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The Nexus between Oil Consumption, Economic Growth, and CO_2 Emissions in Morocco

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ABSTRACT

The intricate nexus between energy consumption, economic growth, and environmental degradation, particularly in the form of CO_2 emissions, has garnered substantial academic attention due to its critical policy implications for sustainable development. This study examines the short- and long-run relationships between CO_2 emissions, GDP growth, oil consumption, and population growth in Morocco, employing the autoregressive distributed lag (ARDL) bounds testing approach. Using time-series data from 1990 to 2022, the analysis reveals that GDP growth and oil consumption significantly drive CO_2 emissions in the long run, reflecting the environmental costs of economic expansion and fossil fuel dependence. However, population growth shows a negative relationship with emissions, suggesting possible gains from energy efficiency and urbanization. In the short run, GDP exhibits mixed lagged effects on emissions, while the error correction term indicates rapid adjustment toward equilibrium. These findings align with global literature on energy-economy-environment linkages and highlight the need for Morocco to prioritize renewable energy adoption and sustainable urban planning.

Keywords: Economic Growth, Energy Consumption, CO_2 Emissions, Autoregressive Distributed Lag Approach
JEL Classifications: C01, Q43, F43

1. INTRODUCTION

Energy, as a fundamental driver of economic growth and social progress, is essential across all sectors of a nation's economy. Changes in energy consumption are closely linked to economic and social development. Ensuring energy security is vital for a country's economic stability, while analyzing the energy structure provides valuable insights into its economic trajectory and future industrial development.

The conventional oil and gas industry is facing significant challenges as it seeks to adapt its business models to the evolving energy landscape while maintaining the relevance of its operations. Although the global transition to renewable energy is underway, fossil fuels will continue to play a central role in energy supply for the foreseeable future. Many nations anticipate that geothermal, tidal, solar, and wind energy will dominate future energy systems (Abban et al., 2023).

Currently, our heavy reliance on finite fossil fuel resources powers essential sectors, including homes, workplaces, schools, public infrastructure, and industries, offering reliable and cost-effective energy. However, this dependence comes at a steep environmental cost, as the continued use of fossil fuels significantly contributes to CO_2 emissions and accelerates climate change.

To mitigate and eventually reverse this environmental harm, a shift to renewable energy sources is imperative. While renewable energy holds immense promise in addressing the adverse effects of fossil fuel use, broader considerations—such as ensuring energy affordability, accessibility, and sustainability—must also be prioritized to meet the demands of a growing global market (De La Peña et al., 2022).

Existing literature has extensively explored the relationship between economic growth and environmental degradation, particularly through the environmental Kuznets curve (EKC) hypothesis. This hypothesis posits a non-linear relationship in which environmental degradation, such as CO_2 emissions, initially increases with economic growth but eventually decreases as a country reaches higher levels of development. However, empirical findings remain mixed, particularly for emerging economies like Morocco, where unique structural and developmental factors may influence the trajectory of emissions differently compared to advanced economies.

In the Moroccan context, key drivers such as industrial expansion, urbanization, and increased energy demand have contributed to rising emissions. Yet, Morocco's progressive adoption of renewable energy, particularly through ambitious initiatives like the Noor solar power project, and investments in sustainable technologies are beginning to shape the country's environmental performance. While innovation plays a crucial role in mitigating emissions, it remains under-researched in Morocco's case. Indicators such as patent applications (PA) for green technologies could provide valuable insights into how innovation supports CO_2 reduction efforts.

Despite Morocco's significant strides in renewable energy and its status as a leader in Africa for clean energy investments, the extent to which these measures have reduced emissions is still unclear. Further research is needed to examine whether Morocco's innovations in green technology align with the EKC hypothesis and how these efforts compare globally.

This paper aims to fill the gap in understanding the determinants of CO_2 emissions in Morocco, with a particular focus on the role of gross domestic product (GDP) and oil consumption as key drivers of environmental degradation. To explore these relationships comprehensively, we employ the autoregressive distributed lag (ARDL) approach, which offers the flexibility to capture both short- and long-run dynamics. This method is particularly suited for analyzing the Moroccan context, where structural breaks, economic cycles, and fluctuations in energy consumption patterns are prevalent.

The specific research questions this study addresses are:
1. What are the short-run and long-run impacts of GDP and oil consumption on CO_2 emissions in Morocco?
2. How do these relationships inform Morocco's policy objectives in balancing economic growth with environmental sustainability?

This research contributes to the literature in several important ways. First, it extends the analysis of the determinants of CO_2 emissions by focusing on Morocco, a developing economy undergoing significant energy and economic transitions. Second, the use of the ARDL approach allows for robust estimation of the short- and long-term relationships while addressing non-linearities and structural dynamics unique to Morocco. Third, the findings will provide insights critical for Moroccan policymakers aiming to design strategies that mitigate emissions without compromising economic development, particularly in a context heavily reliant on fossil fuels.

