Towards a Low-Carbon Future: The Role of Financial Development in North Africa

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Abstract: Transitioning toward cleaner and more energy-efficient sources is vital in mitigating greenhouse gas emissions. This study explores the influence of energy efficiency (EE), financial development (FD), and several macroeconomic factors on carbon dioxide (CO_2) emissions in four North African nations (Algeria, Egypt, Morocco, and Tunisia) over the period 1990–2023. Using advanced panel econometric techniques and quantile regression models, the analysis reveals that the impact of these variables on CO_2 emissions varies across emission levels. Notably, EE consistently reduces CO_2 emissions across all quantiles, with the most substantial effect observed at the 90th percentile. FD also contributes significantly to emission reductions, particularly in high-emission contexts. Conversely, GDP growth is linked to increased CO_2 emissions across all quantiles. The influence of urbanization (URB) weakens at higher emission levels, although a positive and significant relationship is maintained overall. While the effect of industrialization (IND) is less prominent at the upper quantiles, it nonetheless contributes positively to emissions. Overall, the findings highlight the essential roles of energy efficiency and financial development in reducing emissions and offer critical insights for shaping sustainable energy and financial policies in the North African region.

Keywords: Energy efficiency, financial development, carbon dioxide emissions, quantile regression, north africa, sustainable development.

1. INTRODUCTION

At the onset of the 21st century, energy has emerged as a fundamental driver of economic growth and a key element in the global response to climate change, as noted by Zhou *et al.* (2023). The rapid economic expansion witnessed over recent decades has fueled a substantial surge in energy consumption, particularly of fossil fuels, a trend largely driven by developing countries relying on these resources to sustain fast-paced growth, according to Baloch *et al.* (2019) and Adebayo *et al.* (2022). However, this relentless increase in energy demand raises serious sustainability concerns worldwide, as it exacerbates environmental degradation through pollution, resource depletion, global warming, desertification, and climate shifts posing severe social and economic challenges. Hence, as emphasized by Balsalobre-Lorente *et al.* (2023), it is critical to explore the relationship between economic progress and environmental preservation, a topic that has gained considerable attention in the specialized literature.

Following the commitments made at COP 27, transitioning to a low-carbon global economy requires annual investments estimated between 4 and 6 trillion dollars. The conference highlighted the need for innovative climate financing mechanisms and the establishment of dedicated funds to assist developing countries in managing climate-related losses and damages. In response, governments have implemented these mechanisms and funds to support vulnerable nations.

The financial sector is expected to play a pivotal role in the coming years, given its influence on controlling CO2 emissions a major driver of climate change and a critical factor in meeting COP 27 goals (Hasni *et al.*, 2023). Institutions such as banks, investment firms, and insurers have the ability to direct capital flows toward sustainable and eco-friendly ventures, including renewable energy, energy efficiency projects, and green technologies.

By financing such initiatives, the financial industry can accelerate the shift toward a greener economy, as highlighted by Ngoc and Awan (2021). Moreover, institutional investors, particularly large-scale funds, wield considerable influence over the companies in which they invest, encouraging the adoption of environmentally responsible policies and contributing to reductions in CO_2 emissions and enhanced sustainability integration.

Effective financial policies are vital for achieving national energy objectives. A robust financial system, as discussed by Balsalobre-Lorente *et al.* (2023) and supported by Yao *et al.* (2021), facilitates capital mobilization and optimal use of financial resources. Therefore, crafting appropriate financial

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1923-8401 (Online) 1923-7529 (Print)

policies is crucial for steering the transition to sustainable energy systems.

This study aims to empirically analyze the interplay among financial development (FD), GDP, urbanization (URB), industrialization (IND), energy efficiency (EF), and CO_2 emissions in North African countries specifically Algeria, Egypt, Morocco, and Tunisia.

Here, financial development is the core variable, with energy efficiency, urbanization, and industrialization serving as interacting factors. The selection of these countries is motivated by several critical considerations. Notably, climate change has significantly impacted their economies, with per capita GDP growth declining annually by 5% to 15%. The region faces heightened risks from rising temperatures, including drought, water scarcity, and wildfires, yet also offers substantial potential for renewable energy development especially solar and wind estimated at nearly three times Europe's 2021 capacity (AfDB, 2022c; Cos *et al.*, 2022).

