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The Impact of Final Energy Consumption in Transportation and Urbanisation on Environmental Quality in Algeria: An Econometric Study Using the ARDL Model for the Period 1990—2022

Benazza Hicham[1]
Laboratory of Research on Public Governance and Social Economy
ORCID: https://orcid.org/0009-0001-0135-7189
benazza.hicham@cuniv-naama.dz
Mekdad yousra[2]
[12]Ph.D. - Assistant Professor.
mekdad.yousra@cuniv-naama.dz
Khatima Bahadji[3]
Professor of Lecturer Department B
[123]Salhi Ahmed University Center of Naama (**Algeria**).
bahadji.khatima@cuniv-naama.dz
Belaid Hayat
Professor of Higher Education, University Tahri Mohammed bechar, (**Algeria**).
belaid.hayat@univ-bechar.dz
Trifa Mohamed
University of Mohammed Seddik Benyahia Jijel (Algeria).
mohamed.trifa@univ-jijel.dz

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Abstract:
This study aims to measure the impact of both final energy consumption in transportation and urbanisation on the environmental quality in Algeria from 1990--2022. It describes an econometric model whose independent variables are final energy consumption in transportation (OILTRANS), urbanisation, and the growth rate of gross domestic product (GDP), and the dependent variable of environmental quality is expressed as the carbon dioxide emissions index (CO2E). Using an autoregressive bounds analysis method, the distributed lag (ARDL) procedure was applied, and the cointegration test was used. The study results confirmed that final energy consumption in transportation has a significant and positive long-term contribution to CO2 emissions in Algeria. The GDP per capita also has a significant positive effect on CO2 emissions. Furthermore, a significant direct correlation was found between CO2 emissions and urbanisation in the long run.
Keywords: final energy consumption in transportation; urbanisation; environmental quality; ARDL GDP growth rate.

1- Introduction:

Accelerating global demographic trends are expected to drive energy demand in the transportation and mobility sector over the coming decades, presenting significant challenges and promising opportunities for achieving sustainable development goals, according to a recent report published by the International Energy Forum (IEF). The transportation and mobility sector accounts for more than 50% of the total global oil demand and 23% of energy-related carbon dioxide emissions. Therefore, this sector's future directions are pivotal to achieving

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global sustainability goals (Adebayo & Rjoub, 2021). According to a report prepared by Ali Al-Samawi, an energy analyst at the International Energy Forum (IEF), the demand for air transport and jet fuel is expected to rise by 70% by 2050.

Moreover, electric vehicles (EVs) are projected to account for 23% of the total number of vehicles worldwide by 2035. However, long-haul trucking, maritime shipping, and aviation sectors continue to present significant challenges in terms of sustainability. Reducing emissions in these sectors will depend on improving efficiency, integrating oil with low-carbon fuels, and engaging in carbon credit trading.

On the other hand, global energy demand in the transportation and mobility sector is expected to increase significantly in the coming decades, with demand estimates for 2050 ranging between 50 and 70 million barrels of oil equivalent per day (Adebayo, Awosusi, Kirikkaleli, & Akinsola, 2021). By 2050, land transportation in terms of kilometres travelled is expected to grow by 90% in the Middle East and North Africa region, 100% in Southeast Asia, and 200% in Sub-Saharan Africa compared with 2019 levels, driven by economic growth, increased trade, and urban expansion.

Rapid environmental degradation is not a natural phenomenon but is attributed to human activities such as urbanisation, globalisation, and energy consumption. In most countries, urbanisation is accompanied by strong real income growth, the concentration of secondary and tertiary industries in urban areas, and population migration from rural to urban regions, all of which contribute to increased carbon emissions. The global urban population was estimated at 1.52 billion in 1970 and is projected to grow to 4.6 billion by 2030, with a significant portion of this growth occurring in Asian and African cities (Alam, 2011).

Many empirical studies have used urbanisation as a factor contributing to economic degradation and carbon emissions because of the high mobility of people in urban areas and the consumption of energy-intensive goods. As a result of the shift in economic activity and changes in population behavioural patterns following migration from rural to urban areas, the urbanisation process impacts the environment by altering levels of pollutant emissions. This finding indicates that the significance of the relationships among urbanisation, energy consumption within globalisation, and environmental degradation varies across countries on the basis of their actual income levels and stages of development.

In recent decades, attention has been given to the negative ecological and environmental impacts of urbanisation through global economic and social development. In addition to influencing the development of real income, health, education, and socialisation of populations, urbanisation affects environmental protection and management, alongside the exploitation of natural resources through energy consumption (Azam, Khan, Abdullah, & Qureshi, 2016).

1-1-Study problem:

Among all the sectors responsible for greenhouse gas emissions, transportation, including maritime shipping, aviation, and land transport, is the most significant contributor to global warming and fuel consumption across all branches. Although most sectors contributing to carbon emissions have managed to reduce their emissions, the transportation sector has

increased its share, making it the fastest-growing environmental polluter. It is projected that up to 50% of total carbon dioxide emissions will originate from the transportation sector by 2050 (Ahmed, 2021), compared with approximately 30%.
Many studies provide clear evidence regarding the transportation sector's responsibility for emissions. Land transport is the primary source of carbon dioxide and other gas emissions that affect the troposphere, whereas shipping contributes the largest share of methane and sulfate emissions. In an economy whose growth heavily depends on the movement of goods, commodities, and people across cities and countries worldwide, our options are limited: either to develop solutions and begin implementing them seriously through legally binding mechanisms or to leave future generations to face the devastating consequences of unlimited consumption and indifference toward environmental issues on Earth (Hafeez, 2021).
Although land transportation is the most significant contributor to emissions compared with other branches of the transportation sector, its responsibility and ability to devise and implement solutions within a reasonable timeframe are feasible. However, in the maritime shipping and aviation sectors, it is more difficult to pinpoint responsibility for emissions, making it impossible to demand specific climate commitments from a particular entity within these sectors (Aiyetan, 2013).
Accordingly, this study's problem is summarised as measuring the impact of final energy consumption from fuel in the transportation sector and urbanisation on environmental quality in Algeria via the ARDL model from 1990--2022.

