



The Nexus between Energy Consumption, Economic Growth and CO₂ Emissions in MENA Region: Evidence from Panel Data Analysis

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Abstract

It is well-established that energy consumption plays an important role in economic development. Therefore, this study reexamines the nexus between Energy Consumption, Economic Growth and CO₂ Emissions by emphasizing the limitations of previous work. We use recent panel unit root tests and cointegration techniques considering the dependencies and structural breaks for 17 Middle East and North African Countries (MENA) over the period 1971–2008. Additionally, we check the direction of causality between variables included in the model. Our results show that in the long-run GDP and CO₂ emissions significantly influence energy consumption. More interestingly, to avoid heterogeneity problem and bias in the regressors, we apply respectively the FMOLS and the DOLS approach to estimate the long-run relationship between these three variables. Finally, we discuss the policy implications of our results.

Keywords: Energy consumption; Economic growth; CO₂ emissions; MENA countries; Panel unit root and cointegration with dependencies and structural breaks; Panel causality.

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1. Introduction

The nexus between energy consumption, economic growth, and energy consumption is highly debated and appears very complex, especially for developing countries, particularly those in the MENA region. To ensure their growth, these countries must also ensure the well-being of their populations and

respect the quality of their environments. Resource-rich countries such as Algeria and Saudi Arabia rely heavily on hydrocarbon exports for economic growth, but this dependence can hamper diversification and innovation (Al-Mawali, 2015). As countries seek to improve the economic well-being of their populations, pressure on ecosystems increases, exacerbating environmental challenges such as global warming. The MENA region's resource-rich countries are currently at the heart of discussions on the global energy transition. On the one hand, these countries are key players in the global hydrocarbon market, whose exploitation constitutes a key driver of their economic growth. On the other hand, they are particularly vulnerable to the effects of climate change, notably due to their arid climate and their dependence on sectors such as agriculture and tourism. This duality makes it imperative to carefully consider how these economies can move towards low-carbon growth models by attracting non-polluting investments. In theory, the environmental Kuznets curve hypothesis is also often used to explain the relationship between economic development and environmental conditions. According to this hypothesis, pollution increases throughout the early stages of development before decreasing beyond a certain national per capita income threshold. However, its use in the MENA region is controversial. Structural factors, such as dependence on hydrocarbon exports or the institutional-governance environment, alter economic and environmental development, thereby making it oriented differently.

In this context, the study of the relationship between energy consumption, economic growth and CO₂ emissions is an important and strategic topic. It helps to understand the economic challenges of the MENA region countries and to examine the factors that can guarantee their sustainable development. The importance of this study lies in improving the understanding of the role of growth and energy consumption on CO₂ emissions by considering all the structural shocks not previously analyzed in the previous literature and trying to fill the gap existing therein.

Recent work such as that of Mahfoudi et al. (2024) the impact of natural resources (hydrocarbons) and foreign direct investment (FDI) on economic growth in Algeria (1970-2021) in comparison with Saudi Arabia, using the ARDL model. Using the ARDL model, they studied the impact of natural resources (hydrocarbons) and foreign direct investment (FDI) on economic growth in Algeria (1970-2021) in comparison with Saudi Arabia. Their results reveal that in the long run, FDI and natural resource rents positively influence growth, although hydrocarbons play a lesser role, highlighting the need for diversification. Countries such as the United Arab Emirates, having opted for proactive approaches, demonstrate the importance of economic diversification and the consolidation of green technologies. However, in terms of regional capacity, most other countries face serious financial and institutional constraints that negatively impact their potential, highlighting the need for enhanced regional and international cooperation.

This article aims to examine the impact of energy consumption and economic growth on CO₂ emissions in a panel of countries belonging to the MENA region. It aims to enrich the literature by trying to take into account the economic dependency relationships and structural shocks that marked the study period from 1971 to 2008. The analysis is organized around five parts: introduction, literature review, empirical methodology, discussion of the results, which constitutes the heart of the study, and conclusion, highlighting the implications, limitations and research perspectives.

2. Review of Empirical Literature

Based on existing literature, the link between energy consumption, economic growth, and energy consumption is generally verified through an inverse U-shaped link between environmental deterioration and economic growth ([Shahbaz, et al., 2024](#)). The verification of the EKC curve hypothesis stating that as income increases, CO₂ emissions also increase up to a certain income threshold, after which emissions start to decrease is verified in many recent works ([Shahbaz, et al., 2024](#)). Furthermore, this can be explained by the existing non-linearity between these variables impacted by the policy, new technologies, and energy sources ([Mebrek and Louail, 2024](#)).

