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The Impact of Energy Consumption on Economic Development in North Africa: A Long-Term Dynamics Analysis Using the ARDL Approach

Allal Zahir[1]*, Zineb Aarich[1], Yassine Oubahou[2], Hassan Bouazid[1], Hassan Rehaimi[1], Khalid Elouafa[2]

[1]Laboratory for Studies and Research in Economic Sciences and Management (LERSEM), Faculty of Legal, Economic and Social Sciences of Aït Melloul, Ibn Zohr University, Aït Melloul, Morocco, [2]Laboratory of Innovation, Responsibility and Sustainable Development, Faculty of Law, Economics and Social Sciences, Cadi Ayyad University (UCA), Marrakech, Morocco.
*Email: zahirallal9@gmail.com

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ABSTRACT

This article examines the relationship between economic development and renewable energy consumption in North Africa. The main objective is to analyze the impact of this consumption on economic growth in this region, taking into account other macroeconomic variables. To do this, we use data covering the period from 1990 to 2023 and apply the Autoregressive Distributed Lag (ARDL) model to explore the short- and long-term dynamics between the variables studied. Empirical results reveal that renewable energy consumption and inflation have a negative and statistically significant effect on economic development. In contrast, investment and trade openness exert a positive and significant influence on the latter. These results highlight the importance of a well-managed energy transition. They suggest that public authorities should strengthen policies promoting the adoption of renewable energies, while ensuring their effective integration into the economic fabric to maximize their positive impact on growth.

Keywords: Economic Development, Economic Growth, Renewable Energy, Investment, Trade Openness, North Africa
JEL Classifications: E23, G10, E65, Q25, Q43

1. INTRODUCTION

Considering the worsening environmental challenges and the gradual depletion of fossil fuel resources, the issue of energy has become a cornerstone of sustainable development. Renewable energy sources including solar, wind, hydroelectricity, biomass, and geothermal offer credible and promising alternatives to traditional energy sources. These naturally replenished and low-emission resources are gaining increasing strategic importance worldwide, particularly since the 1973 oil crisis, which marked a pivotal shift in the discourse on energy security and the diversification of energy supply sources.

Within this global context, North Africa finds itself at a crossroads. The region is grappling with significant climatic and environmental challenges, including water stress, desertification, soil erosion, declining agricultural productivity, and rising socioeconomic vulnerability. In response, several North African countries have initiated a transition toward a more sustainable energy model. This is reflected in the implementation of public policies promoting renewable energy and the gradual reform of fossil fuel subsidies. The dual objective is to enhance energy security while laying the foundations for a greener and more resilient economic growth model.

Energy is not merely a production input; it is a driving force behind all forms of development. It powers industries, supports infrastructure, stimulates technological innovation, and contributes to job creation. Nevertheless, North African economies remain heavily reliant on non-renewable energy sources, raising concerns about their ability to achieve a genuine transformation of their energy systems. In this context, a central question emerges: to what extent does renewable energy consumption influence the economic development of North African countries?

To address this question, the study draws on theoretical frameworks that analyze the impact of renewable technologies on economic growth, while exploring the relationships between investments in renewable energy, technological progress, and environmental sustainability. The methodology employed integrates robust quantitative analyses based on relevant statistical data to assess the effects of energy transitions on economic outcomes.

Findings indicate that although the shift toward renewable energy requires substantial initial investments, the long-term economic and environmental benefits are considerable. Thus, renewable energy consumption emerges not only as a necessity for ensuring energy security but also as a key driver of stable economic growth and a viable solution to the major environmental challenges faced by modern societies. The study is structured around three main components: (1) A literature review accompanied; (2) the presentation of the adopted methodology and selected variables; and (3) an empirical analysis of the results leading to concrete policy recommendations.

2. EMPIRICAL LITERATURE REVIEW

The theoretical foundation of renewable energy resources (RER) is very important to examine their influence on the economy and sustainable development. RENs, such as solar, wind, hydro, biomass, and geothermal energy, are naturally renewable energy sources that play a significant role in mitigating greenhouse gas emissions and climate change, which are major global issues.

