



Balancing Trade and Ecology: The Impact of Globalization on Algeria's Carbon Footprint

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Abstract:

This study aims to show the impact of trade openness and foreign direct investment (FDI) on CO₂ emissions in Algeria, incorporating key variables such as GDP and urbanization. Using the ARDL approach for the period 1970 to 2023 in EViews 13, the analysis determines short-run and long-run associations, including the interaction between trade openness and FDI. The results support a persistent long-term link between economic growth and emissions, highlighting the ecological consequences of industrial expansion. Notably, while FDI alone contributes to higher emissions, its interaction with trade openness helps mitigate environmental impacts by facilitating cleaner technologies. These findings provide new insights into the relationship between economic globalization and environmental sustainability in Algeria.

Key Words: Trade openness; Globalization; CO₂ missions; Foreign direct investment (FDI); Environmental sustainability.

JEL Classification: F18, Q56, Q58

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Introduction:

Balancing economic growth with environmental sustainability arguably represents one of the defining challenges of the 21st century, especially for developing economies faced with the dual pressures of industrialization and climate action. CO₂ emissions are a key measure of environmental impact, closely tied to urbanization, globalization, and energy-intensive growth.

Algeria is a country that, though rich in natural resources, is highly vulnerable to environmental degradation. This understanding of policies and their impacts on the environment is inevitable, as the country embarks on diversifying an economy dependent on hydrocarbons through trade liberalization and foreign investment. This study fills a gap in regional research by examining how trade openness and FDI, key to Algeria's economic strategy, interact with urbanization and GDP changes to influence CO₂ emissions over time.

Therefore, the following research question will be central to this inquiry: How do trade openness, FDI, urbanization, and economic growth collectively shape the CO₂ emissions of Algeria, and what are the dynamics of these relationships in both the short and long run?



Previous studies have indicated the two-edged edge of globalization. While trade and FDI can spur economic growth, they may also exacerbate environmental harm, particularly in nations with lax regulations or carbon-intensive sectors.

The EKC hypothesis further muddles the narrative by offering that emissions actually rise during an early development phase but then contract as economies mature. Regardless, the unique features of Algeria—specifically, one of rapid urbanization—lead to the hypothesis that trade openness and FDI have a dual impact on CO₂ emissions, influencing both short-term increases and long-term reductions through various factors such as technological diffusion and efficiency gains, and it is also assumed that the interaction between trade openness and FDI plays a crucial role in shaping Algeria's CO₂ emissions trajectory, with potential differences in short- and long-term effects. However, this gap is filled by this study through the use of an autoregressive distributed lag model on dataset 1970-2023 to capture the immediate and lagged effects of these economic variables on emissions. This research also integrates an interaction term between trade openness and FDI, adding a new dimension to understanding how these factors interactively influence environmental outcomes in Algeria. The results of this study are meant to avail evidence-based approaches for policymakers on how economic ambitions can be aligned with climate objectives and eventually bring prosperity and health to the planet.

I. Literature review:

CO₂, or carbon dioxide emissions, is a metric for evaluating human activities on the environment, particularly in urban environments where energy consumption and transportation are prevalent. When countries are trying to grow their economies, keeping greenhouse gas at a low level is a big challenge, as shown in the Kuznets curve.

1. Nexus between Trade Openness and CO₂ emissions:

Trade openness is the ratio of a country's total trade (exports plus imports) to its GDP. It measures how much a country participates in international trade relative to its economic size (Kirton, 2017). This highlights how economic growth and trade openness can impact CO₂ emissions, as explained by the Environmental Kuznets Curve (EKC) (Fang et al., n.d.) .

The relationship between trade openness and CO₂ emissions is complex and differs depending on the location and situation. Different studies find that trade can improve economic growth, but it can also raise carbon emissions, especially in poorer nations. Additionally, a nonlinear relationship across various emission quantiles indicates that higher trade openness in Africa is associated with higher CO₂ emissions (Kitila, 2024). Also, export trade tends to increase emissions in both regions, while import trade tends to decrease emissions in the short and long term (Enongene et al., 2024). Furthermore, despite the Middle East's continuous shift to renewable energy, trade openness has been associated with higher CO₂ emissions in the region. This suggests that economic expansion first raises emissions before lowering them at higher income levels (Maalel, 2024).



Furthermore, depending on the sector and economic conditions, trade openness can have varying effects on emissions. For instance, foreign direct investment (FDI) interacts with trade openness and has different effects on emissions in less carbon-intensive sectors while increasing them in more intensive ones (Bagadeem et al., 2024).

2. Nexus between foreign direct investment and CO₂ emissions:

Foreign direct investment can have two impacts increasing CO₂ level or decreasing it, influenced by various factors such as economic growth, technological innovation, and environmental regulations. For example, (Wang et al., 2024) found that in China, high-quality FDI significantly reduces emissions by promoting technological innovation, especially in regions with strong environmental regulations. On the other hand, (Alparslan, 2024) shows a negative correlation between FDI and CO₂ emissions in developing countries, suggesting that responsible investments can lead to lower emissions. Conversely, the pollution haven hypothesis supposes that countries with easygoing environmental regulations attract foreign investments, leading to increased emissions (Gök et al., 2024). In Africa, a U-shaped relationship was identified, indicating that initial increases in FDI may lead to higher emissions until a turning point is reached, after which emissions may decline (Njie et al., 2024).