[Ozturk & Acaravci, \(2010\)](#) explore the relationship between CO₂ emissions, energy consumption, and economic growth in Turkey for the period 1968–2005. The authors find a unidirectional relationship from energy consumption to CO₂ emissions and from economic growth to emissions.

[Pao, and Tsai, \(2011\)](#) address the impact of economic growth and financial development on environmental degradation using panel data in BRIC countries (Brazil, Russia, India, and China) for the period between 1980 and 2007 (1992–2007). In the long run, CO₂ emissions exhibit elasticity with respect to energy consumption but remain inelastic to FDI. These results support the Environmental Kuznets Curve (EKC) hypothesis. Their results further reveal a robust bidirectional causality from production to emissions and production to energy consumption, while there is a strong unidirectional causality from energy consumption to emissions.

The study by [Apergis, & Payne, \(2010\)](#) investigates the dynamic relationships between CO₂ emissions, energy consumption, and economic growth in the member states of the Commonwealth of Independent States (CIS) over the period 1992–2004. The results show a bidirectional relationship between energy consumption and emissions, as well as a unidirectional relationship from economic growth to emissions. In addition, the authors recommend policies that integrate cleaner technologies and encourage energy diversification to reduce emissions while promoting growth.

[Saboori, Sulaiman, & Mohd, \(2012\)](#) test the environmental Kuznets curve (EKC) hypothesis in Malaysia using time series data spanning 1980–2009. The results confirm the existence of the EKC,

indicating that CO₂ emissions increase as the economy grows before decreasing after a certain income threshold.

Chandran, & Tang, (2013) analyze the effect of transport energy consumption, foreign direct investment (FDI), and income on CO₂ emissions in ASEAN-5 economies (Indonesia, Malaysia, Philippines, Thailand, and Vietnam). The results show that energy consumption in the transport sector and FDI increase emissions, while an increase in income can reduce emissions in the long run through cleaner technologies.

Omri, A. (2013) examines the simultaneous relationship between CO₂ emissions, energy consumption, and economic growth in MENA countries using a simultaneous equation model. The results indicate a bidirectional relationship between economic growth and energy consumption, as well as between energy consumption and CO₂ emissions.

Al-Mulali, *et al.* (2015) test the Environmental Kuznets Curve (EKC) hypothesis for Vietnam using time series data spanning from 1981 to 2011. Trying to examine the relationship between CO₂ emissions, GDP per capita, energy consumption, and trade openness, their empirical results confirm the validity of the EKC for Vietnam, showing that CO₂ emissions increase at the beginning of economic growth before decreasing beyond a certain income threshold.

Farhani, S and Ozturk, I (2015) analyze the causal relationships between CO₂ emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia over the period 1971–2012. Their empirical results reveal a bidirectional relationship between GDP and CO₂ emissions, as well as between energy consumption and CO₂ emissions.

Wang, *et al.* (2016), study the relationships among economic growth, energy consumption and CO₂ emissions in China using regional-level panel data. The empirical results of this work indicate that economic growth and energy consumption increase CO₂ emissions.

The study conducted by Kiliç & Balan (2018) provides a comprehensive analysis of the Environmental Kuznets Curve (EKC) hypothesis across 151 countries (1996–2010), examining the relationship between CO₂ emissions and key economic and institutional variables. The authors argue for a cubic specification for the Environmental Kuznets Curve (EKC) hypothesis, which suggests an inverted U-shaped relationship between income level and environmental degradation.

The study conducted by Jabri *et al.* (2019) examines the link between energy consumption, foreign direct investment (FDI) flows, economic growth and CO₂ emissions in Morocco over the period 1971–2014. Their results reveal the existence of a long-term relationship between the variables of the model, and confirm the hypothesis of the environmental Kuznets curve (EKC) based on the estimates obtained by the FMOLS results.

The research of [González-Alvarez, and Montañesa, \(2023\)](#) assesses the long-term dynamics between CO₂ emissions, energy consumption, and economic growth in a panel of 31 countries, highlighting structural breaks. The authors find that structural breaks play an important role and that their inclusion in this relationship, they observed that most countries had decoupled their CO₂ emissions from their economic growth, especially for advanced economies.