Moreover, COP 27 saw the launch of pan-African initiatives such as the Alliance for Green Infrastructure and the Carbon Markets Initiative, which aim to bolster sustainable investments across the continent and warrant further study.

Importantly, enhancing financial development can improve access to sustainable finance for vulnerable groups, particularly rural populations disproportionately exposed to climate risks. According to the World Bank (WBI, 2021), about 70% of North Africa's poorest lacked bank accounts in 2021, underscoring the need for tailored financial inclusion strategies to support effective climate adaptation.

Additionally, as noted by Jedlane and Saidane (2012), greater integration of financial markets within Africa could mitigate the limited growth of national financial systems. For instance, interlinking stock exchanges such as Egypt's and Morocco's participation in the African Stock Exchanges interconnection project in 2022 can expand financial instruments and reduce cross-border investment costs (AfDB, 2022c).

This research seeks to contribute to the environmental economics literature by providing fresh empirical insights on the contentious relationship between FD and environmental degradation. While some studies argue FD helps reduce emissions and supports sustainable development goals (Pata & Yilanci, 2020; Ashraf *et al.*, 2022), others report that FD may exacerbate environmental harm (Saud *et al.*, 2020; Ahmed *et al.*, 2021; Afshan & Yaqoob, 2022). These conflicting results highlight the necessity for a nuanced investigation into how financial development impacts CO2 emissions both theoretically and empirically.

Theoretically, financial development can influence emissions through multiple pathways (Bui, 2020; Emenekwe *et al.*, 2022; Hasni *et al.*, 2023). On one hand, it can drive investments in renewable energy and clean technologies, fostering innovation in areas like electric vehicles and energy efficiency, which help reduce emissions (Yao *et al.*, 2021; Abid *et al.*, 2021; Zhang *et al.*, 2021). On the other hand, if financial development supports energy-intensive industries or facilitates increased trade openness and foreign investment, it may contribute to higher emissions (Yao *et al.*, 2021; Ngoc & Awan, 2021; Ashraf *et al.*, 2022; Balsalobre-Lorente *et al.*, 2023). Economic activities financed by the sector may also intensify resource exploitation and environmental pressures (Tsaurai, 2019).

Empirical findings remain inconsistent, reflecting the complexity of measuring FD's multifaceted nature through diverse financial indicators, such as access to banking, credit availability, financial market depth, and liquidity. Studies show divergent effects of FD on environmental quality, ranging from beneficial to detrimental, with some showing no significant impact (Jiang & Ma, 2019 ; Acheampong *et al.*, 2020 ; Bayar *et al.*, 2020).

This paper distinguishes itself by :Empirically emphasizing FD's role in reducing carbon emissions in North Africa, assessing FD's influence on the Environmental Kuznets Curve (EKC) hypothesis ; integrating FD as a variable in the relationship between energy efficiency and emissions, a novel approach and employing quantile regression to capture heterogeneous effects across different emission levels, offering robustness to outliers and heteroscedasticity, and providing more efficient estimates under non-normal residual distributions.

The remainder of the study is organized as follows: Section 2 discusses the theoretical framework, data sources, and variable descriptions; Section 3 presents empirical findings and discussion; and Section 4 concludes with policy implications.

2. MODELING AND DATA

2.1. Model Specification

Following the frameworks proposed by Sikder *et al.* (2022) and Hasni *et al.* (2023), our model is defined as:

$$CO_{2it} = f(GDP_{it}, EE_{it}, URB_{it}, FD_{it}, IND_{it})$$

where CO_2 denotes carbon dioxide emissions, GDP stands for economic growth, EE refers to energy efficiency, URB indicates the degree of urbanization, FD represents financial development, and IND corresponds to industrialization levels.