1-2. Study Assumptions:
This study assumes that final energy consumption in the transportation sector negatively impacts environmental quality in Algeria because of increased greenhouse gas emissions, particularly carbon dioxide. In addition, interactions within the processes of urbanisation and economic expansion negatively affect the environmental and climate quality in Algeria due to the associated strong real income growth, the concentration of secondary and tertiary industries in urban areas, and population migration from rural to urban regions, all of which contribute to increased carbon emissions.

1-3. Study Objective:
This study aims to test the two previously stated hypotheses via an econometric approach by applying it to the final energy consumption in the transportation sector from 1990–2022. The choice of this sector is justified by its position as the leading consumer of energy sources since the beginning of the study period. The study also considers the economic reform policy adopted by Algeria at the beginning of the period, which led to the implementation of trade liberalisation policies and increased the country's openness to the global market. The period under analysis concludes in 2022.
1-4. Study Methodology:
The study relies on a methodology to identify the key aspects of energy consumption in the transportation and mobility sector, urbanisation, and the environment. It also seeks to

measure the impact of final energy consumption in the transportation sector and urbanisation on environmental quality in Algeria via the ARDL model from 1990–2022. The analysis is based on data obtained from the World Bank database.

1-5. Study Structure:

The study is divided into two main sections, in addition to the presentation of results and recommendations:

- Theoretical framework and a review of key previous economic studies.
- The measurement of the impact of final energy consumption in the transportation sector and urbanisation on environmental quality in Algeria.

2. Theoretical Framework and Review of the Key Previous Economic Literature

2-1. Theoretical Framework of the Study:

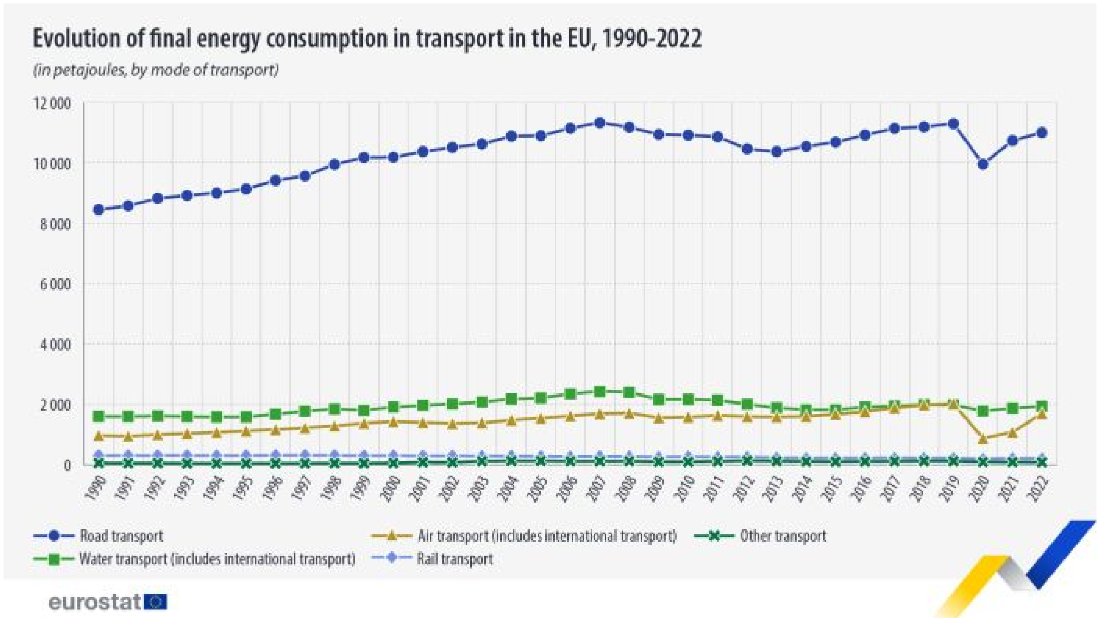
2-1-1. Final energy consumption by sector from 1990–2022

The transportation sector is one of the sectors that directly influences the growth of the global economy, with its importance increasing alongside the continuous expansion of globalisation and interregional trade. As a result, securing energy sources for this sector has gained particular significance. Moreover, since the primary energy source for this sector is oil, an exhaustible resource (Chang, 2012) and given that its use as fuel contributes to the emission of greenhouse gases responsible for global warming, interest in developing alternatives to transportation fuels began in the 1990s (Cheng, 1995).

In this context, many companies and research institutions concerned with energy supplies and the transportation industry have made significant efforts to develop integrated systems that include various types of alternative fuels, their supply methods, and appropriate transportation methods (Akbostanci, 2009).

Figure 1

Evolution of Final Energy Consumption in Transportation in the European Union (1990–2022)



Source : EUROSTAT (2022) (nrg_d_traq)

The transportation sector accounted for 31.0% of final energy consumption, representing the most significant share compared with households (26.9%), industry (25.1%), and services (13.4%).

This article presents data on final energy consumption in transportation within the European Union for 2022, broken down by mode of transport and the type of fuel used for power transport activities (Yuping, 2021).

This consumption is expected to grow at an annual rate of 1% from 2019–2040, reaching 247.4 million barrels of oil equivalent by 2040, including 89.6 million barrels from oil, 45.2 million barrels from natural gas, and 112.6 million barrels from other sources (Akinsola, 2021).