The format of this research is organized as follows: The first section introduces the study, the second section reviews the empirical literature, the third section describes the data and methodology, the fourth section presents the results and discussion, and the fifth section concludes with policy recommendations and research implications.

3. Bibliometrics analysis

This study can be consolidated by a bibliometric analysis using VOS viewer based on Scopus data. Search on “Energy consumption” gave more than 565,000 documents and it reduces to 35000 when associated to “CO₂”. VOS viewer is a tool to manage mapping on the most published authors, their collaborations to form clusters, the citations and the corresponding countries implied in these topics ([Bellii et al., 2020](#); [You et al., 2024](#); [Hammouti et al., 2025](#); [Kachbou et al., 2025](#)). The evolution of the scientific production quantified by Scopus-indexed articles from 2018 to 2024 is shown in [Figure 1](#).

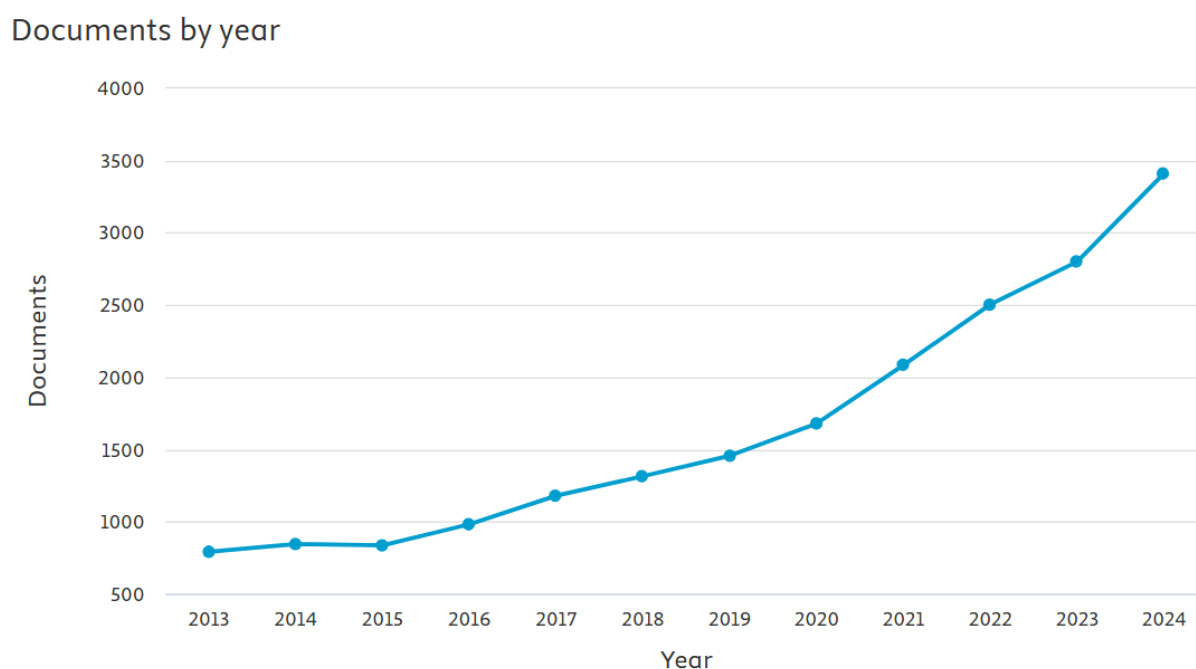


Figure 1. Evolution of the articles from 2018 to 2024

The period is selected to get less than 20,000 articles to be analyzed by VOS viewer. The ranking of authors according to Scopus analysis are collected in [Table 1](#).

Table 1. The top most contributing authors.