To linearize the relationships and stabilize variance, all variables are transformed into their natural logarithms, yielding the following specification:

$$LCO_{2it} = \beta_0 + \beta_1 LGDP_{it} + \beta_1 LEE_{it} + \beta_2 LURB_{it} + \beta_3 LFD_{it} + \beta_4 LIND_{it} + \varepsilon_{it}$$

2.2. Data

This research investigates how economic growth, financial development, energy efficiency, urbanization, and industrialization collectively influence CO2 emissions across Tunisia, Egypt, Morocco, and Algeria.

In the model, CO_2 represents the carbon dioxide emissions for these North African countries. Economic growth (GDP) is measured in constant 2010 US dollars. Energy efficiency (EE) is calculated as the ratio of gross domestic product to total energy consumption. Urbanization (URB) is expressed as the share of the urban population relative to the total population, presented as a percentage. Financial development (FD) is assessed through a composite financial development index. Industrialization (IND) reflects the proportion of industry's value added relative to GDP, also expressed in percentage terms.

Urbanization data were sourced from Statista (2022), CO2 emissions from British Petroleum (2022), financial development index data from the International Monetary Fund (IMF, 2019), while the remaining variables were obtained from the World Development Indicators (2023).

Table 1. Description of Variables.

Variable	Abbreviation	Description	Data Source
Carbon Dioxide Emissions	CO_2	Measured in metric tons	BP Statistical Review of World Energy
Economic Growth	GDP	GDP per capita in constant 2010 US dollars	World Development Indicators (WDI)
Industrialization	IND	Industry value added as a percentage of GDP	World Development Indicators (WDI)
Energy Efficiency	EE	Ratio of GDP to total energy consumption	World Development Indicators (WDI)
Financial Development	FD	Composite index of financial development	International Monetary Fund (IMF)
Urbanization	URB	Urban population as a percentage of total population	Statista

3. ECONOMETRIC APPROACH

3.1. Testing for Cross-Sectional Dependence

Given that the countries analyzed in this study share comparable economic characteristics, it is plausible that cross-sectional interdependencies exist within the panel dataset. Neglecting these potential dependencies can lead to biased or misleading statistical inferences. Accordingly, the first step in our empirical analysis is to test for cross-sectional dependence.

We begin with the traditional Breusch and Pagan (1980) LM statistic, formulated as:

$$CD_{BP} = \sqrt{\frac{1}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\hat{\rho}_{ij}^{2}-1\right)\right)$$

The test assumes that, under the null hypothesis of cross-sectional independence, $T\hat{\rho}_{ij}^{2}$ follows a chi-squared distribution with one degree of freedom, provided that T (the number of time observations) is sufficiently large. However, this approximation becomes less reliable when T is small. In such cases, the expected value of $(T\hat{\rho}_{ij}^{2}-1)$ deviates from zero, and this discrepancy becomes more pronounced as the cross-sectional dimension N increases. Consequently, the Breusch-Pagan statistic may not be suitable when the panel is characterized by a large N and a relatively small T.

To address this issue, Pesaran (2007) proposed an alternative test statistic commonly known as the CD statistic which is better suited for panels with a large number of cross-sectional units and relatively few time periods. This test is based on the average pairwise correlations of the residuals across cross-sections and is defined as:

$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right)$ Like the Breusch-Pagan test, Pesaran's CD statistic also converges to the standard normal distribution N(0,1) under the null hypothesis. The null of cross-sectional independence is rejected if the absolute value of the test statistic exceeds the critical threshold of 1.96 at the 5% significance level.

One of the main strengths of Pesaran's approach lies in its simplicity and flexibility: it does not require the specification of a spatial weight matrix, which is often needed when dealing with spatial or temporal correlations across observational units, such as in the presence of geographic or economic clustering. As such, it provides a robust method for detecting cross-sectional dependence in a wide variety of panel data settings.

3.2. Panel Unit Root Testing

Panel unit root testing extends traditional time series unit root procedures such as the Dickey-Fuller test to accommodate the structure of panel data, which integrates both cross-sectional (multiple entities) and time series (multiple time periods) dimensions. The general form of the panel unit root model can be expressed as :

$$Y_{it} = \rho_i Y_{it-1} + \alpha_i + \beta_{it} + \delta_i D_t + \varepsilon_{it}$$

Where:

- Y_{it} it denotes the dependent variable for unit i at time t,

- Y_{it-1} is its first lag,

- ρ_i represents the autoregressive coefficient for unit i. A value $\rho_i = 1$ suggests non-stationarity (presence of a unit root),

- α_i is the unit-specific intercept,

- β_{it} captures any linear deterministic trend within the unit,

-D_t is a dummy variable for time, equal to 1 when t = T and 0 otherwise,

- ε_{it} is the idiosyncratic error term.