The structure of the paper is as follows. Section 2 reviews the relevant literature and highlights the gap this study seeks to address. Section 3 outlines the data and methodology, detailing the variables, data sources, and the ARDL model specification. Section 4 presents the empirical findings, discussing the implications of GDP and oil consumption on CO_2 emissions. Finally, Section 5 concludes with policy recommendations, emphasizing strategies for reducing emissions while fostering sustainable economic growth in Morocco.

2. LITERATURE REVIEW

2.1. Theoretical Literature Review

Existing literature highlights the intricate relationship between economic growth, energy consumption, and environmental pollution. Studies (e.g., Dabic et al., 2023; Dahinine et al., 2024) point to a bidirectional causality between energy consumption and economic growth, with environmental pollution often escalating as economies expand. However, a shift toward renewable energy sources has been shown to mitigate pollution levels (Awosusi et al., 2024; Deng et al., 2024; Ding et al., 2023; Do et al., 2023).

The nexus between energy consumption and economic growth has been extensively explored across various economies, including emerging markets. Research (Awosusi et al., 2023; Hoa et al., 2023; Hoa et al., 2024) consistently demonstrates a bidirectional causality, where economic growth drives energy consumption, while energy consumption, in turn, fuels economic activities. This dynamic is particularly significant for developing countries like Morocco, where energy infrastructure plays a critical role in supporting industrialization and urbanization. Similarly, Le (2022) emphasizes that energy consumption is a fundamental driver of economic growth in the Commonwealth of Independent States, a finding that resonates with Morocco's developmental trajectory and its increasing energy demands.

Morocco's energy mix still relies heavily on fossil fuels, primarily imported coal and oil, despite substantial renewable energy investments. This dependence comes with significant environmental costs. Research (Jiannan and Waseem, 2024) identifies fossil fuel combustion as a leading contributor to air pollution and greenhouse gas emissions, causing severe environmental and public health challenges. In the Moroccan context, higher fossil fuel consumption correlates with increased emissions of pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NOx), further exacerbating environmental degradation and health risks (Kusuma and Irawan, 2018; Liu et al., 2022; Zhao et al., 2023).

Population growth is a significant factor influencing energy demand and environmental sustainability. In Morocco, a steadily increasing population, coupled with rapid urbanization, places growing pressure on the country's energy infrastructure and natural resources. Research (e.g. Wang, 2020; Pata and Samour, 2023) highlights that population growth directly leads to higher energy consumption, which in turn exacerbates environmental pollution. In Morocco's context, rising electricity demand necessitates the expansion of energy production and infrastructure to support both residential and industrial needs. This trend underscores the importance of adopting sustainable energy solutions to mitigate environmental impacts while meeting the demands of a growing population.

GDP growth is both a driver and a consequence of increased energy consumption. The Environmental Kuznets Curve (EKC) hypothesis (Paudel et al., 2023; Pittz and Adler, 2023; Principato et al., 2023) suggests that economic growth initially leads to environmental degradation but, beyond a certain income threshold, fosters environmental improvements through investments in cleaner technologies and the enforcement of stricter environmental regulations. In Morocco, evidence aligns with the EKC hypothesis, as economic growth has initially intensified environmental pressures, particularly due to the reliance on fossil fuels and energy-intensive industries. However, as Morocco's GDP continues to grow, there has been increased investment in renewable energy projects, such as the Noor Ouarzazate Solar Complex, and the implementation of environmental policies aimed at promoting sustainability. These efforts illustrate Morocco's potential to transition toward a greener economy while addressing the dual challenges of economic development and environmental protection.

Technological innovation plays a pivotal role in reducing emissions by driving the development of cleaner technologies, energy-efficient processes, and renewable energy solutions. Several studies highlight the use of patent applications (PA) as a proxy for measuring innovation. For instance, Popp (2002) emphasizes that advancements in clean technologies can significantly reduce the environmental footprint of economic activities, with patent applications serving as a reliable indicator of a country's technological progress. Innovation-driven growth, particularly in the renewable energy sector, facilitates the creation of low-carbon technologies, helping to mitigate the environmental impact of economic expansion.

The energy transition literature underscores the importance of shifting from fossil fuels to renewable energy sources in lowering CO_2 emissions, a necessity that is increasingly relevant for both developing and developed economies. Renewable energy sources are recognized for their potential to decouple economic growth from emissions, as demonstrated in studies such as Sadorsky (2009). For Morocco, a leader in renewable energy adoption in Africa, the development of large-scale projects like the Noor Solar Power Plant exemplifies the potential for innovation to support a sustainable energy transition. This transition is further bolstered by advancements in energy technologies, which improve the efficiency, scalability, and affordability of renewable energy solutions. Morocco's proactive policy framework and investments in clean energy provide a roadmap for achieving a low-carbon economy while fostering economic growth.