Author	Documents	Author	Documents
Lin, B.	87	Limmeechokchai, B.	30
Adebayo, T.S.	66	Wei, Y.M.	27
Kirik kaleli, D.	58	Cippolone, R.	25
Shahbaz, M.	54	Fuinhas, J.A.	24
Bekun, F.V.	50	Geng, Y.	24
Ozturk, I.	41	Gyamfi, B.A.	23
Fontaras, G.	33	Kartal, M.T.	23
Guan, D.	33	Chen, W.	21
Shan, Y.	33	Dong, K.	21

Among the 18-listed authors in **Table 1**, the profiler researcher, Lin, Boqiang from Xiamen University, China (Scopus ID: 35098935000), has 87 articles in this topic. He reached total citations of 43,265 by more than 28300 documents for the total published papers of 863 and a H-index equal 11. The second from Cupris, Adebayo (total papers: 278, H=74 and 15,900 citations). Among 58,781 authors, 278 having more than 10 articles are visualized by VOS viewer in **Figure 2**. The authors are indicated by circles called nodes with different colors and the size indicates the number of publications. The top author, Lin B. shown by light orange node, Adebayo (light green), Kirikkaleli (light blue), Shahbaz with dark blue.

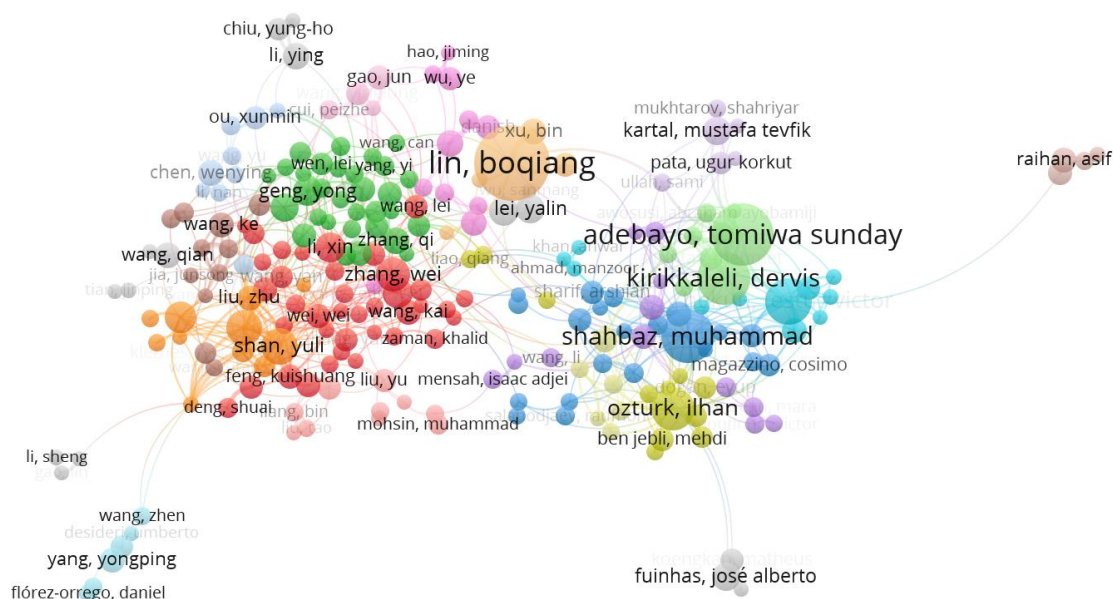
**Figure 2.** Collaboration network of the most productive authors (≥ 10 articles) from 2018 to 2024

Figure 3 is formulated to indicate the production during time, as mentioned by dark blue (2018) to yellow for recent years. In other words, Adebayo published last years and Lin towards 2018. The VOS viewer gives more information about the top countries and China with more than 5800 articles is visualized by the largest green node, followed by the US (>1800 articles), India (>1200), UK and Italy (>1100). The lines interconnecting the nodes show the collaborations between authors and countries (**Figure 4**).