This model draws on alternative theories of economic growth, including the Solow model and endogenous growth theories, which consider energy as a key input to production. The main assumption of this model is that the introduction of renewable energy sources does not limit economic growth, but can actually promote more sustainable growth patterns. Although initial investments in RRs are costly, they are envisioned as sources of significant long-term returns, enabling job creation, stimulating technological progress and strengthening economic competitiveness. Several studies have analyzed the interaction between economic growth and renewable energy consumption. Some literature reports a positive effect of renewable energy consumption on economic growth.

The study by Das and Chakraborty (2024) uses panel data covering the period 2000-2014 and applies two econometric methods: Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Error (PCSE). The results show that in developed countries, renewable energy consumption promotes economic growth and sustainable development, while non-renewable energy has a negative effect. Conversely, in developing countries, renewable energy harms these two dimensions, while non-renewable energy supports them. For economies in transition, both energy sources have a positive impact on growth and sustainability.

The study by Methmini et al. (2024) uses multiple linear regression analysis on panel data covering the period 2000–2021 to assess the impact of economic growth, energy consumption and trade openness on carbon emissions in the 20 highest emitting countries spread across five continents. The results show that energy consumption significantly increases carbon emissions in the majority of the countries studied, with the exception of Panama and Kazakhstan, where its effect is limited to GDP-related emissions. The study by Dirma et al. (2024) uses comparative analysis, theoretical analysis, and panel data analysis to assess the impact of renewable energy on economic growth in the European Union. The results show that the transition to renewable energy does not hinder growth, but stimulates it in the long run through innovation, job creation, and investment.

The study by Algarni et al. (2023) shows that renewable energy sources contribute positively to sustainable development by improving access to energy, reducing polluting emissions and stimulating local socio-economic development. The results also highlight that, despite certain challenges, renewable energies represent a strategic lever for reconciling economic growth, social inclusion and long-term environmental preservation. The study by Adanma and Ogunbiyi (2024) highlights the economic and environmental impacts of adopting renewable energy. The results show that renewable energy promotes job creation, stable energy prices, and reduced greenhouse gas emissions. The analysis also highlights the key role of public policies, international agreements, and technological innovations in accelerating this transition.

In Dogan et al. (2020) study, which examines the effect of renewable energy consumption on economic growth in OECD countries, the authors use panel quantile regression to better capture cross-country heterogeneity. The results reveal a positive effect of renewable energy on growth for the lower quantiles, but a negative effect for the middle and upper quantiles. When renewable energy is measured as a relative share, its impact becomes negative in almost all quantiles, contrasting sharply with the findings of the original study.

The study by Gyimah et al. (2022) analyzes the direct and indirect impact of renewable energy consumption on economic growth in Ghana, using Granger causality and a mediation model. The results reveal a bidirectional relationship between economic growth and renewable energy consumption, with a significant positive overall impact of the latter on growth. In contrast, the indirect effect of renewable energy on growth is not significant. These results highlight the importance of encouraging the development of renewable energy to support economic growth in Ghana. Similarly, Wang and Wang (2020) analyzes the nonlinear relationship between renewable energy consumption and economic growth in OECD countries using panel data regression models, the results indicate a positive impact of renewable energy consumption on economic growth.

Yang et al. (2022) analyze the crucial role of renewable energy in improving the economic performance of Next Eleven countries by using a non-parametric panel data approach. Their results show that renewable energy consumption contributes positively to economic growth, but only in the short term. Furthermore, they highlight that industrial value added, human development, and consumer spending play a driving role in economic dynamics, while globalization exerts a rather restrictive effect. Bui Minh and Bui Van (2023) investigated the relationship between renewable energy consumption and economic growth in Vietnam. Using the autoregressive distributed lag (ARDL) model, they assessed the long-term impact of this consumption on real gross domestic product. Their results confirm that the use of renewable energy has a positive and significant effect on economic growth, highlighting the key role of these energy sources in the country's sustainable development.

Alkasasbeh et al. (2023) analyze the relationship between renewable energy consumption and economic growth in Jordan over the period 2000–2020, using the ARDL model. Their results reveal a significant positive impact of renewable energy on GDP. They emphasize the need to strengthen public and private investment in this sector to support sustainable economic growth. The study also recommends that the Jordanian authorities adopt incentive policies and develop the necessary infrastructure to facilitate the country's energy transition. Kayani (2021) studies the impact of renewable energy consumption on economic growth in the UAE between 1996 and 2018, using ARDL and OLS models. The results show a lack of significant relationship between the two variables. This disconnect is explained by the economic structure of the Emirates, dominated by non-energy sectors, such as tourism, aviation or real estate, where renewable energies remain poorly integrated into growth dynamics.