2.2. Empirical Literature Review

The traditional environmental Kuznets curve (EKC) model describes an inverted U-shaped relationship between economic growth and environmental pollution. According to this model, environmental pollution tends to increase as a country's economic growth rises, reaching a peak, and then declines after surpassing a certain threshold of economic development. Initially, during the early stages of economic growth, industrialization and urbanization contribute significantly to environmental degradation. However, as a country achieves greater economic prosperity, heightened environmental awareness, investments in technological innovation, and the implementation of environmental protection measures lead to a gradual reduction in pollution levels.

Several studies support the EKC hypothesis. For instance, Murshed et al. (2020), Akadırı et al. (2021), and Balsalobre-Lorente et al. (2021) provide evidence affirming the EKC model through various methodologies. Destek and Sarkodie (2019) analyzed the relationship between economic growth, energy consumption, financial development, and ecological footprint using panel data from eleven newly industrialized countries between 1977 and 2013. Employing the augmented mean group (AMG) estimator and heterogeneous panel causality methods, their results confirmed an inverted U-shaped relationship between economic growth and ecological footprint.

Yin and Zhang (2021), using a simultaneous equations framework, explored the causal relationship between foreign direct investment (FDI), CO_2 emissions, and economic growth across 101 countries segmented by income groups. Their findings validated both the pollution haven hypothesis and the EKC hypothesis. Similarly, Farooq et al. (2022) investigated the impact of globalization on CO_2 emissions using data from 180 countries between 1980 and 2016, finding strong evidence that economic globalization negatively affects environmental sustainability, while also confirming the EKC hypothesis across different models. Zhang and Li (2019) tested the EKC hypothesis by analyzing CO_2 emissions from manufacturing and construction in 121 countries from 1960 to 2014, calculating inflection points for those countries where the EKC hypothesis was validated.

Understanding the relationship between energy consumption, economic growth, and carbon emissions is vital for addressing climate change challenges and achieving the sustainable development goals (SDGs). A growing body of empirical research has explored these interconnections, shedding light on their dynamics across different regions and economies.

For instance, Shafiei and Salim (2014) employed the STIRPAT methodology to analyze factors influencing CO_2 emissions in OECD countries during 1980-2011. Their findings revealed that non-renewable energy consumption increases CO_2 emissions, while renewable energy use mitigates them. Similarly, Chen et al. (2016) applied panel cointegration and vector error-correction methods to study the relationship between economic activity, energy consumption, and environmental factors across 188 nations from 1993 to 2010. They found long-term relationships among these variables, with energy consumption directly affecting CO_2 emissions in a unidirectional manner across all economies.

Wang et al. (2018) investigated the linkage between economic growth, energy consumption, and CO_2 emissions in 170 economies from 1980 to 2011. Their panel cointegration tests confirmed a significant positive relationship between these variables over time. However, Granger causality tests revealed variations in causality links across income-based subpanels. Adebayo and Akinsola (2021) focused on Thailand from 1971 to 2018 and found that economic growth changes were closely tied to changes in CO_2 emissions. Their study also highlighted a positive short- and long-term relationship between energy consumption and CO_2 emissions, with a bidirectional causality between the two.

In the North African context, Musah et al. (2022) used CS-ARDL and CCEMG estimators to examine the connection between energy use and CO_2 emissions from 1990 to 2018. They found that increased energy consumption significantly deteriorated environmental quality, contributing to higher CO_2 emissions. Similarly, Raihan (2023) employed the ARDL and VECM methods to study Vietnam's economic growth, energy use, and CO_2 emissions from 1984 to 2020. The results indicated that economic growth and energy consumption led to environmental degradation through increased CO_2 emissions in both the short and long term.

In the case of Saudi Arabia, Khan and Khan (2024) applied ARDL and Granger causality tests to analyze the relationship between energy consumption, economic growth, and CO_2 emissions from 1985 to 2021. They found a positive relationship between energy consumption and CO_2 emissions, with unidirectional causality running from energy use to emissions.

The Malthusian theory, developed during the pre-industrial era, posits that population growth negatively impacts environmental quality. It argues that as populations grow, economic activities such as agriculture intensify, leading to the overexploitation of natural resources and increased use of chemical fertilizers. These practices result in deforestation, soil degradation, and contamination of water sources (Cropper and Griffiths, 1994; Novotny, 1999; Maja and Ayano, 2021). Additionally, population growth drives urban expansion and changes in transportation patterns, which exacerbate air pollution (Lu et al., 2021). Thus, higher population growth is associated with increased production and worsening environmental degradation.

In contrast, Simon (1996) proposed that population growth fosters innovation by expanding the pool of knowledge and expertise. This "Simon effect" suggests that higher population levels lead to the development and adoption of environmentally friendly technologies (Kruse-Andersen, 2023). According to this view, population growth could have a positive impact on environmental quality by driving technological advancements (Bretschger, 2020).