2-1-2. Carbon Dioxide Emissions from the Transportation and Other Sectors

Carbon dioxide emissions from transportation peaked in the mid-2000s, surpassing those from electric power generation. Following the 2007–2009 recession, transport-related emissions declined but later rebounded and approached their prerecession peak when the pandemic struck in early 2020 (Akpan, 2022).

The total energy-related carbon dioxide emissions in the United States peaked in 2005 and will decline by approximately 20% by 2024, with an average decrease of approximately 0.07 billion metric tons (BMTs) annually. Three-quarters of this reduction came from the electric power sector (Bhattacharya, 2020).

Emissions from the transportation sector declined by 6% during the same period, with an average reduction of 0.01 BMT per year. This change accounted for only one-tenth of the overall decline in energy-related emissions. The industrial, residential, and commercial sectors were responsible for the remainder of the reduction (Apergis, 2011).

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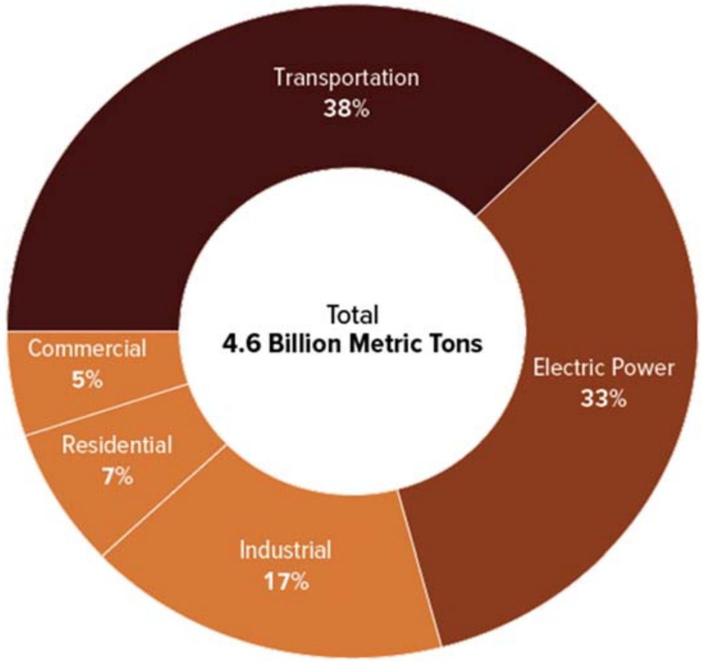
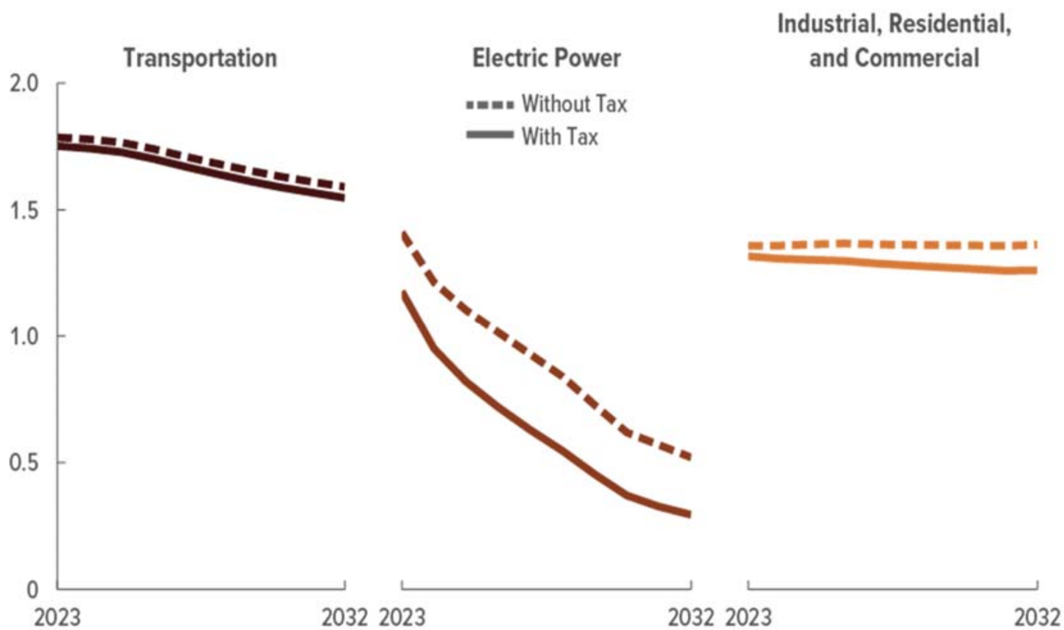
Figure 2
Shares of Energy-Related Carbon Dioxide Emissions by Economic Sector, 2024



Source : EUROSTAT (2022) (nrg_d_traq)

The difficulty of reducing transport emissions can be illustrated by examining the effects of an emissions tax across different sectors. For example, a tax starting at $25 per metric ton and increasing annually at an inflation-adjusted rate of 5% would lead to a minor reduction in carbon dioxide emissions in the transportation sector compared with other sectors (Bowden, 2009).