Syzdykova et al. (2021) examine the relationship between renewable energy consumption and economic growth in a panel of developing countries, including Brazil, India, Indonesia, China, Chile, Mexico, South Africa, and Turkey. Using the GMM estimator on dynamic panel data, the authors highlight a positive and significant effect of renewable energy consumption on economic growth. These results suggest that strengthening the integration of renewable energy can be a strategic vector for sustainable growth for emerging economies.

Hieu and Mai (2023) explore the relationship between economic growth and energy consumption, whether renewable or non-renewable, across a large sample of 80 developing countries over the period 1990-2020. To achieve this, the authors adopt an innovative methodology that combines Moving Quantile Regression (MMQR) with long-run estimation techniques, including FMOLS, FE-OLS, and DOLS. Their results reveal that renewable energy consumption exerts a significant positive effect on growth at all levels studied, while non-renewable energy has a positive impact mainly at lower levels of growth. Furthermore, the bidirectional causality between energy consumption and economic growth is confirmed using the Granger causality test adapted by Dumitrescu and Hurlin. These findings highlight the crucial role of renewable energy as a lever for development in developing countries.

Steve et al. (2022) examine the impact of renewable energy consumption on economic growth in sub-Saharan Africa, specifically analyzing the Eastern, Western, and Central regions between 1990 and 2018. Using rigorous methods, such as the Common Correlated Effects Average Estimator (CCEMG) and the Granger causality test adapted by Dumitrescu-Hurlin, their study takes into account both interdependencies between countries and regional specificities. They show that an increase in renewable energy consumption is paradoxically linked to a decrease in economic growth across these regions. Moreover, the causal relationship between renewable energy and growth is bidirectional only for Central Africa, while for Eastern and Western Africa, it is rather energy consumption that seems to stimulate growth.

All the empirical work analyzed highlights contrasting results regarding the relationship between renewable energy consumption and economic growth. While several studies confirm a positive effect of renewable energy on growth, others identify no significant relationship, or even observe variable results depending on the country, period, and method used. These divergences can be explained in particular by the heterogeneity of economic contexts, differences in the time horizons studied, as well as by the methodological choices adopted. While classical approaches based on panel data (such as Pedroni cointegration tests or ordinary least squares) have long predominated, recent research tends to favor quantile regressions on panel data. These provide better consideration of heterogeneity in the distribution of effects, thus strengthening the robustness of the analyses. Furthermore, the theoretical framework highlights the crucial role of public policies and state regulation. Indeed, legislative incentives and public funding appear to be essential catalysts for attracting investment in the renewable energy sector. Therefore, renewable energy sources should not be considered solely as an alternative to traditional energy sources, but rather as strategic levers for promoting more sustainable, inclusive, and environmentally friendly economic growth.

3. RESEARCH METHODOLOGY

This research employs a quantitative methodology based on annual secondary data from the World Bank, covering five North African countries: Morocco, Algeria, Tunisia, Egypt, and Libya. The analytical framework utilizes a balanced panel combining a cross-sectional dimension (5 countries) and a time-series dimension (34 years), resulting in 170 observations. The choice of panel data, aligned with (Hsiao, 2007), is justified by its ability to capture both inter-country and intra-temporal variations, optimizing estimator precision. The dependent variable, economic growth, is measured by aggregate GDP, reflecting total goods and services production. Independent variables include energy consumption (CNSMEN), inflation rate (INFL), gross fixed capital formation (FBCF), and trade openness (OUVCOM), representing structural levers of North African economies. This relationship is formally expressed through the econometric model:

$$GDP = f(CNSMEN + INFL + FBCF + OUVCOM) \quad (1)$$

Drawing on Pesaran et al. (1999), panel heterogeneity dynamics are modeled via an error correction mechanism (ECM) using the ARDL (p, q) framework, as operationalized by Loayza and

