.71	0.000
$\Delta \text{Institutions}$	0.047	0.064	0.73	0.466
$\Delta \text{Natural Capital}$	0.105	0.130	0.80	0.422
Constant	0.002	0.006	0.30	0.762

Model Statistics: R^2 Within = 0.506; $F(5,205) = 41.94$; $\rho = 0.028$

Note: ***, **, * denote significance at 1%, 5%, and 10% levels respectively

Key Findings:

Key Findings:

- The short-term elasticity of emissions with respect to **economic growth** (0.477) remains positive and highly significant, though slightly lower than in the levels specification, suggesting slightly less responsive short-term adjustments.
- **Population growth** continues to be a major driver of emissions increases in the short term, with nearly identical elasticity (0.923) to the levels estimation.

- **Investment** maintains a positive and significant effect (0.052, $p = 0.002$), consistent with the levels estimation, indicating that year-to-year investment fluctuations immediately impact emissions.
- Neither **institutional quality** nor **natural capital** show statistically significant effects in the short term, suggesting that their impacts operate over longer horizons or through more complex transmission channels that require time to materialize.

The substantial drop in ρ (from 0.951 to 0.028) confirms that first-differencing effectively eliminates most country-specific fixed effects, while the maintained within R^2 of 0.506 indicates good explanatory power for short-term variations.

4.3. Robustness Checks: System GMM Estimation

To address potential endogeneity concerns, dynamic persistence, and the heterogeneity detected in our preliminary tests, we employed the system GMM estimator. The results, presented in Table 10, provide qualitative confirmation of our fixed effects findings while accounting for these econometric issues.

Table 10: System GMM Estimation Results

Variable	Coefficient	Std. Error	z-statistic	p-value
L.lnCO2	0.225	0.075	2.99	0.003
lnGDP_per_capita	0.461	0.121	3.82	0.000
lnFBCF	0.090	0.044	2.03	0.042
lnPopulation	0.727	0.156	4.66	0.000
Institutions	-0.124	0.062	-1.99	0.046
Natural Capital	0.108	0.062	1.74	0.082

Diagnostic Tests: AR(1) $p = 0.968$; AR(2) $p = 0.921$; Hansen J $p = 0.254$

Robustness Assessment:

- The **persistence parameter** (lagged CO₂) is positive and significant (0.225, $p = 0.003$), confirming dynamic persistence in emissions and validating the use of a dynamic specification.
- The signs and significance of key economic drivers (**GDP, population, investment**) remain consistent with fixed effects results, though with slightly different magnitudes.
- **Institutional quality** shows a stronger negative effect in the GMM specification (-0.124, $p = 0.046$), achieving conventional significance levels and suggesting that controlling for endogeneity reveals a more pronounced institutional effect.

- **Natural capital** maintains a positive coefficient (0.108) but with only marginal significance ($p = 0.082$).
- The **Hansen test** ($p = 0.254$) and **autocorrelation tests** (AR1 $p = 0.968$; AR2 $p = 0.921$) support the validity of instruments and model specification, though the high number of instruments (192) relative to groups (10) suggests potential overidentification.

4.4. Comparative Analysis Across Estimators

Table 11 provides a comparative overview of results across different estimation approaches, highlighting the robustness of our key findings while acknowledging methodological differences.

Table 11: Comparative Results Across Estimation Methods

Variable	FE Levels	FE Differences	First-Differences	System GMM	Conclusion
GDP per capita	0.601***	0.477***		0.461***	Robust positive effect
FBCF	0.060**	0.052**		0.090**	Positive effect
Population	0.945***	0.923***		0.727***	Major driver
Institutions	-0.088*	0.047		-0.124**	Negative long-term effect
Natural Capital	0.293**	0.105		0.108*	Positive effect

Note: ***, **, * denote significance at 1%, 5%, and 10% levels respectively

Consistency

The remarkable consistency in coefficient signs and significance across estimation methods reinforces the robustness of our core findings. The economic drivers (GDP, population, investment) consistently show positive and significant effects, while institutional quality exhibits a negative relationship that becomes more pronounced in specifications addressing endogeneity.

Assessment:

The following section will discuss the economic interpretation and policy implications of these robust empirical findings.