The null hypothesis for panel unit root tests typically assumes the presence of a unit root across all entities in the panel:

H_0: $\rho_i = 1$ for all i = 1, 2, ..., N

This implies that each individual series in the panel is non-stationary. To evaluate this hypothesis, several tests can be employed, including the Levin, Lin, and Chu (LLC, 2002) test, the Im, Pesaran, and Shin (IPS, 2003) test, and the Pedroni (2004) cointegration test. These tests assess whether the computed test statistics allow for the rejection of the null hypothesis in favor of stationarity.

Among these, the IPS test is widely used to identify unit roots in panel data. Its hypotheses are formulated as follows:

Null Hypothesis (H_0): All series in the panel contain a unit root, i.e., each individual time series is non-stationary:

H_0: $\rho_i = 1$ for all i = 1, 2, ..., N

Alternative Hypothesis (H_1): At least one of the individual series is stationary:

H_1: ρ_i <1 for some i

If the IPS test rejects the null hypothesis, it indicates that one or more series within the panel are stationary. Therefore, evidence against the null supports the conclusion that the panel data does not uniformly exhibit non-stationarity.

3.3. Panel Cointegration Analysis

Panel cointegration tests examine whether a long-run equilibrium relationship exists between non-stationary variables across panel units. Cointegration indicates that, despite short-term fluctuations, variables move together over time.

The Pedroni (2004) test is a prominent panel cointegration method extending Johansen's approach to panel data. It estimates a model incorporating levels and first differences of the variables, then computes statistics to assess the presence of cointegration by comparing residuals' behavior to critical values.

The null hypothesis assumes no cointegration among the variables, and rejection implies the existence of a stable long-term relationship. It is important to verify model assumptions, such as no autocorrelation or heteroscedasticity, and ensure a sufficiently large panel for reliable results.

3.4. Long-Run Panel Estimation

Upon confirmation of cointegration, estimating the long-run coefficients requires techniques accommodating non-stationary panel data dynamics. Two widely recommended estimators are Fully Modified Ordinary Least Squares (FMOLS, Pedroni 2001) and Dynamic Ordinary Least Squares (DOLS, Kao and Chiang 2001).

The FMOLS estimator corrects for serial correlation and endogeneity in regressors, while DOLS augments the regression with leads and lags of differenced regressors to achieve unbiased estimates. Their respective formulas are:

$$\beta_{FMOLS} = \left[N^{-1} \sum_{i=1}^{N} \left\langle \sum_{t=1}^{T} \left(p_{it} - \bar{p}_i \right)^2 \right\rangle \right] - 1 \times$$
$$\left[\left\langle \sum_{t=1}^{T} \left(p_{it} - \bar{p}_i \right) \right\rangle S_{it} - T\Delta_{\varepsilon u} \right]$$

$$\beta_{DOLS} = \left[N^{-1} \sum_{i=1}^{N} \{ \sum_{t=1}^{T} Z_{it} Z'_{it} \}^{-1} \{ \sum_{t=1}^{T} Z_{it} \} \right]$$

Where p represents the explanatory variables, S is the dependent variable, and Z denotes the vector of regressors ($Z = p - \bar{p}$).

3.5. Quantile Regression Model

While FMOLS and DOLS provide consistent average effect estimates under classical assumptions (e.g., normally distributed errors, homoscedasticity), economic data often violate these conditions by exhibiting heteroscedasticity, fat tails, and outliers.

Quantile regression offers a robust alternative, capturing the influence of regressors across different points (quantiles) of the dependent variable's distribution, not just the mean. This allows for a nuanced understanding of relationships, particularly when the effect varies at different outcome levels.