Figure 3*Estimated effects of a $25 per ton tax on energy-related carbon dioxide emissions*



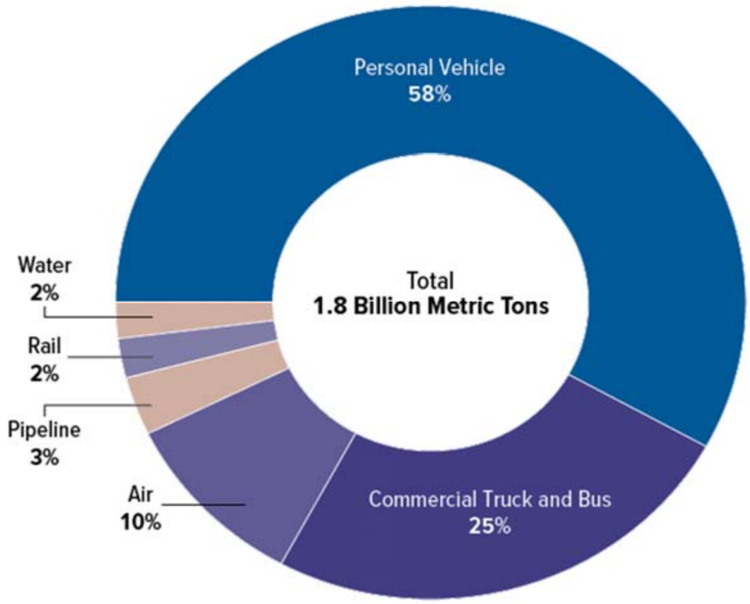
Source : EUROSTAT (2022) (nrg_d_traq)

The figure above illustrates a hypothetical case involving a tax on each metric ton of emitted carbon dioxide, highlighting a major challenge in reducing transport emissions: the demand for transportation is less sensitive to price changes than is the demand for electric power, the second largest source of emissions (Breisinger, 2019).

2-1-2-1. Sources of Transport-Related Emissions

This report highlights that automobiles (including personal vehicles, commercial trucks, and buses) account for most emissions. Emissions from commercial trucks and all buses represented 25% of the total. Motor vehicles, personal vehicles, commercial trucks, and buses collectively accounted for 83% of transportation sector emissions in 2024.

Figure 4*Shares of Transport-Related Carbon Dioxide Emissions by Mode of Transport, 2024*



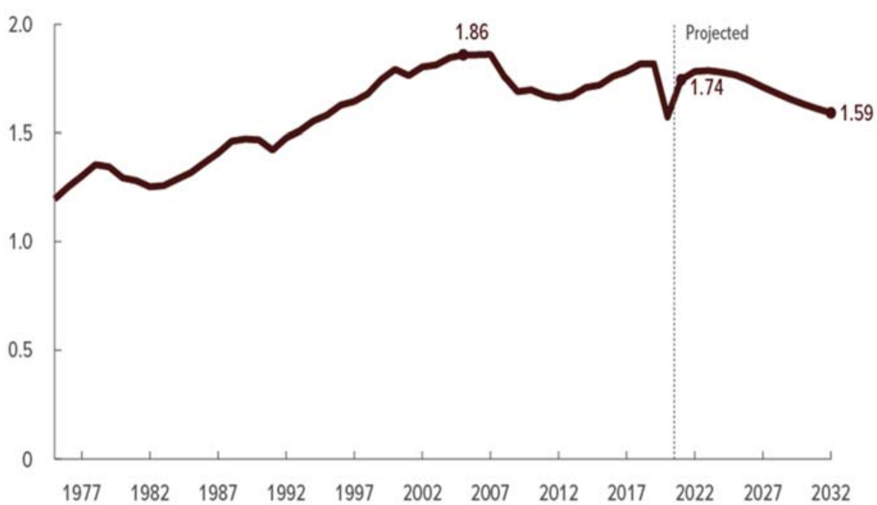
Source : EUROSTAT (2022) (nrg_d_traq)

2-1-2-2. Forecasts of Carbon Dioxide Emissions from Transportation

Carbon dioxide emissions from automobiles are expected to decline as a result of recent and scheduled increases in fuel economy standards for new vehicles, combined with the growing adoption of electric vehicles, gradually reducing the average emission rates of vehicles over time.

Figure 5

Carbon Dioxide Emissions from Transportation, 1975--2032



Source : EUROSTAT (2022) (nrg_d_traq)

2-2- The most important economic literature of the past:

- Study of Nkengfack and Fotio (2019):

This study examined the causal relationship between economic growth and carbon emissions in three of the most environmentally polluting African countries, Egypt, Algeria, and South Africa, from 1971--2015.

This study employed the autoregressive distributed lag (ARDL) model and revealed positive and significant impacts of both energy consumption in the transportation sector and economic growth on environmental degradation in the short and long term. Disaggregation of energy consumption according to its source revealed that petroleum, electricity, and coal were the largest sources of environmental pollution in Algeria, Egypt, and South Africa, respectively.

Moreover, causality test results revealed the existence of a bidirectional causal relationship between energy consumption and carbon emissions, between carbon emissions and economic growth, and between energy consumption and economic growth in Egypt (Dogan, 2016).

-Findings of Omri (2013):

Using the simultaneous equation model, the results of a study applied to fourteen Middle Eastern and North African countries from 1990–2011 indicated a bidirectional causal relationship between economic growth and final energy consumption in the transportation sector, confirming the feedback hypothesis.

These findings also support a unidirectional relationship between energy consumption and environmental degradation and a bidirectional relationship between economic growth and environmental degradation across the entire region (Destek, 2015).

-Study of Farhani and Ben Rejeb (2012):

This study aimed to test the cointegration and causal relationships among economic growth, environmental degradation, and energy consumption in the transportation sector on the basis of panel data for fifteen Middle Eastern and North African countries, including Egypt, from 1973--2008. The study revealed no causal relationship between energy consumption and economic growth or between energy consumption and environmental degradation in the short term. However, a unidirectional relationship was identified between economic growth, environmental degradation and energy consumption in the long term (Cowan, 2022).

-Study of Ang (2007):

This study tested the dynamic causal relationships among energy consumption, carbon dioxide emissions, and real GDP per capita in France from 1960--2000 via the cointegration testing approach and the vector error correction model (VECM).