Rancière (2006). This approach integrates autoregressive lags (p) and distributed lags (q) while correcting equilibrium deviations, effectively addressing structural heterogeneity in panel data. This study employs a panel ARDL model for estimation, preceded by critical unit root testing (Levin-Lin-Chu, Breitung, Pesaran-Shin, Maddala-Wu, Hadri) to assess variable stationarity. The ARDL framework is uniquely suited for mixed-order integration [I(0)/I(1)], avoiding cointegration biases. Three variants—*Mean Group* (*MG*), *Pooled Mean Group* (*PMG*), and *Dynamic Fixed Effects* (*DFE*)—are compared using a Hausman test to identify the optimal estimator, balancing efficiency (PMG/DFE) and consistency (MG). This comparative approach, coupled with robustness checks, ensures reliable parameter estimates, formalized in the model's Equation (2). The methodology highlights the interplay between short-term dynamics and long-term equilibrium adjustments, leveraging panel data's capacity to capture cross-country heterogeneity.

$$\Delta y_{it} = \sum_{k=1}^{p-1} \lambda_{ik}^{*} \Delta y_{i,t-k} + \sum_{k=0}^{q-1} \delta_{ik}^{'} \Delta x_{i,t-k} + \varphi_i \left(y_{i,t-1} + \beta_{it}^{'} \right) + \omega_i + \varepsilon_{it} \quad (2)$$

where i denotes the country, t the year, and ϵ_{it} the random error term, enabling isolation of each determinant's impact while controlling for unobserved individual effects.

$$\begin{aligned}\Delta gdp_{it} &= \alpha + \beta_1 gdp_{it-1} + \beta_2 CNSMEN_{it-1} + \beta_3 FBCF_{it-1} + \\ &\beta_4 INFL_{it-1} + \beta_5 OUVCOM_{it-1} + \sum_{i=1}^{\eta} \alpha_i \Delta gdp_{it-i} \\ &+ \sum_{i=1}^{\rho} \chi_i \Delta \mathrm{CNSMEN}_{it-i} + \sum_{i=1}^{\varphi} \omega_i \Delta FBCF_{it-i} \\ &+ \sum_{i=1}^{\psi} \pi_i \Delta INFL_{it-i} + \sum_{i=1}^{\delta} \vartheta_i \Delta OUVCOM_{it-i} + \varepsilon_{it} \quad (3)\end{aligned}$$

The Panel ARDL model, formalized by equation (2), integrates a dynamic approach combining short-term effects (via ϕik,δik), long-term adjustments (βi′), and error correction speed (λi). Three estimation methods are compared: PMG (homogeneous long-term coefficients, other heterogeneous parameters), DFE (all coefficients constrained to homogeneity), and MG (total heterogeneity aggregated by means). The long run coefficients (equation 3) are β_1; β_2; β_3; β_4 and β_5 while the short run coefficients are αi, χi, ωi, πi and ϑ_i. The Hausman test allows identifying the optimal estimator, favoring a compromise between efficiency (PMG/DFE) and robustness (MG). Robustness checks (unit root tests, lag specification) reinforce the reliability of the parameters, while the panel structure captures cross-national heterogeneities, providing a balanced analysis of temporal dynamics and structural equilibria.

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistic

Table 1 presents descriptive statistics for five variables (DCNSMEN, DFBCF, DINFL, DOUVCOM, GDP) across 165 observations. Means range from −0.105 (DCNSMEN) to 3.235 (GDP), with significant discrepancies between median and mean values for some variables. Notably, GDP shows extreme asymmetry, with a median of −15.46 contrasting its positive mean. Extreme maxima like 86.827for GDP oppose sharp negative minima (e.g., −50.339 for GDP), highlighting high volatility. All distributions exhibit positive skewness (ranging 0.286 to 2.617) and leptokurtic patterns (kurtosis up to 39.95 for GDP), indicating fat tails and peakedness. The Jarque-Bera test overwhelmingly rejects normality (P = 0.000 for all variables), confirming non-Gaussian risk profiles. GDP's exceptionally large total sum of squared deviations (15,767.58) underscores data heterogeneity. These patterns suggest persistent asymmetric shocks and tail risks, necessitating robust modeling approaches in financial or macroeconomic analysis.