3. Nexus between GDP and CO₂ emissions:

The interaction between GDP and CO₂ emissions is deep and differs with different income categories and situations, so economic growth can lead to increased CO₂ emissions, but this relationship may follow an inverted U-shaped curve, suggesting that beyond a certain income level, further growth may lead to reduced emissions through technological advancements and shifts towards renewable energy sources. The Environmental Kuznets Curve (EKC) concept suggests that when nations progress economically and raise their incomes, emissions increase, but at a threshold income level, emissions decrease (Tokpah et al., 2024). Furthermore, economic growth often correlates with higher CO₂ emissions due to increased industrial activity and energy consumption (Mirziyoyeva & Salahodjaev, 2023), while, in others country like India a significant negative relationship between GDP and CO₂ emissions was found, indicating that increasing GDP is associated with a reduction in emissions, emphasizing the need for sustainable economic growth while controlling emissions and conserving energy (G, 2023), also, the same results was demonstrated in 10 Asean countries, where economic growth significantly negatively affects CO₂ emissions in the long term indicating a nexus where increased GDP can lead to reduced emissions supporting the environmental Kuznets curve (EKC) hypothesis, highlighting the importance of sustainable economic practices..(Susilowati et al., 2023).

4. Nexus between urbanization and CO₂ emissions:

Urbanization shows the populations moving from rural areas to cities, which leads to the growth and expansion of urban areas, and by the way, can increase carbon emissions according to the augmentation of human activities(Kumari et al., 2024) and energy demand (Khan et al., 2023). As an illustration, in South Asia, where urbanizations are higher, urban expansion increases CO₂ emissions in the long run,



indicating a unidirectional causal relationship from urbanization to emissions. Conversely, studies show that in non-OECD countries, rising urbanization rates lower CO₂ emissions, suggesting more efficient energy use. (Ma & Ogata, 2024), However, population urbanization has a significant negative effect. Technological urbanization has varying effects, while spatial urbanization factors show no significant impact, highlighting the complex link between urbanization and CO₂ emissions (D. Li et al., 2024), Other studies reveal significant regional differences in this relationship, especially in China, where urbanization in some areas strongly correlates with emissions (Song et al., 2024).

Effective policies, such as promoting renewable energy and improving energy efficiency in cities, are essential for balancing urban growth and sustainability. Additionally, campaigns and better public transportation can help reduce emissions linked to urbanization (R. Ali et al., 2024).

5. Nexus between the interaction of FDI and Trade openness on CO₂ emissions:

The interaction of FDI, trade openness, and CO₂ emissions is intricate, as many other factors are responsible for this nexus, particularly in developing and industrialized countries. While FDI generally adds to the negativity of CO₂ emissions, the contribution of trade openness may be either positive or negative, depending on the sector involved and the degree of carbon intensity. On the other hand, FDI is also characterized by reducing CO₂ emissions when specific contexts are considered, such as less carbon-intensive sectors (Bagadeem et al., 2024) However, FDI causes an increase in emissions in heavily polluting industries, thus supporting the "pollution haven" hypothesis. (Liu et al., 2024) Furthermore, the relationship is nonlinear: while FDI tends to lower emissions in an earlier stage, it can surge over time with intensified industrial activity, and trade openness leads to higher emissions when industries are low in carbon intensity and vice versa, as it may reduce it in high carbon intensity sectors (Krasnobayev et al., 2023). In APEC countries, trade openness was found to correlate with higher CO₂ emissions overall ((şentürk) Kocakaya, 2024) On the other hand, other studies suggest both FDI and trade openness could be used to foster more sustainable practices and signals as to how policies aimed at integrating environmental considerations within trade agreements can achieve a more balanced approach to growth and environmental sustainability. (Khalid et al., 2024).



II. Data and Methodology:

This study aims to show the impact of FDI and trade openness on CO₂ emissions in Algeria for the period of (1970-2023), while GDP and urbanization are used as control variables, and also see both the long- and short-term relationship.

Data used in this was collected from various credible and publicly available sources and are presented in Table 1.

Table 1: provides detailed information on the measurement and sources of all variables used in the analysis

Variable	Abbreviation	Description and Source
CO ₂ emissions	CO ₂	Annual CO ₂ emissions from agriculture, energy, waste, and industrial sectors, excluding LULUCF. (WDI 2023)
Trade openness	TRD	The sum of exports and imports of goods and services as a percentage of GDP. Source: WDI (2023).
Foreign direct investment	FDI	Net inflows of foreign direct investment as a percentage of GDP. Source: WDI (2023).
GDP per capita	GDP	GDP per capita in constant 2015 international dollars. Source: WDI (2023).
Urbanization	URB	Urban population growth (annual %), as defined by national statistical offices. Source: WDI (2023).