The results indicated the existence of a unidirectional causal relationship between energy consumption and economic growth in the short term and between economic growth and both energy consumption and environmental degradation in the long term (Duan, 2008).

Khan et al. (2020) examined the nexus between energy consumption, economic growth and CO2 emissions in Pakistan. The results indicated that energy consumption and economic growth increase CO2 emissions in the short and long run. Furthermore, Khan et al. (2021) reported that energy consumption positively impacts CO2 emissions in 184 countries. However, most studies that have tested this hypothesis have supported the existence of the

EKC, such as Rahman (2017, 2020), Ertugrul et al. (2016), and Kasman and Duman (2015), among others. Furthermore, Apergis and Payne (2011), Hossain (2012), Shahbaz et al. (2013), Kasman and Duman (2015), Uddin et al. (2016), and Rahman and Kashem (2017) demonstrated causality from economic growth to energy consumption and CO2 emissions. In contrast, Soytas and Sari (2009), Ghosh (2010), and Lean and Smyth (2010) reported unidirectional causality between energy consumption and CO2 emissions and economic growth (Gasimli, 2022).

2-3- Research Gap:

The current study differs from previous studies that have been applied to the Algerian economy. The former examines the impact of both final energy consumption in the transportation and urbanisation sectors (as independent variables) on environmental quality (as a dependent variable). Although there are numerous applied studies on the impact of final energy consumption in the transportation and urbanisation sectors on the environment and climate change in many developed and developing economies, few applied studies address the impact of the abovementioned independent variables on environmental quality. Recent studies have increasingly focused on the impact of final energy consumption in the transportation and urbanisation sectors and climate change on the economic growth rate in Algeria. In addition, numerous studies have addressed the impact of environmental policies on foreign trade in the Algerian economy.

3. Measuring the Impact of Final Energy Consumption in the Transportation Sector and Urbanisation on the Environmental Quality of Algeria

This section aims to measure the impact of final energy consumption in the transportation and urbanisation sectors on the environmental quality in Algeria. Environmental quality was expressed as an indicator of carbon dioxide emissions from the Algerian manufacturing sector, and it was applied to the manufacturing sector from 1990--2022. The study relied on the ARDL model to determine the short- and long-term relationships between carbon dioxide emissions and final energy consumption in the transportation sector in Algeria, with an annual dataset spanning 1990–2022. The study explores the impact of final energy consumption in the transportation sector, urbanisation, and GDP as separate variables on carbon dioxide emissions, which are dependent on variables. The choice of the study period and country was based on data availability, as Algeria is a country that relies heavily on fossil fuels.

Table 01

Variable descriptions and sources

	Variables	**Variables symbol**	**Measuring unit**	**Source**

Dependent	Carbon dioxide emissions	CO2	T/J	The global economic
Independent	Fo fuel energy consumption	OILTRANS	Thousands of tonne	International energy agency
	Gross domestic product p/c	GDPPC	Constant 2010 dollars	World bank
	urbanisation	Urb	% of GDP	World bank

Source: Authors' compilations

3-1- Model formulation

To analyse the relationship between carbon dioxide and final energy consumption in the transportation sector and urbanisation, the gross domestic product (GDPPC) was defined as follows:

CO2 = f(OILTRANS, GDPPC, Urb)

3.1.1 - Results and discussion

Compared with other methods, the ARDL model is the most effective econometric method, and it is suitable for determining the effect of dependent variables on the independent variable.

3.1.2 - Results of Unit Root Tests

Before applying the ARDL bounds test to any variable, its unit root must be verified, and all variables must be fixed at I(0), I(1), or both to determine the associated F statistic. On the basis of the augmented Dickey–Fuller (ADF) test and the Phillips–Perron (PP) test, the stationarity test determines the results of the sequence.

Table 2

Results of the augmented Dickey–Fuller (ADF) and Phillips–Peron (PP) unit root tests

	ADF			**PP**			
	T-statistic	**p value**	**Critical value**	**T-statistic**	**p value**	**Critical value**	
CO2	5.528283	0.0005	3.555231	5.552255	0.0005	3.522543	I(1)
OILTRANS	4.114540	0.0106	3.562453	4.552254	0.0116	3.525431	I(1)
GDPPC	4.145289	0.0018	2.965421	4.099222	0.0154	3.562543	I(1)
Urb	5.032544	0.0003	2.962541	4.872254	0.0024	3.563521	I(1)

Source: Authors' computations via Eviews 12 software.

The ADF test results in Table 2 show that all five variables are stable at the first difference I (1), so the boundary test method is applicable in this research, and the ARDL model is the most suitable option.

3-1-3-Lag Order Selection Criteria:

After confirming that all variables were fixed in the same order, we determined the optimal delay order according to six selection criteria for delays from 0 to 2 in this step. Owing to the low number of notes, we did not exceed this value.

Table 03

Lag-Order Selection Criteria Results

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1025.129	NA	1.01e+24	68.16922	67.40088	68.23503
1	-780.6954	250.5225*	2.35e+18*	59.76206*	60.14866*	58.23343*
2	-848.4533	28.82563	3.17e+18	59.94567	61.47686	58.76300

Source: Authors' computations via Eviews 12 software

According to the LR, FPE, AIC and SC standards, the specific delay was 1. We then move to the bounds test after selecting the ARDL model and diagnosing the ARDL model, followed by ECM.

After choosing an appropriate delay length, we apply the Automatic Distributor Delay Limit Test (ARDL) and use Akaike information standards to determine the optimal delay length. Figure 6 shows the ARDL model estimation process with automatic delay selection via the E-views 12 version. The model selected (2, 4, 3, 4, and 4) was based on the lowest AIC.