Empirical studies on the relationship between population density and environmental quality have yielded inconclusive results, which can be categorized into three main perspectives:
1. Population growth reduces pollution: Some studies find that higher population density is associated with reduced environmental pollution, potentially due to improved energy efficiency and resource optimization (e.g., Chen et al., 2020; Wang et al., 2021; Shao and Wang, 2023).
2. Population growth increases pollution: Other studies suggest that higher population density leads to increased CO_2 emissions as economic activities expand to meet growing demand, exacerbating environmental damage (e.g., Rahman and Alam, 2021; Musah et al., 2021; Wang and Li, 2021).
3. Mixed effects- the inverted U-shape: A third group of studies reveals an inverted U-shaped relationship between population density and environmental quality. In this scenario, environmental degradation increases during the early stages of population growth. However, beyond a certain threshold, population growth contributes to improved environmental quality, likely due to heightened environmental awareness and the adoption of sustainable practices (e.g., Gierałtowska et al., 2022; Latief et al., 2022).

By integrating theoretical frameworks and empirical evidence, this study utilizes the ARDL model to investigate the dynamics between economic growth, oil consumption, population growth, and CO_2 emissions in Morocco. Building on the insights from the reviewed literature, the next section outlines the data and methodology used to analyze these intricate relationships among the variables.

3. DATA AND METHODOLOGY

3.1. Data Sources

The data for this study were collected from reliable sources to ensure the accuracy and consistency of the analysis. Data on CO_2 emissions (measured in metric tons per capita), GDP growth (annual percentage), oil consumption (in TJ), and population growth (annual percentage) were obtained from the following sources as summarized in Table 1.

3.2. Data Stationarity

In this study, we conducted a comprehensive examination of the stationarity of each variable using two widely recognized tests: The augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. These tests are crucial in time series analysis as they determine whether the data exhibits stationary behavior or contains a unit root, indicating non-stationarity. The application of these stationarity tests to our variables considered in this study we accurately identified the order of integration for each variable. This step ensures the validity and reliability of our time series analysis, providing a robust foundation for meaningful and accurate results.

3.3. Model Specification and Estimation Method

In this study, the estimated model is specified as follows:

$$CO_2 = f(GDP, Oil, Pop)$$

The data were analyzed using a time series analysis approach, with STATA software employed for data management, handling, and analysis. The study utilized the autoregressive distributed lag (ARDL) model, developed by Pesaran and Shin (1999) and later extended by Pesaran et al. (2001). The ARDL model offers significant advantages over related econometric models, particularly its suitability for shorter time series and its ability to accommodate variables with different orders of integration (I(0) and I(1)). Additionally, the ARDL bounds testing procedure corrects for endogeneity and provides efficient long-run estimates with valid t-statistics.

Table 1: Data description and sources

Variable	Description	Unit	Source	Time period
CO_2 emissions	Annual carbon dioxide emissions	Metric tons per capita	World Bank	1990-2022
GDP growth	Annual percentage change in GDP	Percentage	World Bank	1990-2022
Oil consumption	Annual oil consumption	TJ	International Energy Agency	1990-2022
Population growth	Annual population growth rate	Percentage	World Bank	1990-2022

The initial step in time series analysis involves testing the stationarity of the data to ensure reliability and efficiency. This was achieved using the Augmented Dickey-Fuller (ADF) unit root test (Dickey and Fuller, 1979). Once the stationarity properties were confirmed, the ARDL bounds test was employed to examine the presence of a long-run relationship among the variables. The bounds test compares the calculated F-statistic against critical values provided in the Pesaran et al. (2001) table. The Akaike information criterion (AIC) was used to determine the optimal lag length for the model.

The model specification for the autoregressive distributed lag (ARDL) framework, as proposed by Pesaran et al. (2001), is expressed as follows:

$$\Delta CO_{2t} = a_0 + \sum_{k=1}^{n} a_{1k}\Delta CO_{2t-k} + \sum_{k=0}^{p} a_{2k}\Delta GDP_{t-k} + \sum_{k=0}^{q} a_{3k}\Delta Oil_{t-k} + \sum_{k=0}^{s} a_{4k}\Delta Pop_{t-k} + \beta_1 CO_{2t-1} + \beta_2 GDP_{t-1} + \beta_3 Oil_{t-1} + \beta_4 Pop_{t-1} + \varepsilon_t$$

If cointegration is established, an error correction model (ECM) is estimated to analyze both the short- and long-run dynamics. The ECM requires the inclusion of an error-correction term (ECt-1), which indicates the speed of adjustment toward equilibrium. For convergence in the long run, the ECM coefficient must be negative and statistically significant. A positive ECM coefficient would imply model divergence and a lack of long-run equilibrium. In cases where no cointegration is detected, only the short-run equation is estimated.