Source: made by researchers based on databases.

To explore the short- and long-term dynamics of these variables, this study employs the Autoregressive Distributed Lag (ARDL) model. The ARDL approach is particularly suitable because it allows for the estimation of relationships irrespective of whether the variables are integrated at level I(0) or first difference I(1), making it flexible for handling mixed stationarity properties of macroeconomic variables. Furthermore, ARDL is well-suited for small sample sizes, ensuring robust and reliable results. By employing this analytical framework, the research aims to offer significant insights into Algeria's pursuit of sustainable development, the influence of economic and trade factors on environmental outcomes, and the investigation of long-term effects of TRD, FDI, GDP, and URB on CO₂ in Algeria. The steps are outlined below:

- **Data Collection and Description:** Annual data for the period 1970–2023 were collected from reliable sources. The key characteristics of CO₂, TRD, FDI, GDP, and URB were summarized. All variables were converted into natural logarithms to standardize the dataset and interpret the results in terms of elasticities. The choice of these variables is based on empirical evidence and theoretical frameworks relevant to environmental economics. CO₂ emissions serve as the dependent variable, reflecting environmental impact.



Foreign direct investment (FDI) and trade openness (TRD) are key economic factors influencing emissions. GDP per capita is included as a control variable to measure the effect of the economic growth scale, whereas urbanization (URB), measured by urban population growth rate, is considered for its potential impact on energy consumption and infrastructure development. This selection aligns with existing literature on the trade-environment relationship, providing a strong framework to analyze the factors influencing CO₂ emissions in Algeria.

- **Stationarity and Cointegration Tests:** Unit root tests were conducted using ADF and PP methods. A variable is considered stationary if the test statistic is below the critical value at the 5% significance level. The ARDL bounds test was applied to assess cointegration, confirming a long-run relationship if the F-statistic exceeds the upper bound critical value.
- **Estimating Short- and Long-Run Effects:** The ARDL model was used to evaluate the short- and long-term impacts TRD, FDI, GDP, and URB on CO₂. The error correction model (ECM) captured the speed of adjustment toward equilibrium after short-term shocks.
- **Diagnostic and Robustness Checks:** Diagnostic tests were performed, including checks for heteroskedasticity, serial correlation, and model specification. Robustness was further assessed using alternative models and variable substitutions.
- **Results and Discussion:** The empirical results were analyzed and discussed to provide insights into the dynamic interactions between economic, trade, and environmental variables influencing CO₂ emissions in Algeria.

Furthermore, to guide the analysis and provide a framework for interpretation, this study tests the following hypotheses based on the research objectives and variables:

- **H1:** Trade openness significantly increases CO₂ emissions in Algeria due to the intensification of economic activities and industrial production.
- **H2:** Trade openness and FDI influence CO₂ emissions in Algeria through both pollution-intensive investments and potential cleaner technology transfer.
- **H3:** FDI raises CO₂ emissions by driving industrial growth, while GDP does not have an immediate effect but significantly contributes to emissions in the long run.

The ARDL model tests these hypotheses by examining both short-term dynamics and long-term relationships between CO₂ emissions, economic factors, and trade.

Model Specification:

The general econometric model for this study, expressing CO₂ emissions (CO₂) as a function of the independent variables, is specified as follows

$$CO2_t = \alpha_0 + \alpha_1(TRD_{openness_t}) + \alpha_2(\{FDI\}_t) + \alpha_3(\{URB\})_t + \alpha_4(\{GDP\})_t + \alpha_5(\ln\{TRD_{openness} * \ln FDI\})_t + \mu$$

Where CO₂ refers to carbon emissions and TRD_Openess, FDI, URB, GDP, refers to Trade openness, Foreign direct investment, Urbanization, GDP per capita



respectively, and α are coefficients of each variable and μ represents the error term.

The Autoregressive Distributed Lag (ARDL) model developed by (Pesaran et al., 2001) is a robust econometric technique used to analyze both short- and long-run relationships among variables with the possibility in smaller samples and provide separate insights into short-term dynamics and long-term equilibrium.

The model constructed based on the objective of this study can be formed as follows:

$$\begin{aligned} & \{\mathrm{CO2}\}_{t-i} \\ & \mathrm{CO2}_{t-i} = \alpha_0 + \sum_{j=1}^p \beta_j \mathrm{CO2}_{t-j} + \sum_{i=0}^{q_1} \alpha_{1,i} \mathrm{TRD_Openess}_{t-i} + \sum_{i=0}^{q_2} \alpha_{2,i} \mathrm{nURB}_{t-i} + \sum_{i=0}^{q_3} \alpha_{3,i} \\ & \mathrm{FDI}_{t-i} + \sum_{i=0}^{q_4} \alpha_{4,i} \mathrm{GDP}_{t-i} + \sum_{j=0}^{q_5} \varphi_j \ln(\ln \mathrm{TRD_Openess} * \ln \mathrm{FDI})_{t-j} + \epsilon_t \end{aligned}$$