The quantile regression model is expressed as:

$$y_i = x_i^T \beta_\theta + \varepsilon_i$$

$$Q(y/x) = x' \beta_q$$

Where:

y_i is the dependent variable for observation i.

x_i is the vector of explanatory variables for observation i.

β_θ is a vector of coefficients that depend on the quantile θ you wish to estimate.

ε_i is the error term for observation i.

$Q(y|x)$ represents the conditional quantile of the dependent variable y given the independent variables x.

β_q is a vector of coefficients that depend on the quantile q you wish to estimate.

This approach is less sensitive to outliers and heteroscedasticity and allows investigation of the impact of independent variables across the full distribution of y.

Given these benefits, quantile regression has become increasingly popular across various disciplines, and it is employed in this study to analyze CO2 emissions, providing deeper insights into their determinants.

4. EMPIRICAL RESULTS

4.1. Statistical Description

Table **2** presents descriptive statistics for key economic and environmental variables, including carbon dioxide emissions (LCO2), gross domestic product (LGDP), energy efficiency (LEE), urbanization level (LURB), financial development (LFD), and industrial contribution (LIND).

- Carbon Dioxide Emissions (LCO2): The average emissions stand at approximately 11.37, with a median slightly higher at 11.73, indicating a mild

Table 2. Summary Statistics.

Statistic	LCO_2	LGDP	LEE	LURB	LFD	LIND
Mean	11.37	7.44	0.87	17.95	18.27	0.47
Median	11.73	7.85	1.95	18.97	18.51	0.76
Maximum	11.12	8.38	3.53	22.06	22.24	1.71
Minimum	10.73	5.63	2.22	12.78	13.15	1.39
Standard Deviation	0.73	0.79	1.38	0.93	1.47	0.04
Skewness	2.05	0.89	1.14	0.12	0.58	0.70
Kurtosis	1.30	1.10	0.60	0.95	1.65	5.14
Jarque-Bera	13.40	11.56	4.43	0.902	6.108	43.96
Probability	0.00005	0.00008	0.00007	0.00016	0.00000	0.00000
Sum	870.03	541.09	212.04	1315.94	1324.89	101.58
Sum of Squared Deviations	42.97	48.10	11.59	78.39	252.02	92.44

right-skew in the distribution. The maximum value of 11.12 highlights the presence of countries with considerably higher emissions, while the minimum of 10.73 reflects regions with relatively low emissions.

- Gross Domestic Product (LGDP): The mean GDP is around 7.44, with the median at 7.85, suggesting a similar slight right-skew. The highest GDP is 8.38, reflecting highly developed economies, whereas the lowest value of 5.63 points to less developed regions within the sample.
- Energy Efficiency (LEE): The average energy efficiency index is approximately 0.87, with a maximum of 3.53 indicating high efficiency in some countries, and a minimum of 2.22 reflecting lower efficiency elsewhere.
- Urbanization Level (LURB): The average urbanization rate is about 17.95, with the median closely matching at 18.97, showing a fairly symmetric distribution. The maximum urbanization value is 22.06, representing highly urbanized regions, while the minimum is 12.78.
- Industrial Contribution (LIND): The average industrial share in the economies studied is approximately 0.47, indicating a moderate industrial presence across the sample countries.
- Financial Development (LFD): The mean value of 18.27 suggests a moderate level of financial sector development among the North African countries considered.

Overall, these descriptive statistics reveal substantial heterogeneity across the variables studied, providing valuable insights for assessing economic and environmental performance. Such variations are crucial for designing targeted and effective public policies in the region.

4.2. Cross-sectional Dependence and Panel Unit Root Test Results

The outcomes of the cross-sectional dependence test are presented in Table **3**. The test decisively rejects the null hypothesis of independence across panel units, indicating the presence of statistically significant cross-sectional dependence in the dataset.

Table 3. Cross-Sectional Dependence Test Results by Variable

Variable	CD Statistic	Breusch-Pagan (CD_BP) Statistic
LGDP	9.170611*	87.61252*
LFD	0.174064*	11.12160*
LURB	2.216711*	67.52593*
LCO_2	1.262261*	66.20285*
LIND	1.201147*	8.752063*

In parallel, the results of the panel unit root tests are reported in Table **4**. The analysis employs the Im, Pesaran, and Shin (IPS) W-statistic to assess the stationarity of the variables. The results show that none of the variables are stationary at level [I(0)], but all become stationary after first differencing [I(1)]. This supports the assumption that the series are integrated of order one, I(1), and hence eligible for cointegration analysis.