The hypotheses for the bounds test are as follows:

- Null hypothesis (H_0): No cointegration exists among the variables: H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4$
- Alternative hypothesis (H_1): A long-run relationship exists among the variables: H_1: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4$
- The F-statistic serves as the decision criterion:
- If the F-statistic is below the lower bound, H_0 cannot be rejected, indicating no long-run relationship
- If the F-statistic exceeds the upper bound, H_0 is rejected, confirming a long-run relationship
- If the F-statistic falls between the bounds, the result is inconclusive.

A series of post-estimation diagnostic tests, including assessments for normality, serial correlation, heteroscedasticity, and stability, were conducted. These tests are essential to ensure the reliability of the model and to identify any potential issues that could affect the validity of the results. Performing these diagnostics after the main analysis helps confirm that the model is robust and free from significant econometric problems.

4. FINDINGS AND RESULTS

4.1. Descriptive Statistics

In Morocco, oil consumption and GDP have shown a general upward trend from 1990 to 2022. Oil consumption increased steadily from 150,664 TJ in 1990 to a peak of 543,759 TJ in 2022, reflecting rising energy demand. GDP also grew significantly, from 30 billion USD in 1990 to 130 billion USD in 2022, showcasing economic expansion. However, temporary fluctuations in both oil consumption and GDP are observed, particularly in 2020 during the COVID-19 pandemic, which caused a decline in oil consumption to 485,868 TJ and GDP to 121 billion USD before recovering in subsequent years. The trend followed by each variable considered in this study is shown in Figure 1.

The following Table 2 summarizes descriptive statistics for log-transformed variables. All variables display relatively symmetric distributions with close means and medians, indicating consistency. The range is largest for GDP (24.13-25.68) and smallest for population growth (0.0069-0.59). Standard deviations indicate moderate variability, with LOGPOP showing the least dispersion (0.15). Skewness and kurtosis values suggest that all variables are fairly normally distributed. Jarque-Bera test probabilities exceed 0.05, confirming the normality assumption for all variables.

4.2. Stationarity Test

The ARDL model accommodates variables that are either stationary at level (I(0)) or first-difference stationary (I(1)), or a combination of both. However, it cannot be applied to variables integrated of order 2 (I(2)) or higher, as this could lead to spurious regressions. Therefore, conducting a unit root test is essential to ensure that all variables in the model meet this requirement. Table 3 presents the results of the augmented Dickey-Fuller (ADF) and Phillips-Perron tests. The Akaike Information Criterion (AIC) was employed to determine the appropriate lag length for the series.

The results of the stationarity tests, using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) methods, show that all variables (Log(CO2), Log(GDP), Log(Oil), and Log(Pop)) are non-stationary at their levels, as indicated by high p-values (greater than 0.05). However, after taking the first differences, all variables become stationary, with p-values below 0.05, leading to the rejection of the null hypothesis of non-stationarity. The results of both, ADF and PP tests indicate that all variables are integrated of order one (I(1)), making them suitable for inclusion in the ARDL model.

4.3. F-Bound Test

Table 4 presents the results of the ARDL bounds test for cointegration. The test indicates that the variables in the model (Log(CO2), Log(GDP), Log(Oil), and Log(Pop)) are cointegrated at the 1% significance level. The calculated F-value (13.08) exceeds the upper bound I(1) critical value (4.66) at the 0.01 significance level. This result leads to the rejection of the null hypothesis of no cointegration, confirming the existence of a long-run relationship among the variables.

4.4. Long Run Estimation Results

The long-run estimation results reveal significant relationships between the dependent variable (Log(CO_2)) and the independent variables (Log(GDP), Log(Oil), and Log(Pop)). All coefficients are statistically significant, as indicated by their P-values, which are below the 0.05 threshold, highlighting their importance in explaining CO_2 emissions (Table 5).

The coefficient associated with GDP indicates is 0.13, suggesting that a 1% increase in GDP is associated with a 0.13% increase in CO_2 emissions in the long run, holding other variables constant. This positive relationship implies that economic growth contributes to environmental degradation, likely due to increased industrial activities and energy demand.

The positive and statistically significant coefficient of GDP indicates that economic growth is associated with an increase in CO_2 emissions in Morocco. This finding aligns with the environmental Kuznets curve (EKC) hypothesis, which posits that emissions rise during early stages of economic growth due to industrialization and energy-intensive activities before declining as economies transition to cleaner technologies and heightened environmental awareness (Acheampong, 2018; Kuziboev et al., 2024). Studies on Saudi Arabia (Al-Mulali, 2011) and Indonesia (Vu Ngoc Xuan, 2024) show similar patterns, where GDP growth drives emissions due to fossil fuel reliance in early development phases. However, countries with strong renewable energy adoption, like Kazakhstan, demonstrate potential to decouple GDP growth from emissions in the long term (Kuziboev et al., 2024).