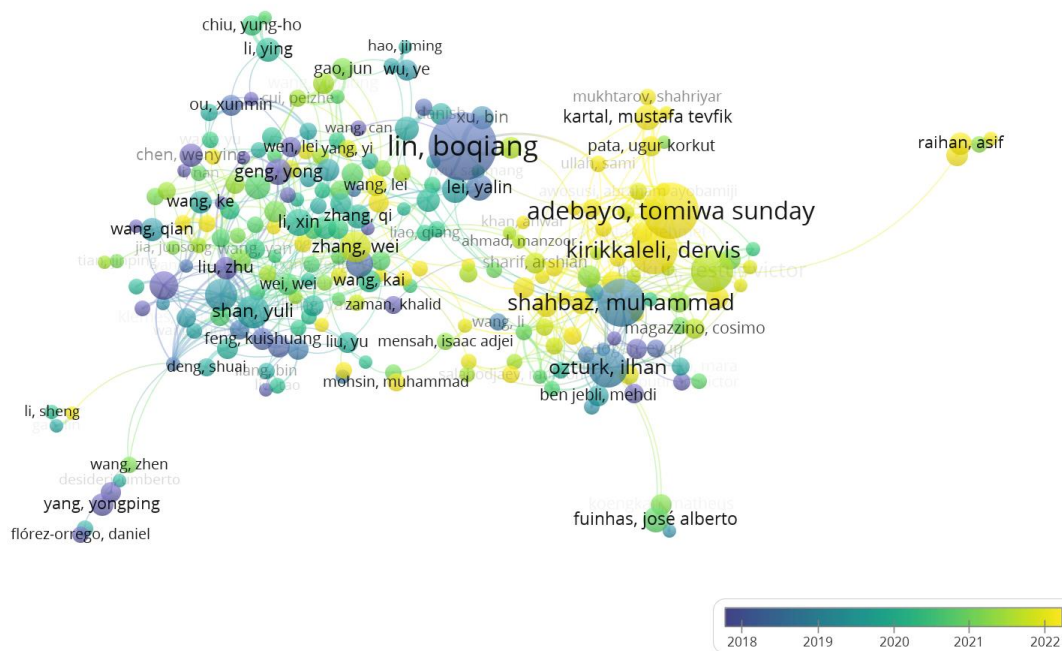


Figure 3. Overlay network of the most productive authors (≥ 10 articles) from 2018 to 2024

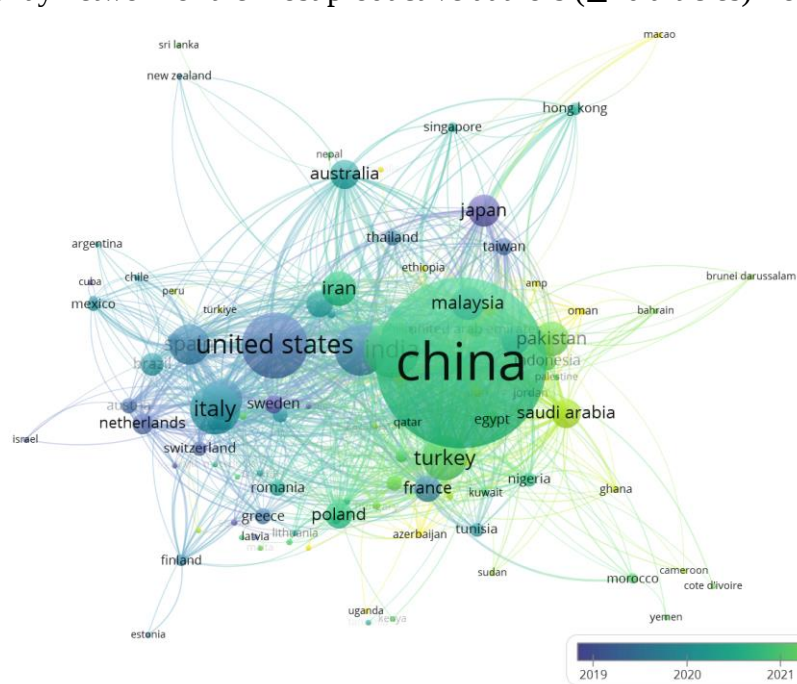


Figure 4. Overlay network of the most productive authors (≥ 10 articles) from 2018 to 2024

4. Data and Methodology

This study employs a balanced panel dataset comprising 17 countries from the MENA (Middle East and North Africa) region, covering the period from 1971 to 2008. The available data is sourced from the World Development Indicators (WDI) database (Figure 5). The data includes the following key variables: Energy Consumption (EC), Economic Growth (GDPC) – Measured by GDP per capita and CO₂ Emissions (CO₂). Following prior literature, we estimated the model specified as:

$$\ln EC_{it} = \alpha + \ln GDPC_{it} + \ln CO2_{it} + \varepsilon_{it} \quad (1)$$

From 1971 to 2008, Morocco experienced a general upward trend in GDP per capita (GDP), energy consumption (EC), and CO₂ emissions, with notable variations reflecting economic and external shocks. The close correlation between GDP and energy consumption suggests a strong dependence of economic growth on energy consumption, while the parallel but more moderate increase in CO₂ emissions shows that energy consumption remains a major source of emissions, although there are signs of disconnection possibly due to improved energy efficiency or cleaner energy sources. Periodic declines observed in all three variables are likely linked to events such as oil crises, structural reforms, or economic recessions. Overall, the observed trends highlight the need for Morocco to reconcile economic development with sustainable energy policies and environmental protection measures.