The unit root test results thus confirm that all variables are integrated of the same order, reinforcing the validity of proceeding with cointegration testing in subsequent analyses.

Table 4. Panel Unit Root Test Results (Im, Pesaran and Shin W-Statistics)

Variable	Level [I(0)]	First Difference [I(1)]
LCO_2	-0.80718	-2.71219
LGDP	-0.05575	-1.83895
LEE	1.63600	2.70926
LURB	0.14440	2.33886
LFD	0.60348	3.57645
LIND	-1.54285	-4.87825

4.3. Cointegration Analysis in Panel Data Using Pedroni's Method

Table **5** displays the outcomes of Pedroni's panel cointegration tests. Across all six scenarios, the results consistently reject the null hypothesis of no cointegration. This implies that the variables under study are cointegrated within the context of North African countries, reflecting the presence of a stable long-term relationship among them.

4.4. Panel Regression Results

Table **6** summarizes the main findings from the tests. The results show that economic growth leads to higher CO_2 emissions in both the FMOLS and DOLS models. Specifically, a 1% increase in GDP causes CO_2 emissions to rise by 0.047% in the FMOLS model and by 0.119% in the DOLS model. This supports the Environmental Kuznets Curve (EKC) idea, which links economic growth to environmental harm. In short, economic growth is the key factor driving CO2 emissions in North African countries, making global climate problems worse. These findings agree with earlier studies by Talbi *et al.* (2022) in Tunisia, Adebayo *et al.* (2021) in South Africa, Soylu *et al.* (2021) in China, and Kirikkaleli and Adebayo (2021) in India.

The study also finds that, when other factors stay the same, a 1% increase in urbanization leads to a 1.16% rise in CO_2 emissions according to the FMOLS model, and a 0.69% increase based on the DOLS model. This shows that as North Africa's cities grow, energy use mostly from fossil fuels goes up, which causes more CO_2 emissions. This makes sense because emissions come from many sources like more household appliances, building construction, and transportation.

At early stages of urban growth, people tend to focus on comfort and personal travel, often preferring private cars over eco-friendly transport. This pattern matches findings from studies in Malaysia (Zhang *et al.*, 2021), Turkey (Kalmaz and Kirikkaleli, 2019), and other countries (Shahzad *et al.*, 2017). Similar results were also reported by Pata (2018), Yang *et al.* (2018), and Ali *et al.* (2019).

For North African countries, financial development actually helps reduce CO_2 emissions, meaning it improves environmental quality. These countries usually have advanced industries and strict environmental rules. Governments support green finance, funding eco-friendly projects, and investors focus more on new technologies than quick growth. This agrees with research by Boutabba (2014) and Majeed & Mazhar (2019).

Energy efficiency also plays an important role in lowering CO_2 emissions in North Africa. Better energy use helps cut down carbon emissions. This matches earlier findings by Destek *et al.* (2019), Shahbaz *et al.* (2019), and Sharif *et al.* (2019).

Finally, the data shows that a 1% increase in industrialization raises CO_2 emissions by 0.018% in the FMOLS model and 0.028% in the DOLS model. This happens because industries rely heavily on burning fossil fuels. As industrialization grows, more energy-demanding factories appear, often harming the environment. Also, heavy industries release pollutants into the air. These results align with previous studies by Wang *et al.* (2018), Liu *et al.* (2018), and Zhou *et al.* (2019).

4.5. Regression Analysis at Different Quantiles

This section explains the results of the quantile regression, which shows how GDP, energy efficiency (EE), urbanization (URB), financial development (FD), and industrialization (IND) affect CO2 emissions differently across various levels. We looked at nine points from 0.10 to 0.90 quantiles. Table **7** shows that the impact of these variables changes a lot depending on the quantile.

Table 5. Panel Cointegration Assessment by Pedroni.