The coefficient associated with oil consumption indicates is 0.52, indicating that a 1% increase in oil consumption results in a 0.52% increase in CO_2 emissions, all else being equal. This strong positive relationship highlights the significant role of oil consumption in driving emissions, emphasizing the need for Morocco to accelerate its transition toward cleaner energy sources. This result is consistent with findings from MENA countries, where oil consumption directly correlates with higher CO_2 emissions (Al-Mulali, 2011). The study by Al-Mulali (2011) confirmed that oil consumption significantly contributes to economic growth while exacerbating environmental degradation in resource-dependent economies. Similar patterns are observed in Indonesia, where fossil fuel dependency intensifies pollution despite efforts to transition toward renewable energy (Vu Ngoc Xuan, 2024).

The coefficient associated with population indicates that a 1% increase in population is associated with a 0.77% decrease in CO_2 emissions, holding other factors constant. This unexpected negative relationship may suggest that population growth in Morocco drives shifts toward more energy-efficient practices or urbanization patterns that lower per capita emissions. typically, population growth intensifies energy demand and emissions, as seen in ASEAN countries (Winny Perwithosuci et al., 2022) and Central Asia (Kuziboev et al., 2024). This unexpected result for Morocco may indicate shifts in energy efficiency, urbanization, or demographic changes that reduce per capita emissions. Acheampong (2018) highlighted similar complexities in sub-Saharan Africa, where energy use efficiency moderated the effects of population growth on emissions.

4.5. Short Run Estimation Results

The short-term dynamics indicate that changes in GDP growth Δ(LOGGDP) have a mixed and lagged impact on CO_2 emissions. The immediate change Δ(LOGGDP) is not statistically significant (P = 0.1474), suggesting that GDP growth in the current period

Table 2: Descriptive statistics of variables

Parameter	LOGCO$_2$	LOGGDP	LOGOIL	LOGPOP
Mean	3.770394	24.97049	12.75685	0.286751
Median	3.820465	25.05247	12.83632	0.293103
Maximum	4.328477	25.67925	13.20626	0.590804
Minimum	3.111772	24.13044	11.92281	0.006895
Standard Deviation	0.366623	0.525694	0.405514	0.148119
Skewness	−0.196459	−0.218570	−0.477734	−0.187432
Kurtosis	1.764933	1.445183	1.866151	2.697928
Jarque-Bera	2.309689	3.586755	3.022986	0.318685
Probability	0.315107	0.166397	0.220580	0.852704

Table 3: ADF and PP stationarity tests results

Variables	Stationarity	ADF		PP		Order of integration
		t-Statistic	P-value	t-Statistic	P-value	
Log (CO_2)	Level	−1.554161	0.7878	−.605922	0.2803	I (1)
	1st difference	−9.10811	0.000	−10.7948	0.000	
Log (GDP)	Level	−1.382016	0.8471	−1.346537	0.8573	I (1)
	1st difference	−5.810111	0.0002	−5.818030	0.0002	
Log (Oil)	Level	−1.317081	0.8653	−1.234224	0.8859	I (1)
	1st difference	−6.609225	0.0000	−6.814061	0.0000	
Log (Pop)	Level	−2.565115	0.2974	−2.084411	0.5345	I (1)
	1st difference	−3.415265	0.0013	−3.746679	0.0338	

Table 4: ARDL bound test for cointegration results

F-bounds test		Null hypothesis: No levels relationship		
Test statistic	Value	Significant (%)	I (0)	I (1)
F-statistic	13.08212	10	2.37	3.2
k	3	5	2.79	3.67
		2.5	3.15	4.08
		1	3.65	4.66

Table 5: Long-run estimation results

Variable	Coefficient	Standard Error	t-Statistic	Prob.
LOGGDP	0.12917	0.04969	2.599452	0.0145
LOGOIL	0.517266	0.116686	4.432970	0.0003
LOGPOP	−0.766998	0.085846	−8.934622	0.0000
C	−5.825748	0.875618	−6.653297	0.0000

Table 6: Short-run estimation results

Variable	Coefficient	Standard Error	t-Statistic	Prob.
Δ(LOGGDP)	0.070803	0.046983	1.506988	0.1474
Δ(LOGGDP(-1))	−0.091952	0.047444	−1.938100	0.0669
Δ(LOGGDP(-2))	−0.128187	0.051642	−2.482224	0.0221
Δ(LOGGDP(-3))	0.099624	0.050211	1.984127	0.0611
CointEq(-1)*	−0.821847	0.092763	−8.859612	0.0000

Table 7: Diagnostic statistic tests results

Diagnostic test	Statistical test	Value	P-value
Normality	Jarque-Bera	1.01058	0.6033
Serial correlation	Breusch-Godfrey serial correlation LM test	1.55239	0.4602
Heteroskedasticity	Bresuch-Pagan Godfrey	4.22191	0.8366

does not significantly influence emissions. However, lagged changes show significant effects: the second lagΔ(LOGGDP(-2)) has a negative coefficient (−0.128187, P = 0.0221), indicating that GDP growth two periods earlier reduces emissions in the current period (Table 6).