A natural logarithm (LN) is introduced for all variables, while the log version of the variables will indicate the short-run (SR) and long-run (LR) elasticity of the tested variables. It can also reduce the sharpness of the time series data so that we can have a consistent and reliable estimation (Ridzuan et al., 2022). The updated model is as follow:

$$\begin{aligned} & \ln\{\mathrm{CO2}\}_{t-i} \\ & \ln \mathrm{CO2}_{t-i} = \alpha + \sum_{j=1}^p \gamma_j \ln \mathrm{CO2}_{t-j} + \sum_{i=0}^{q_1} \alpha_{1,i} \ln \mathrm{TRD_Openess}_{t-i} + \sum_{i=0}^{q_2} \alpha_{2,i} \ln \mathrm{URB}_{t-i} + \sum_{i=0}^{q_3} \alpha_{3,i} \\ & \ln \mathrm{FDI}_{t-i} + \sum_{i=0}^{q_4} \alpha_{4,i} \ln \mathrm{GDP}_{t-i} + \sum_{i=0}^{q_4} \alpha_{4,i} (\ln \mathrm{TRD_Openess} * \ln \mathrm{FDI})_{t-i} + \epsilon_t \end{aligned}$$

A cointegration technique is employed to assess the long-term relationships between variables in this study. Specifically, the F-statistics from the ARDL bounds testing approach are used to determine whether a long-run relationship exists among the variables. The computed F-statistic is compared against critical values corresponding to the lower and upper bounds. If the F-statistic is below the critical value at the lower bound, no cointegration is present, indicating that the variables do not share a long-term relationship. If the F-statistic lies between the lower and upper bounds, the variables are considered cointegrated (Zergui et al., 2023). The following hypotheses are tested to explore the cointegration relationship between the variables:

The hypotheses tested for the cointegration analysis are as follows:

$H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$ (No cointegration)

$H_1: \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq 0$ (Cointegration exists)

This method provides a robust framework for examining whether a stable long-run relationship exists between the ecological footprint (EF) and the independent variables, and the long-run relationship (cointegration equation) from the ARDL model is expressed as:



$$L\{NEF\}_t = \mu + \beta_1 LNFD_t + \beta_2 LNFDI_t + \beta_3 LNGDP_t + \beta_4 LNGT_t + \beta_5 LNREC_t + v_t$$

The short-run dynamics from the ARDL model are captured by the following error correction representation

$$\begin{aligned} \Delta LNEF_t = & \beta_0 + \lambda \cdot ECT_{t-1} \\ & + \sum_{i=1}^p \alpha_i \Delta LNCO2_{t-i} + \sum_{j=0}^{q_1} \theta_j \Delta LNTRS_Openess_{t-j} + \sum_{j=0}^{q_2} \beta_j \ln URB_{t-j} + \sum_{j=0}^{q_3} \gamma_j \\ & \ln FDI_{t-j} + \sum_{j=0}^{q_4} \delta_j \ln GDP_{t-j} + \sum_{j=0}^{q_5} \delta_j (\ln TRD_Openess * \ln FDI)_{t-j} + \epsilon_t \end{aligned}$$

λ is the coefficient of the error correction term (ECT), which indicates the speed of adjustment toward the long-run equilibrium. The ECT represents the deviation from the long-run equilibrium at the previous period ($t-1$) and measures how quickly the system returns to equilibrium after a short-term shock. It is specified as:

$$\begin{aligned} \{ECT\}_{t-1} = & LNCO2_{t-1} - (\beta_0 + \beta_1 LNURB_{t-1} + \beta_2 LNFDI_{t-1} \\ & + \beta_3 LNGDP_{t-1} + \beta_4 LNTRD_Openess_{t-1} \\ & + \beta_5 LNTRD_Openess * FDI_{t-1}) \end{aligned}$$

III. Results and discussions:

1. Descriptive Analysis of the Variables:

Table 2 here presents the descriptive statistics for the variables used in this study, covering the period from 1970 to 2023. The table provides key summary measures, including the mean, median, maximum, and minimum values for each series. These statistics offer an initial understanding of the central tendency, dispersion, and range of the variables, which is crucial for interpreting the characteristics of the dataset.

Table 2: descriptive statistics of the variables.

	LNCO2	LNFDI	LNGDP	LNTRD_OP ENESS	LNURB	LNFDI_TRD
Mean	4.3889271	-3.2337208	7.7462845	4.001213	1.212633	-3.283179
Median	4.3809335	-1.0411750	7.7580530 40652825	3.983871538 514095	1.092635	-1.320242
Maximum	5.1862477	0.9969834	8.7151738	4.3393087	1.673257	0.996983
Minimum	2.9456067 18146441	-13.121274	5.8660310 39522881	3.486903543 770258	0.821249	-13.12127
Std. Dev.	0.5115598	4.2522025	0.6965522	0.1837153	0.262516	4.279382
Skewness	-0.511715	-1.280780	-0.783962	-0.448544	0.562553	-1.280780
Kurtosis	3.3778342	3.5408430	3.4596424	3.0697375	1.876289	3.548576
Observations	51	51	51	51	51	51

Source: made by researchers based on EViews.