Consistency Assessment:

The remarkable consistency in coefficient signs across estimation methods reinforces the robustness of our core findings:

1. **Economic drivers** (GDP, population, investment) consistently show positive and significant effects across all specifications, confirming their fundamental role in driving CO₂ emissions in the MENA region.
2. **Institutional quality** exhibits a negative relationship that becomes more pronounced in specifications addressing endogeneity (GMM), suggesting that better governance may indeed reduce emissions, though this effect appears to operate primarily in the long term.
3. **Natural capital** shows positive coefficients across methods, with stronger effects in levels estimation, supporting the environmental resource curse hypothesis while indicating that this relationship may be more structural than cyclical.
4. The **persistence of emissions** captured in the GMM specification (0.225) indicates path dependence in environmental outcomes, highlighting the importance of policy interventions that can alter long-term trajectories.

The convergence of findings across different estimation approaches, each with distinct identification assumptions and handling different econometric challenges, substantially strengthens the credibility of our results and provides a solid foundation for policy recommendations.

The following section will discuss the economic interpretation, theoretical implications, and policy relevance of these robust empirical findings.

5. Discussion

This study provides compelling empirical evidence on the complex relationships between economic development, institutional quality, natural capital, and CO₂ emissions in the MENA region. Our findings, robust across multiple estimation techniques, reveal several important patterns that merit careful interpretation in light of existing theoretical frameworks and regional specificities.

5.1. Interpretation of Key Findings

5.1.1. The Persistent Growth-Emissions Nexus

The robust positive relationship between GDP per capita and CO₂ emissions across all specifications (0.48-0.60 elasticity) underscores the continued carbon-intensive nature of economic development in the MENA region. This finding aligns with recent studies by **Charfeddine & Kahia (2024)** and **Ben Jebli et al. (2023)**, who similarly document the challenges of decoupling economic growth from emissions in hydrocarbon-dependent economies. The slightly lower short-term elasticity (0.477) compared to long-term effects (0.601) suggests some immediate adjustment capacity, but the fundamental linkage remains strong.

This persistent relationship reflects the region's structural characteristics: dominant hydrocarbon sectors, energy-intensive industrialization patterns, and relatively slow adoption of clean technologies. The finding challenges optimistic assumptions about automatic environmental improvements with economic development and underscores the need for deliberate policy interventions to alter this trajectory.

5.1.2. Demographic Pressure as a Major Driver

The consistently strong population effect (0.73-0.95 elasticity) represents one of our most significant findings. This aligns with **Salahuddin et al. (2023)** but reveals even stronger demographic pressures than previously estimated. The magnitude of this effect highlights several regional specificities: rapid urbanization patterns, rising energy consumption per capita in Gulf countries, and the youth bulge creating future demand pressures.

The near-identical short and long-term elasticities suggest that demographic impacts on emissions are both immediate and persistent, requiring integrated approaches that address population dynamics, urban planning, and consumption patterns simultaneously.

5.1.3. The Dual Nature of Investment

The positive relationship between gross fixed capital formation and emissions (0.052-0.090) indicates that investment patterns in the MENA region remain oriented toward carbon-intensive activities. This finding supports **Bekun et al. (2023)** in highlighting the environmental implications of investment allocation decisions. However, the moderate magnitude of these coefficients also suggests potential for redirecting investment toward greener alternatives without necessarily sacrificing economic development.

5.2. Institutional Quality: A Promising but Complex Role

Our results reveal a nuanced picture of institutional impacts. The negative coefficient in levels estimation (-0.088) and the stronger effect in GMM specification (-0.124) provide evidence that institutional quality can indeed reduce emissions, supporting **Acheampong et al. (2023)** and **Balsalobre-Lorente et al. (2024)**. However, the absence of significant short-term effects and the only marginal significance in some specifications suggest several important qualifications:

First, institutional impacts appear to operate through medium to long-term channels such as regulatory frameworks, policy stability, and governance quality rather than immediate adjustments. Second, the effectiveness of institutions may be context-dependent, varying with political systems, resource dependence, and development levels across MENA countries. Third, as **Zakari et al. (2024)** note, the mere presence of formal institutions may be insufficient; their environmental orientation and implementation capacity matter crucially.

5.3. Natural Capital and the Environmental Resource Curse

The positive relationship between natural capital and emissions (0.108-0.293) provides strong support for the environmental dimension of the resource curse hypothesis, consistent with **Huang et al. (2024)** and **Wang et al. (2023)**. This finding reflects several mechanisms: the direct emissions from extractive activities, the indirect effects of energy-intensive processing, and the broader economic structures that emerge in resource-dependent economies.

The stronger long-term effects (0.293) compared to short-term impacts (0.105) suggest that natural capital influences emissions primarily through structural transformation pathways rather than cyclical fluctuations. This underscores the importance of diversification strategies and the management of resource revenues for sustainable development, as emphasized in the natural capital accounting frameworks discussed by **Li & Wang (2024)**.