Estimates	Common AR Statistic	Common AR Probability	Weighted Statistic	Weighted Probability	Individual AR Statistic
Panel v-Statistic	-0.239618	0.5317	-0.29675	0.5620	-
Panel rho-Statistic	1.66138	0.0193	1.587631	0.0004	-
Panel PP-Statistic	-0.242494	0.2460	0.454391	0.0003	-
Panel ADF-Statistic	-1.242021	0.0000	-0.726110	0.1015	-
Group rho-Statistic	-	-	-	-	2.739419
Group PP-Statistic	-	-	-	-	-0.271061
Group ADF-Statistic	-	-	-	-	-1.548755

Table 6. Panel Regression Results (FMOLS and DOLS Estimates).

Variable	FMOLS Coefficient	Significance	DOLS Coefficient	Significance
LGDP (Log of GDP)	0.0475	Statistically significant (p = 0.0016)	0.1191	Statistically significant (p = 0.0247)
LEE (Log of Energy Efficiency)	-0.3176	Highly significant (p = 0.0002)	-1.3592	Highly significant (p = 0.0000)
LURB (Log of Urbanization)	1.1629	Highly significant (p = 0.0000)	0.6891	Highly significant (p = 0.0000)
LFD (Log of Financial Development)	-1.75E-11	Significant (p = 0.0180)	-9.05E-11	Not significant (p = 0.1974)
LIND (Log of Industrialization)	0.0185	Statistically significant (p = 0.0043)	0.0282	Statistically significant (p = 0.0326)

Table 7. Quantile Regression Results Across the Distribution of CO_2 Emissions.

Variable	Q(0.10)	Q(0.20)	Q(0.30)	Q(0.40)	Q(0.50)	Q(0.60)	Q(0.70)	Q(0.80)	Q(0.90)
LGDP	12.5151***	14.7850***	14.0501***	14.4333***	14.8580***	15.7201***	16.2347***	16.8525***	16.0439***
LEE	-24587.79***	-26455.92***	-27567.63***	-31577.35***	-32669.27***	-32668.73***	-32932.50***	-33133.30***	-33811.12***
LURB	84406.53***	85119.44***	85468.49***	81708.80***	72680.10***	67652.88***	69237.97***	67728.72***	73947.68***
LFD	-3.29E-08*	-2.19E-06**	-2.46E-06**	-2.79E-06**	-2.75E-06***	-2.99E-06***	-2.08E-06***	-1.45E-06***	-0.34E-06***
LIND	1099.36**	1574.88*	1883.46*	3139.88***	4160.06*	5627.93**	6206.61*	6171.78*	6050.29***

Note: * $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$.

GDP's effect on CO_2 emissions is different at each quantile but always significant. The effect gets stronger as we move to higher quantiles. This means that at higher income levels, CO2 emissions increase more, supporting the Environmental Kuznets Curve idea, which says environmental harm grows with income but may slow after a certain point. Similar results were found for BRICS countries (Danish *et al.*, 2019), ASEAN countries (Salman *et al.*, 2019), and China (Dong *et al.*, 2018a, 2018b).

Energy efficiency shows a negative effect on CO2 emissions at all quantiles, meaning better energy use reduces emissions. This effect is stronger at higher quantiles and slightly weaker at lower ones. This could be due to investments and research in energy-saving technologies. These results agree with studies by Pereira and Pereira (2010), the United Nations (2017, 2011), and the International Energy Agency (2017). North African countries, with their fast growth and energy-heavy industries, benefit from energy efficiency efforts to reduce emissions. Many such projects have already helped lower greenhouse gases, especially in construction and transportation. Thus, policies to improve energy efficiency are important for cutting CO_2 emissions in developing countries.

Urbanization increases CO_2 emissions too, but its effect is stronger at lower quantiles and lessens at higher ones. Table **7** shows that the impact of urban growth decreases as we move to higher quantiles. This matches findings from Ali *et al.* (2019) in Pakistan and Du and Xia (2018) in 60 countries. Urbanization leads to more energy use because rural people move to cities for jobs, increasing energy and resource consumption.