2. Empirical results and discussion:

To analyze the data with the ARDL model, we first conduct unit root tests to assess stationarity. Specifically, we use the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests to determine whether the variables are stationary or require



differencing. These tests are commonly used in time series analysis. The results of these tests, presented in Table 3, reveal that certain variables are integrated at level $I(0)$, while others are integrated at first difference $I(1)$.

The ARDL approach is suitable for this study because it accommodates variables integrated at different orders ($I(0)$ and $I(1)$). By ensuring that all variables are stationary, we can apply the ARDL bounds test to analyze cointegration and long-term relationships.

Table 3: ADF and PP unit root tests

Variables	Augmented Dickey-Fuller (ADF)				Phillips-Perron (PP)			
	At level		First Difference		At level		First Difference	
	t-stat.	Prob.	t-stat.	Prob.	t-stat.	Prob.	t-stat.	Prob.
CO2	- 3.11	0.03	-5.31	0.00	-3.08	0.03	-5.15	0.00
TRD_Openness	-2.08	0.25	-6.48	0.00	-2.26	0.18	-5.51	0.00
FDI	-2.10	0.24	-9.50	0.00	-2.06	0.25	-9.11	0.00
GDP	-3.05	0.03	-5.08	0.00	-2.67	0.08	-5.29	0.00
URB	-1.173	0.67	-3.96	0.03	-1.006	0.74	-3.87	0.004

Source: made by researchers based on EViews.

The unit root tests (ADF and PP) show that most of the variables, including TRD_Openness, FDI, and URB, are non-stationary at the level and become stationary after first differencing with the ADF test, while GDP and CO2 are stationary at the level. On the other hand, the PP test shows a stationary at $I(1)$ for all variables except CO₂, which is stationary at the level.

The results indicate that the variables have a mixed order of integration $I(0)$ and $I(1)$, making the ARDL model a suitable choice. Using the VAR lag length criteria, we determine the optimal lag length to be (2, 4).

Tables 4: The ARDL model results from

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LNCO2(-1)	0.630792	0.117530	5.367093	0.0000
LNNGDP	-0.065369	0.099612	-0.656239	0.5195
LNGDP(-1)	-0.024170	0.146091	-0.165447	0.8703
LNGDP(-2)	0.001995	0.109137	0.018281	0.9856
LNGDP(-3)	0.030915	0.103188	0.299598	0.7677
LNGDP(-4)	0.286850	0.090440	3.171736	0.0050
LNTRD	0.010696	0.147171	0.072676	0.9428
LNTRD(-1)	-0.309041	0.165717	-1.864873	0.0777
LNURB	0.332378	0.209899	1.583516	0.1298
LNURB(-1)	0.273983	0.219685	1.247166	0.2275
LNURB(-2)	-0.305145	0.237273	-1.286051	0.2139
LNURB(-3)	-0.180231	0.248633	-0.724888	0.4774
LNURB(-4)	-0.314454	0.164528	-1.911251	0.0712
FDITRD	-0.017653	0.027329	-0.645956	0.5260
FDITRD(-1)	-0.089653	0.037118	-2.415361	0.0260
FDITRD(-2)	0.029364	0.023052	1.273822	0.2181
FDITRD(-3)	-0.065978	0.019565	-3.372328	0.0032
LNFDI	0.071867	0.107600	0.667910	0.5122
LNFDI(-1)	0.354780	0.147198	2.410216	0.0262
LNFDI(-2)	-0.117023	0.091708	-1.276044	0.2173
LNFDI(-3)	0.256323	0.077801	3.294585	0.0038
C	1.383799	0.769016	1.799441	0.0879

Source: made by researchers based on EViews.



The Autoregressive Distributed Lag (ARDL) model analyzes the impact of Algeria's trade and globalization on CO₂ emissions from 1975 to 2022. The analysis was conducted using the EViews program. The ARDL model estimates provide critical information on the determinants of CO₂ emissions. In that respect, the results show a high persistence of CO₂ emissions with $LNCO_2(-1) = 0.63$, $p = 0.000$, indicating a significant strong persistence over time. This relationship shows that past emissions strongly affect current levels. This finding is consistent with (Acheampong et al., 2019) and (Shahbaz et al., 2018), who found that emissions accumulate over time and show strong dependencies.

Economic growth (LNGDP) affects emissions with a delay, as indicated by $LNGDP(-4) = 0.286$ ($p = 0.005$), showing a significant long-term relationship. However, the other lags are not statistically significant, suggesting instability in the effect of GDP. This result is consistent with the work of (Ozturk et al., 2023), who show that the effect of GDP on emissions can vary depending on a country's stage of development and energy transition. However, unlike the classic Environmental Kuznets Curve (EKC) findings (Stern, 2004), these results do not show a clear link between GDP and long-term emissions reduction. This highlights the need to consider other structural factors.