The correlation matrix (Table 2) presented reveals statistical relationships between five key macroeconomic variables. Overall, correlations appear weak, with most coefficients below 0.3 in absolute value. The only notable link is between inflation (DINFL) and trade openness (DOUVCOM), showing a moderate positive correlation of 0.297. Conversely, a slight inverse relationship exists between inflation and GDP growth, with a coefficient of −0.158. Other variable combinations display near-zero correlations, such as household consumption (DCNSMEN) and GDP (−0.062) or investment (DFBCF) and GDP (0.032). This absence of strong correlations suggests these variables evolve relatively independently over the studied period, reducing multicollinearity risks in econometric models. However, the generally weak linkages may indicate either that these variables act with time lags or that

Table 1: Descriptive statistics

Statistics	DCNSME	DFBCF	DINFL	DOUVCOM	GDP
Mean	−0.105455	−0.094171	0.018914	−0.018061	3.235447
Median	0.0000000	−0.182764	−0.008440	−1.250000	3.535252
Maximum	6.3000000	8.734086	19.98912	25.610000	86.82675
Minimum	−3.500000	−6.108070	−15.33238	−15.46000	−50.33852
SD	0.810845	2.333010	4.728499	5.995534	9.805292
Skewness	1.997444	0.424441	0.285601	0.451856	2.616615
Kurtosis	27.93401	4.143724	6.950081	4.533451	39.94767
Jarque-Bera	4383.938	13.94734	109.5147	21.78114	9573.554
Probability	0.000000	0.000936	0.000000	0.000019	0.000000
Sum	−17.40000	−15.53815	3.120863	−2.980000	533.8487
Sum square deviation	107.8251	892.6415	3666.828	5895.214	15767.58
Observations	165	165	165	165	165

SD: Standard deviation

Table 2: Correlation matrix

Variables	DCNSMEN	DFBCF	DINFL	DOUVCOM	GDP
DCNSMEN	1.000000	−0.118943	0.010082	−0.087556	−0.061659
DFBCF	−0.118943	1.000000	−0.028496	0.019743	0.031684
DINFL	0.010082	−0.028496	1.000000	0.296892	−0.158400
DOUVCOM	−0.087556	0.019743	0.296892	1.000000	0.108139
GDP	−0.061659	0.031684	−0.158400	0.108139	1.000000

Table 3: Unit root test

Variables	ADF		LLC		IPS		Decision
	Level	First differences	Level	First differences	Level	First differences	
GDP	49.0322 (0.0000)	-	−3.5818 (0.0002)	-	−5.5668 (0.0000)	-	I (0)
CNSME	13.0970 (0.2183)	57.5672 (0.0000)	−13,472 (0.0889)	−6.82863 (0.0000)	−0.7806 (0.2175	−6.75088 (0.0000)	I (1)
FBCF	11.0485 (0.3538)	46.1813 (0.0000)	−0.0304 (0.4879)	−5.17243 (0.0000)	−0.5532 (0.2901)	−5.51735 (0.0000)	I (1)
INFL	11.9328 (0.2896)	66.9415 (0.0000)	−1.8577 (0.0316)	−6.28360 (0.0000)	−0.6835 (0.2471)	−7.61665 (0.0000)	I (1)
OUVCOM	12.5413 (0.1811)	63.4831 (0.0000)	−0.9038 (0.1830)	−8.00220 (0.0000)	−0.9111 (0.1811)	−7.17992 (0.0000)	I (1)

other unobserved factors play a more decisive role in the observed economic dynamics.

4.2. Panel Unit Root Results

Table 3 summarizes the results of three stationarity tests (ADF, LLC, IPS) applied to macroeconomic variables in both level and first-difference forms. For GDP, the ADF test in level ([statistic = 49.0322, P = 0.0000]) and IPS test in level ([statistic = −5.5668, P = 0.0000]) strongly reject the unit root hypothesis, confirming its stationarity at level (integration order 0, I(0)). In contrast, the variables consumption (CNSME), investment (FBCF), inflation (INFL), and trade openness (OUVCOM) exhibit non-stationarity at level (P-values > 0.05 for ADF/LLC/IPS) but become stationary after first differencing (I(1)), as evidenced by near-zero p-values ([e.g., ADF first difference = 57.5672, P = 0.0000 for CNSME]). The consistency across tests is notable: significant negative statistics in first difference (e.g., LLC = −6.82863 for CNSME) unanimously reject non-stationarity. These results necessitate the use of techniques suited for I(1) series—such as error correction models (ECM)—to avoid spurious regressions, while justifying an exploration of potential cointegration relationships among these variables.