Figure 6

Akaike information criterion

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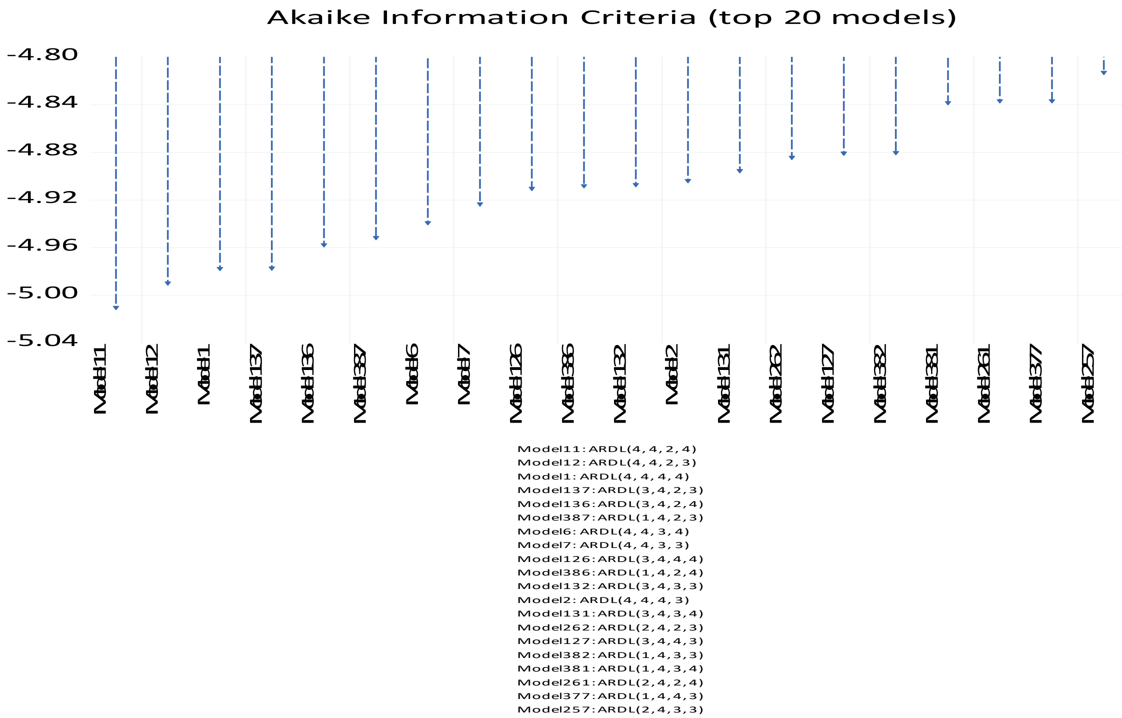

Source: Authors' computations via Eviews 12 software

Figure 06 shows that ARDL (2, 4, 3, 4,4) is our appropriate model.

3-2-Estimation of the ARDL model.

3-2-1-ARDL Bounds Test for Cointegration.

The boundary test shows whether the variables in the ARDL model have a common integration link. Under the zero hypothesis of noncointegration, if the estimated F statistic is below the minimum critical value, this indicates a lack of cointegration. However, if they are greater than the higher critical value, this indicates a common integration link.

Table 4

Results of the ARDL bound test

Test statistic f-statistic	**13.54622**					
	10%		5%		1%	
Sample size	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
30	2.48	3.48	3.05	4.22	4.39	5.95
asymptotic	2.54	3.59	2.59	3.45	3.38	4.37

Source: Authors' computations via Eviews 12 software

Table 04 shows that the calculated F-number of 14.54,833 is greater than the critical values of I(0) and I(1) at the indicative levels of 1%, 5% and 10%; hence, there is cointegration among the variables in the laboratory model, indicating the feasibility of estimating the error

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correction model to explore the short-term effects of final energy consumption in the transportation sector, urbanisation and GDP per capita on CO2 emissions.

3-2-2-Cointegrating ARDL Model Estimate

After confirming their stability and complementarity, the distributed self-decelerating model (ARDL) was applied to examine the long-term and short-term relationships among all the variables.

Empirical Results of ARDL Estimation

Table 5

Error Correction Model (ECM), Short-Run, and Long-Run Regression Results

ECM Regression, short-run

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D OILTRANS	-0.129225	0.031306	-4.255751	0.0032
D(GDPPC)	38.88523	3.755254	14.71442	0.0000
D Urb	1523.154	520.3245	2.711542	0.0301
CointEq(-1)*	-1.339900	0.118422	-13.25313	0.0000

R-squared	0.982516	Mean dependent var	3456.172
Adjusted R-squared	0.958757	S.D. dependent var	4250.646
S.E. of regression	902.0356	Akaike info criterion	15.76722
Sum squared resid	9764583.	Schwarz criterion	16.55673
Log-likelihood	-224.6597	Hannan-Quinn criteria.	17.99824
Durbin-Watson stat	2.664669		

* p value incompatible with the t-Bound distribution

Long -run

Variable	Coefficient	Std. Error	t-Statistic	Prob.
OILTRANS	0.388090	0.025364	22.63295	0.0000
GDPPC	33.82252	2.352563	11.99962	0.0000
Urb	-3524.993	1125.407	-5.555006	0.0028
C	-44200.53	3587.506	-13.26583	0.0000

OILTRANS = CO2 - (0.3881* **OILTRANS** + 33.8225*GDPPC -3524.9932* **Urb** - 44200.5314)

Source: Authors' computations via Eviews 12 software

In this study, the ECM evaluation was negative, with CointEq(-1) = -1.449 at a coefficient of less than 1%, confirming the existence of long-term equilibrium between the independent variables and the carbon dioxide variable. This result demonstrates that long-term equilibrium is achieved once short-term errors are adjusted by 144.9%. Furthermore, the long-term adjusted R2 and R2 values are 0.9823 and 0.9587, respectively, indicating that the proposed regression model fits the data well. This finding indicates that approximately 98% of the variance in the independent variables component can be explained.