The effect of FDI (LNFDI) on emissions is mixed. The current coefficient (0.071 , $p = 0.5122$) is not significant, indicating that FDI has no immediate impact on emissions. However, the lags show a delayed influence, notably $LNFDI(-1) = 0.354$, $p = 0.026$ and no significance at the second lag $LNFDI(-2) = -0.117$, $p = 0.2173$, before having an effect at $LNFDI(-3) = 0.256$, $p = 0.0038$. This dynamic suggests that initial FDI tends to favor industrial and energy growth, leading to an increase in emissions, and that even in the longer term, investments continue to be associated with higher emissions rather than a transition to cleaner technologies. These results are consistent with (Apergis et al., 2022) also find that FDI contributes to increased emissions in the short and medium term due to its role in boosting industrial activity. The urbanization rate growth (LNURB) shows a positive coefficient of 0.3323 , but the p-value (0.1299) indicates that this effect is not statistically significant at the 5% level. Examining the lagged effects, $LNURB(-1)$ and $LNURB(-3)$ are positive but not significant. In contrast, $LNURB(-2)$ and $LNURB(-4)$ are negative, with $LNURB(-4)$ having a p-value of 0.076 , which is not significant at the 5% level. On the other hand, trade openness (LNTRD) has no significant effect on emissions, with a coefficient of 0.01 ($p = 0.9428$). Its first lag, $LNTRD(-1) = -0.309$ ($p = 0.077$), is also not statistically significant at the 5% level.

The interaction (FDITRD) of foreign direct investment (FDI) and trade openness (TRD) is not significant at the current level. $FDITRD = -0.017$ ($p = 0.52$), showing no immediate effect. However, its first and third lags have a significant negative impact: $FDITRD(-1) = -0.0895$ ($p = 0.026$) and $FDITRD(-3) = -0.0659$ ($p = 0.0032$). This suggests that the combination of FDI and trade openness helps reduce emissions in the long run. However, $FDITRD(-2) = 0.029364$, $p = 0.2181$ is not significant, suggesting a temporary fluctuation before the long-term trend of emission reduction takes effect. This relationship indicates that FDI facilitates the diffusion of cleaner



technologies and infrastructure when accompanied by greater trade openness. The negative correlation observed indicates that the global flow of capital and commodities increases energy efficiency while at the same time reducing the carbon intensity that is inherent in industrial activities. These results confirm several recent studies. For example, (S. Ali et al., 2020) show that the interaction between trade openness and FDI flows plays a complementary role in promoting cleaner technologies and thereby reducing the environmental impacts of manufacturing industries. (Shahbaz et al., 2018) also highlight that in developing countries, the synergistic relationships between FDI and trade can drive the formulation of stricter environmental regulations and encourage investment in green infrastructure. Lastly, (Zugravu, 2009) suggests that when trade openness has an overall negative impact on the environment, trade in environmental goods can reduce air pollution. These results indicate that trade liberalization, when combined with FDI flows directed towards clean technologies, can improve environmental quality.

2.1. ARDL Bounds Test for Cointegration:

Table 5: results of ARDL Bounds Test for Cointegration.

Test Statistic	Value	Signif.	I (0)	I (1)
F-statistic	9.2805	10%	2.306	3.353
K	5	5%	2.734	3.920
		1%	3.657	5.256

Source: made by researchers based on EViews.

Table 5 summarizes the ARDL bounds test results, showing an F-statistic of 9.2805. This value is compared to critical values at the 10%, 5%, and 1% significance levels. The F-statistic (9.2805) exceeds the upper bound critical values I(1) and I(0) at all significance levels (10%, 5%, 1%), when the critical values for I(1) are 3.353 at 10%, 3.920 at 5%, and 5.256 at 1%, all of which are lower than the calculated F-statistic. Furthermore, the critical values for I(0) are 2.306 at 10%, 2.734 at 5%, and 3.657 at 1%; all are lower than the F-statistic (9.2805).

Since the F-statistic (9.2805) exceeds the upper bound at all significance levels, the null hypothesis of no cointegration is rejected. This confirms a long-run relationship between CO₂ emissions and the independent variables: trade openness, urbanization, GDP, FDI, and their interaction.

This result indicates that changes in these variables have persistent, long-term effects on CO₂ emissions, highlighting the importance of sustainable policies in trade, urbanization, and green FDI to reduce emissions over time.

Table 6 presents the cointegration results, showing the long-run relationship between CO₂ emissions (LNCO₂) and the other variables. The cointegration equation is as follows:

$$CE = LNCO2(-1) - (0.623554 * LNGDP(-1) - 0.808070 * LNTRD(-1) - 0.524012 * LNURB(-1) - 0.389810 * FDITRD(-1) + 1.532870 * LNFDI(-1) + 3.748026)$$

**Table6: Cointegration Equation and Long-Run Relationship.**

Variable*	Coefficient	Std. Error	t-Statistic	Prob
LNGDP (-1)	0.623554	0.091122	6.843072	0.0000
LNTRD (-1)	-0.808070	0.305233	-2.647386	0.0121
LNURB (-1)	-0.524012	0.169209	-3.096827	0.0038
FDITRD (-1)	-0.389810	0.107783	-3.616630	0.0009
LNFDI (-1)	1.532870	0.423779	3.617148	0.0009
C	3.748026	1.303836	2.874615	0.0068

Source: made by researchers based on EViews.