These results are consistent with studies such as Vu Ngoc Xuan (2024), which identified lagged relationships between GDP and emissions, reflecting the time it takes for economic activities and policies to translate into environmental impacts. Similarly, Al-Mulali (2011) found that short-term GDP fluctuations in MENA countries did not immediately alter CO_2 emissions but had delayed effects due to the inertia of industrial and energy systems.

The coefficient for the error-correction term CointEq(-1) is −0.821847 and highly significant (P = 0.0000), indicating rapid adjustment toward the long-run equilibrium. Approximately 82% of the deviation from the long-run equilibrium is corrected in the next period, reflecting a robust long-term relationship between the variables. This aligns with findings from Acheampong (2018), who observed similar correction speeds in sub-Saharan Africa, emphasizing the strong pull toward equilibrium in economies with integrated policies for growth and emissions reduction.

In comparison with ASEAN countries (Winny Perwithosuci et al., 2022), the short-term dynamics in Morocco appear to have a more delayed and mixed effect, possibly due to differences in industrial structure and energy dependence. Studies in Central Asia (Kuziboev et al., 2024) have shown more immediate short-term effects, reflecting the region's reliance on energy-intensive activities and fossil fuels. Morocco's relatively rapid adjustment speed suggests that its policies and economic systems are more responsive in aligning short-term fluctuations with long-term sustainability goals.

4.6. Model Diagnostic Results

To validate the robustness and reliability of the model, three key diagnostic tests were performed: the Jarque-Bera test for normality, the Breusch-Godfrey LM test for serial correlation, and the Breusch-Pagan-Godfrey test for heteroskedasticity (Table 7).

The Jarque-Bera test was used to evaluate the normality of the residuals in the model. With a test statistic value of 1.01058 and a P = 0.6033, the null hypothesis, which states that the residuals are normally distributed, cannot be rejected. This result indicates that the residuals follow a normal distribution, satisfying one of the key assumptions for the validity of the model.

The Breusch-Godfrey serial correlation LM test was employed to check for autocorrelation in the residuals. The test yielded a statistic of 1.55239 with a P = 0.4602, leading to the acceptance of the null hypothesis, which states that there is no serial correlation in the residuals. This implies that the residuals are independent over time, further supporting the robustness of the model.

The Breusch-Pagan-Godfrey test was used to assess whether the residuals have constant variance (homoskedasticity). The test statistic of 4.22191 with a P = 0.8366 indicates that the null hypothesis of homoskedasticity cannot be rejected. This result confirms that the residuals exhibit constant variance, suggesting the absence of heteroskedasticity in the model.

The stability of the short-run and long-run coefficients in the model was assessed using the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests, as recommended by Pesaran and Shin (1999) for post-estimation diagnostics. The null hypothesis (H_0) assumes that the regression coefficients are stable over time. The graphical results of these stability tests are displayed in Figures 2 and 3. The CUSUM test plot crosses the lower limit around 2020, indicating a potential deviation from stability at that point. Overall, the results suggest that the model is stable at the 5% significance level, confirming its reliability within this threshold.

Figure 1: The evolution of CO2, gross domestic product, oil consumption, population in logarithmic form