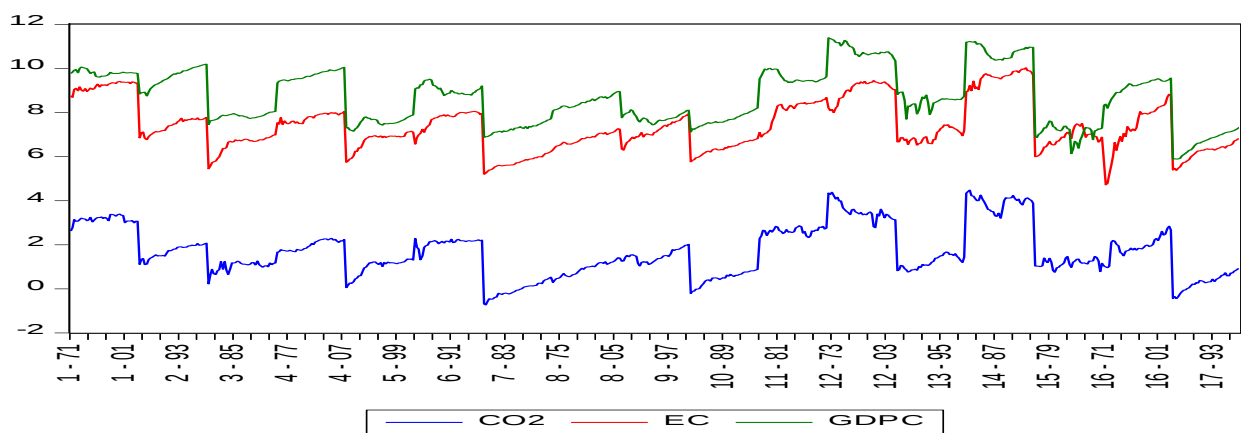


Figure 5. The graph illustrates the trends of energy consumption (EC), carbon dioxide emissions (CO₂), and GDP per capita (GDPC) in Morocco over the period 1971–2008.

4.1 Panel unit root

Panel data are often found to be non-stationary in their levels and thus produce spurious results when used for regression analysis. To assess the stationarity of the variables, the study employs first, second and third-generation panel unit root tests. These tests help determine the order of integration of

the variables and address potential cross-sectional dependencies and structural breaks. **Table 2** presents panel unit root test results for energy consumption (LnEC), GDP per capita (LNGDPC), and CO₂ emissions (LNCO₂) in MENA countries, showing that all variables are non-stationary in levels but become stationary after first differencing (I(1)), confirming the need for cointegration analysis.

Table 2: Panel unit root tests

Variables	Breitung (2000)	Im, Pesaran & Shin (2003)	Moon and Perron (2004)		Choi (2002)		Carrion-i-Silvestre & Del Barrio-Castro (2005) LM(λ)-test			
	T-stat	W-stat	Ta*	Tb*	Pm	L*	Without Breaks Homogeneous		With Breaks Heterogeneous	
<i>LnEC</i>	1.056 (0.854)	-1.138 (0.127)	-3.542 (0.000)	-4.187 (0.000)	-0.867 (0.807)	2.455 (0.993)	8.143 (0.000) [6.813]	8.264 (0.000) [7.729]	9.881 (0.000) [11.710]	19.928 (0.000) [21.613]
$\Delta(LnEC)$	-7.313 (0.000)	-11.878 (0.000)	-	-	25.519 (0.000)	-16.243 (0.000)	-	-	-	-
<i>LNGDPC</i>	-0.493 (0.310)	1.803 (0.964)	-2.485 (0.006)	-2.369 (0.008)	-0.693 (0.755)	1.542 (0.938)	6.509 (0.000) [5.822]	10.440 (0.000) [7.445]	17.703 (0.000) [23.326]	44.237 (0.000) [45.053]
$\Delta(LNGDPC)$	-6.496 (0.000)	-9.299 (0.000)	-	-	21.717 (0.000)	-13.980 (0.000)	-	-	-	-
<i>LNCO₂</i>	-1.805 (0.035)	-2.672 (0.003)	-5.425 (0.028)	-5.223 (0.08)	4.539 (0.000)	-3.138 (0.000)	3.198 (0.000) [5.271]	7.766 (0.000) [6.818]	5.245 (0.000) [12.059]	15.770 (0.000) [18.290]
$\Delta(LNCO_2)$	-	-	-	-	-	-	-	-	-	-