This equation expresses the equilibrium deviation of CO₂ emissions from its economic factors. Each coefficient indicates the long-term effect of the explanatory variables on CO₂ emissions.

Economic Growth (LNGDP(-1)) has a significant positive impact on CO₂ emissions, with a coefficient of 0.6236 ($p = 0.0000$). This validates the Environmental Kuznets Curve (EKC) theory, which holds that first environmental degradation results from economic development before possible improvements via laws and clean technologies as GDP rises CO₂ emissions (Hannesson, 2022).

Trade Openness (LNTRD(-1)) has a negative and statistically significant effect on CO₂ emissions (-0.8081, $p = 0.0121$). A higher trade openness can lead to an increase in industrial production and freight transport, thus contributing to emissions. However, if accompanied by strict environmental regulations, this negative effect could be mitigated (Chhabra et al., 2023) (Barkat et al., n.d.).

Urbanization (LNURB(-1)) has a negative and significant effect (-0.5240, $p = 0.0038$) on CO₂ emissions, suggesting that it may lead to lower emissions over time. This could be attributed to increasing population density, better public transportation, and more energy-efficient infrastructure. However, the impact of urbanization on emissions remains highly dependent on the nature of urban development and energy policies (A. Li et al., 2022).

Foreign Direct Investment (LNFDI(-1)) has a positive and significant effect (1.5329, $p = 0.0009$) on CO₂ emissions, indicating that FDI inflows contribute to pollution, possibly through investments in emissions-intensive businesses. This data confirms the pollution haven hypothesis, which states that foreign investments in developing countries frequently seek less-regulated sectors with a high environmental effect.

The interaction between FDI and trade (FDITRD(-1)) shows a negative and significant effect (-0.3898, $p = 0.0009$). This suggests that international economic integration promotes the transfer of clean technologies and the improvement of energy efficiency. This result is consistent with recent studies showing that economic liberalization, when well regulated, can reduce CO₂ emissions through the diffusion of green technologies (Mahmood et al., 2023).

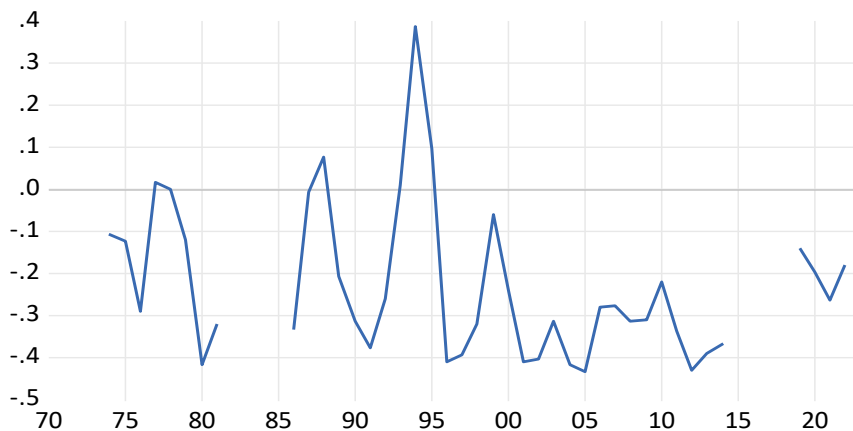
The results show that economic growth has a substantial long-term impact on CO₂ emissions, highlighting the importance of policies that balance development with environmental sustainability. Trade openness, while typically associated with reduced emissions, needs robust regulatory structures to maintain its environmental advantages. Urbanization tends to help reduce emissions, implying that sustainable urban design and energy-efficient infrastructure are critical. The negative impact of



FDI-trade interaction on emissions demonstrates that economic integration can promote the transfer of cleaner technology, hence creating a more sustainable industrial environment. These findings reflect current studies on globalization and environmental sustainability, emphasizing the need for integrated economic and environmental measures to reduce CO₂ emissions and promote sustainable growth.

Plot 1: Dynamics of the ARDL Cointegration Series.

ARDL Cointegrating Series



Source: made by researchers based on EViews.

The dynamics of equilibrium deviations during the investigated time is emphasized by the study of the ARDL cointegration series graph (plot 1) where significant volatility is noted at the start of the period, indicating quick adaptations to economic and environmental shocks. Subsequently, the series appears to bounce around a reasonably steady trend, indicating a gradual convergence toward long-run equilibrium. However, certain swings missing, indicating temporary impacts caused by changes in economic drivers. These findings support the validity of the cointegration model utilized and emphasize the significance of structural changes in order to maintain a sustainable emissions trajectory.