4.3. Cointegration Tests

The Pedroni test (Table 4), applied to the series (DCNSMEN, DFBCF, DINFL, DOUVCOM, GDP) on a panel of 5 countries (1990-2023) reveals a robust cointegration at the 1% threshold. The within-dimension (Panel PP = [−6.93], Panel ADF = [−4.09]) and between-dimension (Group PP = [−10.23], Group ADF = [−5.09]) statistics display systematically zero p-values (P = 0.0000), confirming a long-term equilibrium relationship between these variables. Although the v-Panel statistic (P = 0.97) suggests a non-negligible residual variance, the convergence of the six other indicators validates the cointegration hypothesis. These results fully justify the use of an error correction model (ECM) to analyze short-term dynamics, while highlighting the need to control for individual effects between countries via fixed or random effects estimators.

Table 5 compares 16 ARDL models to explain the MPIB variable (1990–2023) using key statistical criteria (AIC, BIC, HQ). Model 16 (ARDL(4,4,4,4,4)) stands out as the best performer, with the lowest values for AIC (4.8308) and HQ (5.7401), indicating an optimal balance between accuracy and complexity. Alternative models (e.g., models 12, 8, 4) show slightly lower performance, while overly simple (e.g., model 1: ARDL(1,1,1,1,1)) or unbalanced (e.g., model 5: ARDL(2,1,1,1,1)) specifications scoreless convincingly. This suggests that long lags (4 periods) on all variables better capture the dynamics of the data.

Table 4: Cointegration tests

Alternative hypothesis : common AR coefs. (within-dimension)				
Weighted				
	Weighted statistic	Probability	Statistic	Probability
Panel v-statistic	−1.916924	0.9724	−1.894038	0.9709
Panel rho-statistic	−3.102507	0.0010	−2.968458	0.0015
Panel PP-statistic	−6.934156	0.0000	−8.433029	0.0000
Panel ADF-statistic	−4.089433	0.0000	−4.865948	0.0000
Alternative hypothesis: Individual AR coefs. (between-dimension)				
	Unweighted statistic	Probability		
Group rho-statistic	−2.677726	0.0037		
Group PP-statistic	−10.23174	0.0000		
Group ADF-statistic	−5.089644	0.0000		

4.4. Long-run Analysis

This P-ARDL(4,4,4,4,4) model estimated over the period 1995-2023 (Table 6) reveals robust long-term structural relationships between GDP and the macroeconomic variables studied. All coefficients display high statistical significance (P < 5%), with contrasting elasticities. Household consumption (DCNSMEN) exerts a significant depressing effect at 5% ([β = −1.16], P = 0.018), potentially reflecting saturation or substitution effects, while productive investment (DFBCF) stimulates GDP with an elasticity of [+0.67] (P = 0.017), validating its role as a growth driver. Inflation (DINFL) appears as a major brake ([β = −0.31],

Table 5: Lag criteria

Modèle	Log likelihood (LogL)	AIC*	BIC	HQ	Specification
16	−241.236037	4.830842	7.068525	5.740088	ARDL (4,4,4,4,4)
12	−248.059452	4.855992	6.991029	5.723530	ARDL (3,4,4,4,4)
8	−265.002806	5.020728	7.053119	5.846557	ARDL (2,4,4,4,4)
4	−275.089160	5.090885	7.020630	5.875005	ARDL (1,4,4,4,4)
5	−330.680200	5.099037	5.899676	5.424364	ARDL (2,1,1,1,1)
6	−311.293940	5.107503	6.318725	5.599663	ARDL (2,2,2,2,2)
10	−306.431676	5.109402	6.423271	5.643272	ARDL (3,2,2,2,2)
15	−281.575595	5.111388	6.938486	5.853799	ARDL (4,3,3,3,3)
9	−327.040414	5.117799	6.021084	5.484834	ARDL (3,1,1,1,1)
13	−323.121321	5.132708	6.138639	5.541452	ARDL (4,1,1,1,1)
14	−303.283251	5.134941	6.551456	5.710519	ARDL (4,2,2,2,2)
1	−338.393375	5.136460	5.834453	5.420078	ARDL (1,1,1,1,1)
11	−289.722414	5.154792	6.879245	5.855495	ARDL (3,3,3,3,3)
7	−296.627658	5.181071	6.802878	5.840066	ARDL (2,3,3,3,3)
3	−303.722970	5.209972	6.729133	5.827258	ARDL (1,3,3,3,3)
2	−325.455145	5.233864	6.342441	5.684316	ARDL (1,2,2,2,2)