In the short run, the ARDL estimation results show that final energy consumption in the transportation and urbanisation sectors has a significant negative effect on carbon dioxide and that per capita GDP has a significant positive effect on carbon dioxide. - In the long run, final energy consumption in the transportation and urbanisation sectors has a significant positive effect on carbon dioxide emissions, and per capita GDP has a significant positive effect on carbon dioxide emissions.

3-3-Arch test:

Engel (1982) created the ARCH model to model police variability. Its variation and average equations are conditional. The ARMA procedure (p, q) follows the conditional average formula, which explains how to create return chain data. Although parity describes the method of obtaining parity data, the variance depends on the square delay of the remaining term.

Table 6

Arch test

Heteroskedasticity Test: ARCH			
F-statistic	0.547522	Prob. F(21,7)	0.8653
Obs*R-squared	0.056733	Prob. Chi-Square(1)	0.8113

Source: Authors' computations via Eviews 12 software

Table 6 shows that the f value associated with the arc test is 0.54, with a probability of 0.86. This probability is greater than the 5% indicative level, and we accept the zero hypothesis, which confirms the stability of the variability of the error terminology series.

Table 7

Breusch–Godfrey serial correlation LM test

F-statistic	0.537336	Prob. F (21,7)	0.8752
Obs*R-squared	18.05474	Prob. Chi-Square (21)	0.6444
Scaled explained SS	1.095441	Prob. Chi-Square (21)	1.0000

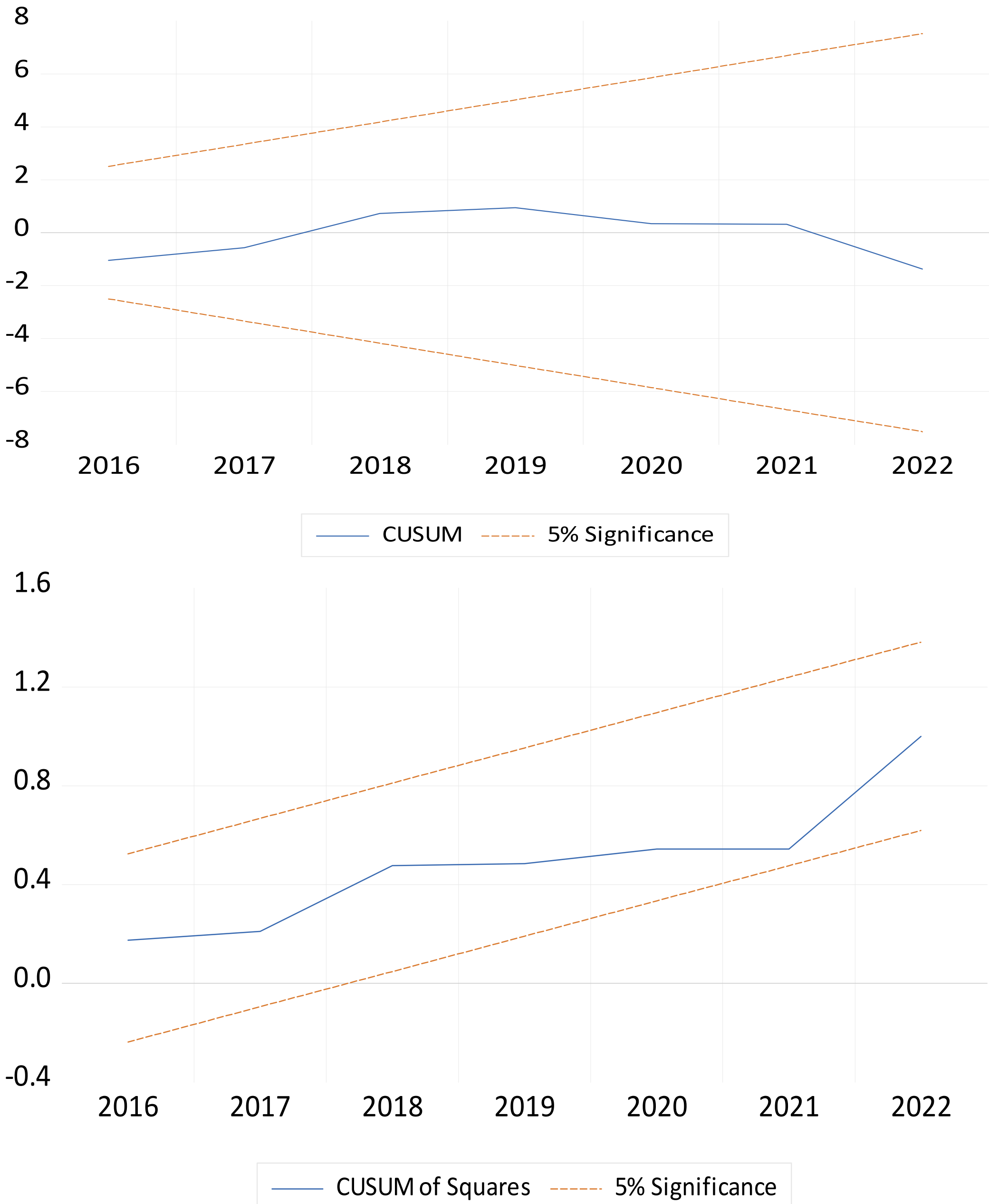
Source: Authors' computations via Eviews 12 software

From Table 7, the value of f is 0.53; the associated probability (0.87) exceeds 5%. Therefore, we accept the zero hypothesis, suggesting that there is no automatic chain link between errors. This study used two statistical tests: CUSUM and CUSUM SQ.