2.2. Diagnostics Tests:

Table 7: Diagnostic Tests for Model Specification and Assumptions.

Test	Statistic	Value	p-value	Interpretation
Breusch-Godfrey Serial Correlation LM Test	F-statistic	0.415394	0.6666	Fail to reject the null hypothesis: No significant serial correlation.
	Obs*R-squared	1.911090	0.3848	Fail to reject the null hypothesis: No significant serial correlation.
Heteroskedasticity Test: ARCH	F-statistic	0.727438	0.3994	Fail to reject the null hypothesis: no heteroskedasticity.
	Obs*R-squared	0.752643	0.3856	Fail to reject the null hypothesis: no heteroskedasticity.
Ramsey RESET Test	t-statistic	1.413747	0.1745	Fail to reject the null hypothesis: no specification error.
	F-statistic	1.998679	0.1745	Fail to reject the null hypothesis: no specification error.



	Likelihood ratio	4.3117074	0.0877	Reject the null hypothesis: model specification error.
Jarque-Bera Normality Test	JB Statistic	0.384678	0.825027	Fail to reject the null hypothesis: residuals are normally distributed.
	Skewness	-0.17661		Residuals are symmetrically distributed.
	Kurtosis	2.683141		Residuals do not have extreme outliers (close to 3).

Source: made by researchers based on EViews.

The results of the diagnostic tests in Table 7 reveal several important elements regarding the quality and validity of the econometric model.

The Breusch-Godfrey test for serial correlation does not reject the null hypothesis, showing no significant autocorrelation in the residuals. This suggests that past errors do not influence future errors, meaning the model correctly captures the relationships among the variables without omitted dynamics. The ARCH test for heteroskedasticity fails to reject the null hypothesis, showing that the variance of the residuals remains stable over time. This ensures that the model does not suffer from heteroskedasticity, making the standard errors reliable and allowing for accurate hypothesis testing.

The Ramsey RESET test and the likelihood ratio test confirm the model's correct specification by failing to reject the null hypothesis. There is no strong evidence of missing variables or incorrect transformations. No strong evidence suggests missing variables or incorrect transformations, confirming the model's structural adequacy. Finally, the Jarque-Bera normality test fails to reject the null hypothesis, indicating that the residuals follow a normal distribution. The skewness and kurtosis values indicate that the residuals are symmetrically distributed and free from extreme outliers, supporting the reliability of statistical inference.

Table 8: The Variance Inflation Factor (VIF) Analysis

Variable	Coefficient Variance	VIF
LNFDI	4.60E-05	1.881832
LNGDP	0.000967	1.055969
LNTRD	0.019288	1.489658
LNURB	0.007555	1.162349
FDITRD	0.000151	2.205482

Source: made by researchers based on EViews.

The variance inflation factor (VIF) test was also conducted to check for multicollinearity among the independent variables. The results in table 8 show a VIF below the critical threshold of 10 for all independent variables where the VIF of LNFDI is (1.88), LNGDP (1.05), LNTRD (1.48), LNURB (1.16) and FDITRD (2.20). This suggests that the explanatory variables used in the model are not highly correlated, ensuring reliable coefficient estimates.

**Conclusion:**

This study examined the interaction between trade openness, foreign direct investment (FDI), economic growth, urbanization, and CO₂ emissions in Algeria using the Autoregressive Distributed Lag (ARDL) approach. The findings reveal that economic growth is linked with a significant rise in emissions in the long run, underscoring Algeria's continued reliance on carbon-intensive industries. This result contradicts the Environmental Kuznets Curve (EKC) hypothesis, as no evidence supports the idea that a rise in GDP leads to a decrease in emissions over time. In addition, FDI appears as a key driver of emissions, suggesting that foreign investments continue to flow predominantly into pollution-intensive sectors instead of leading to a transition towards cleaner alternatives. However, the relationship between trade openness and FDI shows a moderating effect, suggesting that higher trade openness can facilitate cleaner technology transfer and improve energy efficiency. The findings also indicate that trade openness by itself has no significant influence on CO₂ emissions, which contradicts the assumption that heightened global trade always aggravates environmental problems. Rather, its impact seems to depend on the quality of attracted investments and the strength of the existing regulatory system. The research also finds that urbanization has a long-run negative impact on emissions, indicating that efficient infrastructure, improved public transport, and environmentally sound urban planning contribute to environmental benefits over time.

These findings highlight the necessity of keeping in balance economic growth and protection of the environment. Spending on greener industrial technology and strengthening protection of the environment can limit the environmental burden of trade growth. Encouragement of FDI in clean industries and ensuring consistency of trade agreements with global emissions standards is also crucial for low-carbon transformation. Furthermore, leveraging digitalization and clean technologies can support more energy efficiency and less waste production in core industries. However, as the study is conducted on historical data, it may not be a true representation of the effects of possible future structural changes or technological advancements. Future studies must examine sectoral patterns in emissions, other environmental indicators, and how green finance will affect sustainable development.

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