* Significant at 5%

Table 6: Panel ARDL long-Run PMG estimation

Variable	Coefficient	SE	t	Probability*
Long run equation				
DCNSMEN	−1.157321	0.475523	−2.433786	0.0182
DFBCF	0.668857	0.272894	2.450983	0.0174
DINFL	−0.314721	0.059020	−5.332431	0.0000
DOUVCOM	0.107372	0.037626	2.853678	0.0060

SE: Standard error, *Significant at 5%

P < 0.001), each point of increase reducing GDP by 0.31% in the long term, while trade openness (DOUVCOM) contributes moderately but significantly ([+0.11], P = 0.006). The consistency of the theoretical signs, the precision of the estimators (low standard errors) and the robustness of the AIC criterion confirm the reliability of the model for prospective analysis and the formulation of economic policies targeting simultaneously inflationary control and investment incentives.

4.5. Short-Run PMG Estimation

The error correction term (COINTEQ01) (Table 7) is significant at the 5% level ([β = −0.88], P = 0.015), indicating a rapid adjustment speed toward long-term equilibrium (88% of disequilibrium is corrected each period). Lagged changes in GDP ([D(GDP(-1))] to [D(GDP(-3))]) show limited inertia (non-significant coefficients, P > 0.23). Only the second lag of household consumption ([D(DCNSMEN(-2))]) has a significant positive impact ([+1.28], P = 0.039), suggesting delayed effects of household demand. Investment shocks ([D(DFBCF)]) and inflation shocks ([D(DINFL)]) show no immediate significant effects (P > 0.69), while the one-period lagged commercial openness ([D(DOUVCOM(-1))]) exhibits a marginally significant effect at the 10% level ([+0.17], P = 0.096). The significant constant term ([+2.75], P = 0.030) reflects structural growth trends not explained by the model's variables. The weak explanatory performance (*implicit adjusted* $R^2 \approx 1 - (5.07^2/17.42^2) \approx 0.91$) and the predominance of non-significant coefficients highlight the complexity of short-term dynamics, where only specific channels (delayed consumption, equilibrium adjustment) emerge as key drivers.

Table 7: Panel ARDL short-run PMG estimation

Variable	Coefficient	SE	t	Probability
Short-run equation				
COINTEQ01	−0.881858	0.350522	−2.515844	0.0148
D (GDP (-1)	−0.090745	0.305543	−0.296997	0.7676
D (GDP (-2)	0.231301	0.201758	1.146428	0.2565
D (GDP (-3)	0.111954	0.092804	1.206347	0.2328
D (DCNSMEN)	2.280246	7.220767	0.315790	0.7533
D (DCNSMEN (-1)	−3.751599	3.778287	−0.992937	0.3250
D (DCNSMEN (-2)	1.277590	0.605999	2.108236	0.0395
D (DCNSMEN (-3)	−4.901354	5.371420	−0.912488	0.3654
D (DFBCF)	−0.156752	0.403826	−0.388168	0.6994
D (DFBCF(-1)	−0.065065	0.272863	−0.238452	0.8124
D (DFBCF(-2)	−0.086666	0.273622	−0.316735	0.7526
D (DFBCF(-3)	−0.088740	0.363758	−0.243954	0.8082
D (DINFL)	−0.142236	0.436987	−0.325492	0.7460
D (DINFL(-1)	0.323595	0.371018	0.872180	0.3868
D (DINFL(-2)	0.332327	0.277257	1.198623	0.2357
D (DINFL(-3)	−0.006818	0.234948	−0.029020	0.9770
D (DOUVCOM)	0.215734	0.218770	0.986122	0.3283
D (DOUVCOM(-1)	0.168393	0.099544	1.691648	0.0963
D (DOUVCOM(-2)	0.067121	0.130447	0.514548	0.6089
D (DOUVCOM(-3)	0.324794	0.291976	1.112400	0.2707
C (Constant)	2.750331	1.232238	2.231979	0.0296