The CUSUM and CUSUM box tests were also used to verify the model's stability, modularity, and structural stability. Brown et al. first introduced them in the standard statistical and economic literature. Figure 8 shows the model's stability by placing blue lines between red lines. This indicates the importance and stability of all the transactions in the error correction form.

Figure08

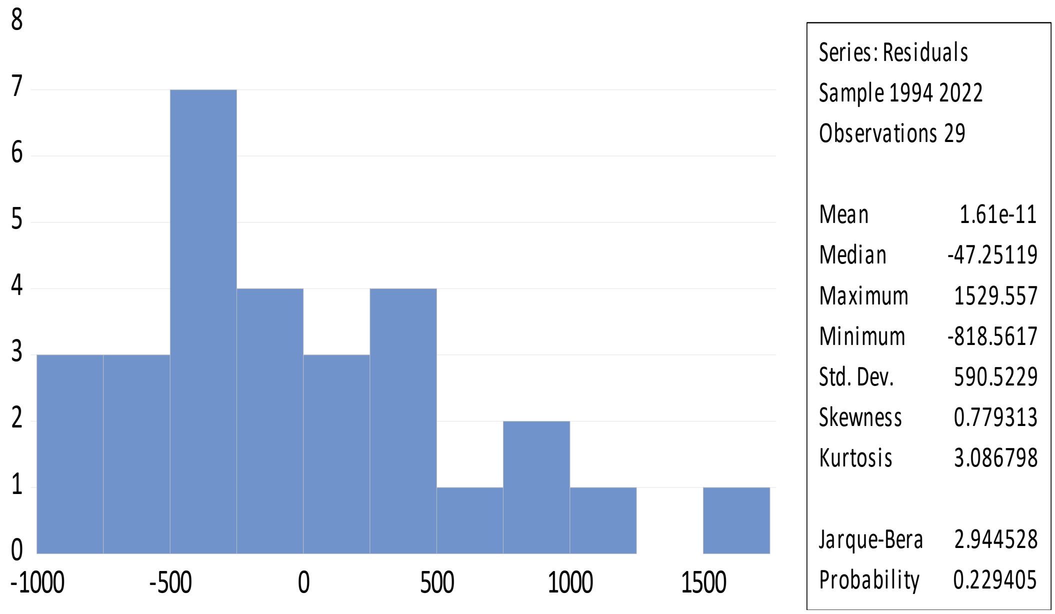
CUSUM and consumption of squares.



Source: Authors' computations via Eviews 12 software

The formats and results of the CUSUM and CUSUM calculations of the boxes are presented. Both graphs illustrate that blue lines may be found within red lines. This finding indicates that the variables used in the model were stable throughout the investigation.

3-4-Normality test:



Source: Authors' computations via Eviews 12 software

Natural testing, as shown in our neighbor plot, confirms that the errors are naturally distributed because the statistical probability value is 2.94 and is greater than 0.05.

Conclusion

The analysis of carbon emission trends reveals a gradual increase in carbon dioxide emissions, with an average annual growth rate of 3.5% from 1990--2022.

The combustion of fossil fuel sources is identified as the primary cause of carbon dioxide emissions, accounting for approximately 59% of total emissions. Economic growth impacts the environment through three main channels: the economic structure, the share of different economic sectors in total energy consumption, and the energy mix of consumed sources. An analysis of the evolution of Algeria's economic structure reveals a decline in the contribution of the industrial sector (which is energy intensive) and a rise in the contribution of the service sector (which is less energy intensive). Furthermore, the analysis of the development of Algeria's energy consumption patterns indicates a lack of diversification in the energy mix and an increasing dependence on fossil fuels, namely, coal, petroleum, and natural gas, alongside weak exploitation of renewable energy sources. The results of the long-term causality tests, which were based on the vector error correction model (VECM) analysis, revealed a bidirectional relationship between economic growth and energy consumption, supporting the feedback hypothesis.

Additionally, a bidirectional relationship was found between energy consumption and environmental degradation, as well as between environmental degradation and economic growth, confirming the interconnectedness of these variables. The pilot study revealed that fossil fuel consumption in the transportation sector, GDP per capita, and urbanisation caused carbon dioxide emissions in the long term, indicating that fossil fuel consumption in the transportation sector negatively impacted the environment in the short term. The Algerian government must accelerate the implementation of actions that reduce carbon emissions and reflect on environmental sustainability, the transition from conventional to cleaner energy sources, and the use of renewable energies that can reduce carbon emissions. Emissions help achieve sustainable social and economic development.

Recommendations:

- It is necessary to diversify the energy mix with a continuous adjustment in favour of replacing nonrenewable sources with new and renewable energy sources over the long term.
- Strict programs should be implemented to improve energy efficiency and reduce emissions across various economic sectors.
- Environmental policies should be integrated into long-term economic development plans and programs, clear policies for environmental assessment processes should be formulated, and environmental monitoring networks across all provinces should be expanded to facilitate the identification and accountability of pollution sources.
- To develop binding environmental legislation and strengthen enforcement mechanisms, appropriate criminal penalties for entities responsible for environmental pollution should be applied.
- Financial support and effective economic incentives should be provided to encourage institutions and individuals to preserve the environment and transition to cleaner production technologies. This would generate government revenues to fund pollution mitigation and treatment activities. Examples include government subsidies, pollution taxes, and emissions fees.
- Community environmental awareness should be promoted, and the transfer of technical know-how through investment in education and human resource training in clean production methods should be facilitated, thereby enhancing technical performance.

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