Financial development has a significant negative impact on CO_2 emissions, especially at higher quantiles. This is mainly because foreign-owned firms bring more money and technology, increasing local tax revenues. Governments can then invest in clean and efficient technologies (Ermasova *et al.*, 2019). Also, more state-owned enterprises raise tax income, helping fund green projects. So, financial development helps reduce emissions in North Africa by supporting green investments.

Industrialization raises CO_2 emissions at all quantiles but has a smaller effect at the 90^{th} quantile. This is linked to differences in fertilizer use and heavy energy consumption in industry. As countries grow, they eventually enter a post-industrial phase where emissions decrease due to economic changes and stricter environmental rules (Cheng *et al.*, 2019). Developing countries often use cheap energy and resources extensively during growth, which can harm the environment. But with time, stricter policies and economic shifts help reduce pollution.

In short, industrialization initially increases emissions, but this can improve with economic progress and better regulations, highlighting the need for a green transition as countries develop.

5. CONCLUSION AND POLICY IMPLICATIONS

This study explored how energy efficiency (EE), financial development (FD), urbanization (URB), and industrialization (IND) affect CO_2 emissions in four North African countries (Algeria, Egypt, Morocco, and Tunisia) from 1990 to 2023. We also tested the Environmental Kuznets Curve (EKC) hypothesis. To do this, we used quantile regression, which helps show how these factors affect emissions at different levels.

Our results show that the impact of these variables on CO2 emissions changes depending on the quantile. Unlike other methods like FMOLS and DOLS, quantile regression shows clearly how the effects vary. GDP has a stronger positive impact at higher quantiles. EE shows a stronger negative impact (reducing CO2) at higher quantiles. URB has a stronger positive effect at lower quantiles, but this effect weakens at higher ones. FD reduces CO2 emissions more at higher quantiles. IND also increases emissions, though less so at the highest quantile.

Overall, both EE and FD help reduce CO_2 emissions, but FD has a stronger impact in this region.

Based on these results, several actions can help balance economic growth and environmental protection in North Africa:

1. Promote Clean Energy: Governments should support the shift to renewable energy like solar, wind, and hydropower. Financial support (such as subsidies or tax breaks) can help encourage companies to adopt cleaner energy sources.
2. Invest in Green Technology: Funding research and development in areas like electric vehicles or carbon capture technologies can reduce emissions and create jobs. Governments can lead efforts in innovation while supporting economic growth.
3. Encourage Green Finance: Financial institutions should be encouraged to fund clean energy projects. Governments can offer incentives for banks and investors to support renewable energy and energy efficiency initiatives.
4. Integrate ESG Principles: Financial decisions should consider environmental, social, and governance (ESG) factors. This can push investments toward eco-friendly sectors.
5. Improve Climate Risk Disclosure: Financial institutions should be required to assess and report how their investments might be affected by climate risks. This would help reduce investments in polluting industries.
6. Support Green Financial Products: Develop tools like green bonds or eco-friendly loans. These can fund energy-saving projects, such as building renovations or clean transport systems.
7. Encourage Energy Efficiency: Energy efficiency projects can reduce emissions and create jobs in construction, engineering, manufacturing, and R&D. For example, upgrading buildings with better insulation and efficient heating systems increases job opportunities and reduces energy use.
8. Strengthen Energy Security: Using less energy also means relying less on imports. This protects countries from energy price shocks and supply problems.
9. Boost R&D for Better Energy Sources: Investing in new, cleaner energy—renewable or not—helps cut emissions and supports long-term sustainable development.

FUTURE RESEARCH

This study focused on only four countries. Future research could include more countries with similar characteristics. Also, combining data analysis with real-world case studies could give deeper insight into how these relationships work in practice.

SUPPLEMENTARY MATERIALS

Please refer to any additional supplementary material available online: online appendices, datasets, codes, *etc*.

DATA AVAILABILITY STATEMENT

The manuscript contains data thatwill be made available upon reasonable request.

CONFLICT OF INTEREST

The author declares no conflict of interest.

FUNDING STATEMENT

No funding was received.Ethical approval statement:To ensure objectivity and transparency in research, all ethical and professional conduct standardshave been followed.

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Received: July 25, 2025 Revised: July 30, 2025 Accepted: August 05, 2025