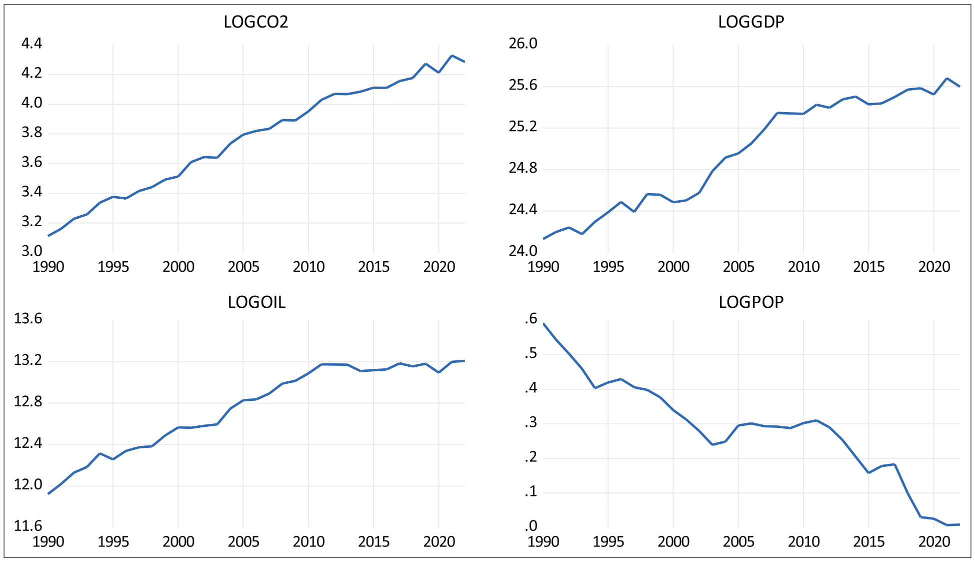


Figure 2: Cumulative sum tests for model

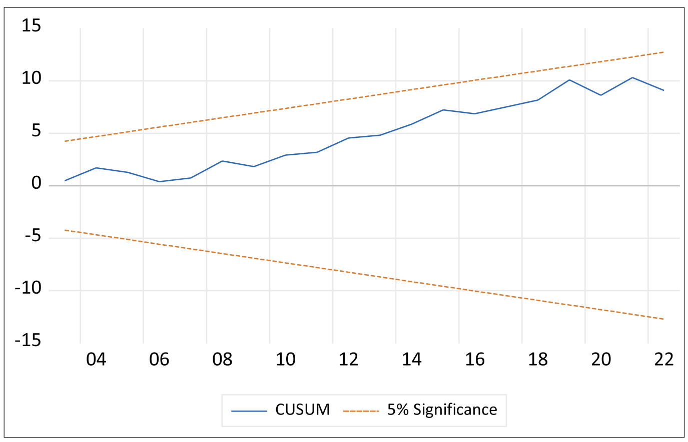
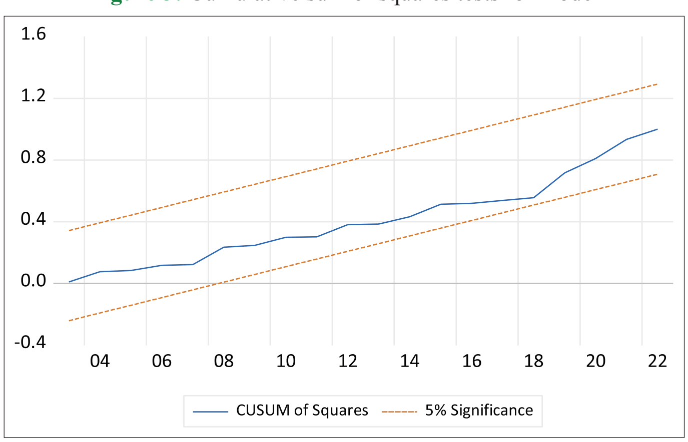


Figure 3: Cumulative sum of squares tests for model



5. CONCLUSION

This study explores the short- and long-term dynamics between CO_2 emissions, GDP growth, oil consumption, and population growth in Morocco using the ARDL bounds testing approach. The findings provide valuable insights into the interplay between economic growth, energy consumption, demographic changes, and environmental sustainability.

In the long run, GDP growth and oil consumption are significant drivers of CO_2 emissions, underscoring the environmental costs associated with Morocco's economic expansion and dependence on fossil fuels. Conversely, population growth exhibits an unexpected negative relationship with emissions, suggesting that demographic factors may be influenced by shifts in urbanization and energy efficiency. The short-term dynamics reveal mixed effects of GDP on emissions, with lagged impacts reflecting the delayed influence of economic activities and policies on environmental outcomes. The significant and negative error-correction term indicates a rapid adjustment toward long-run equilibrium, highlighting the robustness of the long-term relationships.

These results align with existing literature, including studies from MENA, ASEAN, and Central Asia, which emphasize the role of GDP and oil consumption as critical determinants of emissions. However, Morocco's rapid adjustment speed and the unexpected population-emissions relationship indicate unique characteristics that warrant further exploration. Comparatively, countries like Indonesia and Kazakhstan demonstrate the potential for renewable energy adoption and energy efficiency to decouple economic growth from emissions, offering valuable lessons for Morocco.

This study contributes to the growing body of knowledge on the determinants of environmental degradation in emerging economies, providing a nuanced understanding of Morocco's specific context. The findings emphasize the need for targeted policies that promote renewable energy, reduce fossil fuel dependence, and leverage demographic trends for sustainable development. Future research could delve deeper into the mechanisms underlying the population-emissions relationship and explore sectoral contributions to emissions to refine policy recommendations further. Also, it emphasizes the need for Morocco to adopt energy policies that address its economic and environmental challenges. The substantial role of oil consumption suggests an urgent need to diversify energy sources and enhance renewable energy investments. Comparatively, countries like Indonesia (Vu Ngoc Xuan, 2024) and Kazakhstan (Kuziboev et al., 2024) have outlined strategic plans to integrate renewables into their energy mix, offering a roadmap for Morocco to mitigate emissions. Additionally, leveraging population growth through urban planning and technology-driven energy efficiency could help Morocco replicate the successes seen in other emerging economies while transitioning toward a sustainable future. Finally, the mixed short-term effects and significant long-term adjustments underline the importance of sustained economic and environmental policies. Policies in Morocco should focus on smoothing short-term volatility in emissions while reinforcing the long-term trajectory toward sustainability. Comparative evidence from Indonesia and Central Asia highlights the potential for targeted renewable energy investments and gradual GDP decoupling strategies to reduce emissions effectively.

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