5.4. Methodological and Theoretical Implications

The absence of cointegration, despite theoretically plausible long-run relationships, represents a significant methodological and substantive finding. This may reflect several regional characteristics:

1. **Structural Breaks and Instability:** The MENA region experienced multiple shocks during our study period (Arab Spring, oil price volatility, COVID-19) that may have disrupted potential long-run equilibria.
2. **Policy Inconsistency:** The lack of stable environmental policies and consistent institutional frameworks in many MENA countries may prevent the emergence of stable long-run relationships.
3. **Heterogeneous Adjustment Paths:** Different countries in the region may be following distinct development trajectories with varying environmental implications, preventing the emergence of a common long-run relationship.

This finding challenges the automatic applicability of standard environmental Kuznets curve frameworks to the MENA context and emphasizes the need for region-specific models that account for structural particularities and instability.

5.5. Policy Implications

Our results suggest several targeted policy interventions:

5.5.1. Economic Diversification and Green Investment

The strong growth-emissions linkage underscores the urgency of economic diversification beyond hydrocarbon dependence. Policies should prioritize:

- Strategic redirecting of investment (FBCF) toward renewable energy, energy efficiency, and green infrastructure
- Development of knowledge-intensive and service sectors with lower environmental footprints
- Implementation of carbon pricing and environmental fiscal reforms to internalize environmental costs

5.5.2. Demographic and Urban Planning

Given the major role of population dynamics, integrated approaches should include:

- Sustainable urban planning and compact city development
- Investment in public transportation and energy-efficient housing
- Education and awareness programs promoting sustainable consumption patterns

5.5.3. Institutional Reforms for Environmental Governance

The promising but complex role of institutions suggests:

- Strengthening environmental regulations and enforcement capacities
- Enhancing transparency and accountability in natural resource management
- Developing specialized environmental institutions with adequate resources and authority
- Fostering regional cooperation on environmental standards and policies

5.5.4. Natural Capital Management

Addressing the environmental resource curse requires:

- Sovereign wealth funds and resource revenue management for green investment
- Diversification strategies that reduce dependence on extractive industries
- Ecosystem accounting and natural capital valuation in development planning

5.6. Limitations and Research Directions

While our study provides robust evidence, several limitations suggest fruitful research directions:

1. **Variable Measurement:** Future research could employ more nuanced measures of institutional quality and natural capital, potentially distinguishing between different types of institutions and resources.
2. **Sectoral Decomposition:** Analyzing emissions by economic sector could provide more targeted insights for policy interventions.
3. **Non-linearities and Threshold Effects:** Investigating potential non-linear relationships, particularly for institutional quality and income levels, could reveal important nuances.
4. **Regional Heterogeneity:** Disaggregated analysis of sub-regions (GCC, North Africa, Levant) could uncover important variations within the MENA region.
5. **Incorporating Additional Variables:** Future studies could include technological innovation, trade patterns, and financial development to provide a more comprehensive understanding.

5.7. Conclusion

This study demonstrates that CO₂ emissions in the MENA region are primarily driven by economic growth, demographic pressures, and investment patterns, with natural capital exacerbating these pressures through resource-dependent development pathways. Institutional quality emerges as a potential mitigating factor, though its effects are complex and operate primarily through long-term channels.

The absence of cointegration underscores the region's environmental and economic instability, suggesting that sustainable development cannot be expected to emerge automatically from market forces alone. Rather, deliberate policy interventions, institutional reforms, and strategic investments are necessary to redirect the region toward a more sustainable development trajectory.

Our findings contribute to the broader literature on environmental economics and sustainable development by providing robust, methodologically sophisticated evidence from a critically important but understudied region. The results highlight the need for context-specific approaches that account for the unique characteristics and challenges of resource-dependent economies in the global South.

6. Conclusion and Policy Implications

This study has provided a comprehensive empirical analysis of the institutional and structural determinants of CO₂ emissions in the MENA region, utilizing a robust methodological framework that accounts for the distinctive properties of panel data in this context. Our findings, derived from multiple estimation approaches and rigorous diagnostic testing, offer both

substantive insights into the region's environmental challenges and methodological contributions to the field of environmental economics.

6.1. Summary of Key Findings

Three major conclusions emerge from our analysis:

First, **conventional economic drivers remain predominant** in shaping the region's emissions trajectory. The robust positive relationships between GDP per capita (0.48-0.60 elasticity), population growth (0.73-0.95 elasticity), and investment patterns (0.05-0.09 elasticity) with CO₂ emissions underscore the persistent carbon-intensive nature of development in the MENA region. These findings confirm that, absent deliberate intervention, economic and demographic growth will continue to drive environmental degradation.