Notes: For the test of Carrion and al. (2005), the number of breaks points has been estimated using LWZ information criteria allowing for a maximum $m^{max}=5$ structural breaks. The long variance is estimated using the Bartlett kernel with automatic spectral window bandwidth selection as in Andrew (1991). The p-values and bootstrapped critical values are respectively in the brackets.

First-generation tests (Breitung, 2000; Im-Pesaran-Shin, 2003) largely fail to reject the null hypothesis of non-stationarity for level variables, while second-generation tests (Moon-Perron, 2004; Choi, 2002) and structural break tests (Carrion-i-Silvestre & Del Barrio-Castro, 2005) reveal that accounting for cross-sectional dependence and breaks (e.g., policy shifts or economic crises) significantly affects stationarity conclusions. For instance, the Carrion-i-Silvestre test with breaks strongly rejects non-stationarity ($p=0.000$) for all variables, emphasizing the importance of modeling structural breaks in MENA economies. These findings justify the study's use of cointegration techniques (FMOLS/DOLS) and causality tests to analyze long-run relationships between energy consumption, growth, and emissions while addressing heterogeneity and breaks in the data.

4.2. Panel Cointegration Analysis

Given the stationary nature of the variables (with structural breaks), panel cointegration tests are performed to examine whether there is a long-run equilibrium relationship between energy consumption, GDP per capita and CO₂ emissions. The cointegration test results reveal complex dynamics in the relationship between energy consumption (LnEC), GDP per capita, and CO₂ emissions in MENA

countries. The cointegration test results reveal complex dynamics in the relationship between energy consumption (LnEC), GDP per capita, and CO₂ emissions in MENA countries.

Table 3 (Pedroni tests) shows mixed evidence of cointegration: while the panel PP and rho statistics strongly reject the null of no cointegration ($p=0.000$), other statistics like the panel v-statistic fail to do so ($p=0.424$), suggesting the relationship may be sensitive to model specification.

Table 3. Tests of cointegration panel without dependencies and structural breaks
1-Cointegration Tests of Pedroni (1999)

Alternative hypothesis: common AR coeffs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	0.191	0.424	-0.834	0.798
Panel rho-Statistic	-1.624**	0.052	-3.380***	0.000
Panel PP-Statistic	-4.193***	0.000	-6.683***	0.000
Panel ADF-Statistic	1.128	0.870	0.148	0.559
Alternative hypothesis: individual AR coeffs. (between-dimension)				
	Statistic	Prob.		
Group rho-Statistic	-2.483***	0.006		
Group PP-Statistic	-6.169***	0.000		
Group ADF-Statistic	-0.2231	0.411		

Notes: The null hypothesis of Pedroni (1999, 2004) tests is no co-integration. Probability values are in brackets.

Tables 4 and 5, which account for cross-sectional dependence and structural breaks, provide more robust evidence - the Westerlund tests (Table 3) show significant cointegration when considering asymptotic p-values (0.000), though bootstrap results are less conclusive. Most notably, Table 4 demonstrates that accounting for structural breaks (particularly regime shifts) yields the strongest evidence of cointegration ($p=0.001$ for $Z_{\tau}(N)$), highlighting that major economic or policy changes fundamentally alter the long-run equilibrium relationship between these variables. These findings collectively emphasize that energy, growth and emissions in MENA countries share a cointegrated relationship, but this relationship is contingent on proper modeling of cross-country dependencies and structural breaks in the region.

Table 4. Panel cointegration tests results with cross- section dependence:
a- Westerlund and Edgerton test (2007)

	Stat-LM p-value	p-value Asymptotic	p-value Bootstrap
Model			
Model with constant	7.068	0.000	0.835
Model with constant and trend	5.015	0.000	0.976

Notes: The bootstrap is based on 2000 simulations. The null hypothesis of the test is the existence of a long-term relationship between LnEC and independent variables.

b- Westerlund error correction model and panel cointegration test (2007)

Statistic	Value	Z-value	P-value	Robust P-value
Gt	-1.838	-1.797	0.036	0.05
Ga	-4.938	0.668	0.748	0.435
Pt	-8.156	-3.231	0.001	0.01
Pa	-4.038	-1.295	0.098	0.095

Note: *** (1%) ** (5%) and * (10%) represent the significance level.