SE: Standard error

4.6. Discussion

The P-ARDL(4,4,4,4,4) model results for 1995-2023 highlight strong structural links between GDP and key macroeconomic variables in North Africa. The significant positive effect of productive investment on growth (+0.67, P = 0.017) confirms its vital role in addressing infrastructure gaps and low diversification. Recovery strategies should prioritize both public and private investment in high-potential sectors like modern agriculture, renewables, light industry, and digital economy, supported by stronger institutions, improved project governance, and better SME financing.

Unlike traditional assumptions, energy consumption shows a significantly negative long-term impact on GDP (β = −1.16, P = 0.018) in North Africa. This suggests that inefficient or excessive energy use may reflect waste and reliance on costly fossil fuel imports, undermining economic performance. These findings highlight the urgency of reforming energy policies by investing in efficiency, promoting renewables, and encouraging more rational energy use in both industry and households. Inflation has a strong negative impact on GDP ($\beta = -0.31$, $P < 0.001$), confirming its destabilizing role in North Africa. Driven by global price shocks, currency depreciation, and food and energy pressures, inflation undermines growth and can trigger social unrest. Central banks must therefore strike a careful balance between maintaining price stability and supporting economic activity through prudent monetary policy. Trade openness has a modest but significant positive effect on GDP (+0.11, $P = 0.006$), indicating gradual global integration. However, its benefits are limited by low value-added exports, weak competitiveness, and import dependence. To maximize gains, North African countries must reform trade strategies to support productive transformation through upgrading, diversification, and deeper integration into regional and global value chains.

The error correction coefficient (−0.88, $P = 0.015$) shows that 88% of macroeconomic imbalances are corrected each period, indicating strong long-term adjustment capacity and resilience in North African economies. However, this resilience often depends on socially costly measures like austerity and devaluations, highlighting the need for more inclusive economic governance that can absorb shocks without deepening inequality. Short-term dynamics show significant inertia, with mostly insignificant effects except for household consumption after two periods (+1.28, $P = 0.039$), likely reflecting delayed impacts of social support measures. This highlights the need for medium-term economic planning and consistent, predictable policies—especially in transitioning economies like those of North Africa.

5. CONCLUSION

The analysis of North Africa's economic dynamics from 1995 to 2023 reveals structural weaknesses but also key policy levers. To drive growth, countries must refocus their development strategies on productive investment, both public and private. This involves increasing investment volumes and improving their efficiency through better governance, SME financing, and targeted investments in high-value-added sectors like modern agriculture, renewables, light manufacturing, and the digital economy.

The negative impact of energy consumption on growth calls for a major shift in energy policy. Priorities should include improving energy efficiency, reducing reliance on imported fossil fuels, and promoting sustainable energy. Achieving this requires a comprehensive approach involving fiscal incentives, technological advancement, and consumer education to lower energy costs and enhance economic efficiency. Combating inflation is crucial for maintaining macroeconomic stability, protecting purchasing power, preventing social tensions, and encouraging private investment. This requires prudent monetary policy, control of food and energy prices, and strong coordination between fiscal and monetary policies. While trade openness positively affects growth, its impact remains limited, reflecting weak global integration. North African countries should therefore revise their trade strategies by diversifying exports, promoting regional industrialization, and strengthening integration into global value chains, particularly through the AfCFTA.

The study highlights strong short- and long-term adjustment capacity, indicating resilience. However, this resilience should no longer rely on socially costly mechanisms. There is a need for more inclusive economic governance to reduce inequality, protect vulnerable groups, and absorb shocks without increasing social tensions. Delayed short-term responses also underscore the importance of consistent and credible policies to support domestic demand and growth. In conclusion, North Africa must align its strategy around three key pillars: boosting productive investment and sustainable industrialization, strengthening macroeconomic stability to guard against inflation and energy risks, and transforming trade openness into a driver of productive upgrading. A comprehensive strategy that integrates stability, diversification, energy transition, and social inclusion is essential for achieving sustainable and resilient growth.

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