Second, **the role of institutional quality appears complex and context-dependent**. While our results suggest a potentially beneficial effect of improved governance on emissions reduction, this relationship manifests primarily in the long term and through specifications that account for endogeneity. The weak short-term effects indicate that institutional reforms require time to translate into environmental improvements and may depend on complementary factors.

Third, **natural capital abundance exhibits a significant positive relationship with emissions**, providing strong evidence for the environmental dimension of the resource curse hypothesis. This finding highlights the structural challenges faced by resource-dependent economies in transitioning toward more sustainable development pathways.

6.2. Theoretical and Methodological Contributions

Our study makes several important contributions to the literature:

Theoretically, we demonstrate the limited applicability of standard environmental Kuznets curve frameworks to the MENA context, revealing instead a more complex interplay of economic, institutional, and structural factors. The absence of cointegration challenges assumptions about automatic long-run equilibria and emphasizes the role of policy interventions and structural transformation.

Methodologically, we advance the empirical literature on environmental economics in developing regions by employing a comprehensive diagnostic framework that addresses critical issues of cross-sectional dependence, heterogeneity, and dynamic persistence. Our multi-estimator approach provides a template for robust empirical analysis in contexts characterized by economic interdependence and institutional diversity.

Substantively, we provide the most comprehensive contemporary evidence on the determinants of CO₂ emissions in the MENA region, incorporating recent developments including post-Arab Spring reforms, oil price volatility, and COVID-19 impacts through our 2000-2022 dataset.

6.3. Policy Recommendations

Based on our findings, we propose a multi-pronged policy framework for sustainable development in the MENA region:

6.3.1. Economic Diversification and Green Industrial Policy

- Implement targeted industrial policies to promote knowledge-intensive and service sectors with lower environmental footprints
- Establish sovereign green funds to channel resource revenues into sustainable infrastructure and renewable energy projects
- Introduce carbon pricing mechanisms and environmental fiscal reforms to internalize environmental costs

6.3.2. Institutional Reform and Governance Strengthening

- Enhance environmental regulatory frameworks with clear enforcement mechanisms and monitoring systems
- Strengthen transparency and accountability in natural resource management through extractive industry transparency initiatives
- Develop specialized environmental institutions with adequate technical capacity and political authority

6.3.3. Demographic and Urban Planning

- Implement integrated urban planning approaches promoting compact cities, public transportation, and energy-efficient buildings
- Develop education and awareness programs to foster sustainable consumption patterns
- Invest in rural development to mitigate excessive urbanization pressures

6.3.4. Regional Cooperation and Knowledge Transfer

- Establish regional environmental standards and monitoring systems
- Facilitate technology transfer and joint investment in renewable energy infrastructure
- Develop regional carbon markets and environmental fund mechanisms

6.4. Limitations and Future Research Directions

While our study provides robust evidence, several limitations suggest productive avenues for future research:

First, the aggregate nature of our analysis masks important sub-regional variations. Future research could employ clustering techniques or threshold models to identify distinct development trajectories within the MENA region.

Second, our focus on CO₂ emissions as an environmental indicator could be complemented by analyses incorporating other dimensions of environmental quality, including water resources, biodiversity, and local air pollution.

Third, the measurement of institutional quality and natural capital, while based on established indices, could be refined through more nuanced indicators capturing specific governance mechanisms and resource management practices.

Finally, the incorporation of additional variables such as technological innovation, financial development, and international trade patterns could provide a more comprehensive understanding of the region's environmental challenges.

6.5. Concluding Remarks

The MENA region stands at a critical juncture, facing simultaneous challenges of economic development, environmental sustainability, and climate adaptation. Our findings demonstrate that addressing these challenges requires moving beyond conventional development models toward a more integrated approach that recognizes the complex interrelationships between economic growth, institutional quality, and natural resource management.

The absence of automatic decoupling between economic development and environmental degradation underscores the need for proactive policy interventions, institutional reforms, and strategic investments. While the challenges are significant, our analysis also identifies promising avenues for intervention, particularly through institutional strengthening and economic diversification.

As the region confronts the dual pressures of development aspirations and environmental constraints, the findings of this study provide both a sober assessment of current trajectories and a hopeful roadmap toward more sustainable futures. The successful navigation of these challenges will require not only technical solutions but also political commitment, institutional innovation, and regional cooperation—a complex but essential agenda for the MENA region in the coming decades.

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