Table 5. Panel cointegration tests results with structural breaks and cross-section dependence

	$Z_{\tau}(N)$		$Z_{\phi}(N)$	
	Value	P-value	Value	P-value
Model				
No break	1.983	0.976	1.655	0.951
Level break	2.864	0.998	2.263	0.988
Regime shift	-3.105***	0.001	-1.688**	0.046

Notes: The test is implemented using the Campbell and Perron (1991) automatic procedure to select the lag length. We use three breaks, which are determined by grid search at the minimum of the sum of squared residuals. The P-values are for a one-sided test based on the normal distribution.

4.3. Panel Granger Causality tests:

The Granger causality tests (Table 6) reveal bidirectional relationships between CO₂ emissions (CO₂), energy consumption (EC), and GDP per capita (GDPC), particularly at longer lags (K=3), with CO₂ and GDPC strongly predicting EC, while EC also influences CO₂ and GDPC over time.

Table 6. Panel Granger Causality tests

	Pairwise Granger Causality Test	F-Statistic	p-value
Sample 1971-2008			
K=1			
CO2 does not Granger Cause EC	45.6487	0.000	
EC does not Granger Cause CO2	4.17829	0.041	
GDPC does not Granger Cause EC	14.2123	0.000	
EC does not Granger Cause GDPC	0.43463	0.51	
K=2			
CO2 does not Granger Cause EC	45.0326	0.000	
EC does not Granger Cause CO2	2.14829	0.117	
GDPC does not Granger Cause EC	13.6142	0.000	
EC does not Granger Cause GDPC	5.93405	0.002	
K=3			
CO2 does not Granger Cause EC	31.8174	0.000	
EC does not Granger Cause CO2	3.30159	0.000	
GDPC does not Granger Cause EC	8.29409	0.000	

The Dumitrescu-Hurlin panel causality tests (Table 7) show that these causal relationships are not uniformly present across panels at shorter lags (K=1 to K=3) but become statistically significant and homogeneous at longer lags (K=4 to K=6), indicating consistent bidirectional causality in the long run.

Table 7. Panel Causality tests (suite)

Pairwise Dumitrescu Hurlin Panel Causality Test: W-Statistic Zbar-Statistic p-value			
Sample 1971-2008			
K=1			
CO2 does not homogeneously cause EC	3.23419	5.68175	0.000
EC does not homogeneously cause CO2	4.32446	8.53420	0.000
GDPC does not homogeneously cause EC	4.48759	8.96099	0.000
EC does not homogeneously cause GDPC	3.40879	6.13854	0.000
CO2 does not homogeneously cause EC	3.97375	3.30416	0.000
EC does not homogeneously cause CO2	4.14778	3.61739	0.000
GDPC does not homogeneously cause EC	5.15219	5.42515	0.000
EC does not homogeneously cause GDPC	5.47045	5.99797	0.000
K=3			
CO2 does not homogeneously cause EC	5.40490	3.09141	0.000
EC does not homogeneously cause CO2	5.07221	2.61835	0.000
GDPC does not homogeneously cause EC	7.19472	5.63636	0.000
EC does not homogeneously cause GDPC	6.12239	4.11161	0.000

This suggests that while short-term dynamics may vary across regions, the interdependence between economic growth, energy use, and emissions stabilizes over time, emphasizing the need for policies that account for these delayed feedback effects in energy and environmental planning.

Conclusion and Policy Recommendations

This study confirms a long-run equilibrium and bidirectional causality between energy consumption, economic growth, and CO₂ emissions in MENA countries, with stronger interdependencies emerging over time. To promote sustainable development, policymakers should prioritize diversifying energy sources toward renewables, strengthening regional cooperation on climate goals, and implementing long-term strategies like carbon pricing and energy efficiency incentives. Institutional reforms to support green investments and technology adoption are also critical, drawing lessons from successful models like the UAE's diversification approach. These measures can help reconcile economic growth with environmental sustainability while addressing the region's unique vulnerabilities to climate change.

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