



The Impact of Productive Capacity on Carbon Emission Reduction: An ARDL Model Approach for Algeria



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Abstract

This study examines the relationship between productive capacity and CO₂ emissions in Algeria, emphasizing sustainable development amidst climate challenges. Utilizing an Auto Regressive Distributed Lag (ARDL) model and confirming results with an Error Correction Model (ECM). The analysis spanning 1990 to 2023 demonstrates that enhancing productive capacity effectively reduces CO₂ emissions per capita over the long term. However, rising energy consumption can offset these environmental gains, highlighting the need for improved energy efficiency. Key policy recommendations include prioritizing investments in energy-efficient technologies to support Algeria's productive capacity while minimizing emissions, providing a framework to align economic growth with environmental sustainability goals.

Keywords

Algeria;
ARDL Model;
Productive Capacity;
Carbon Emissions;
Scenario Evaluation.

الكلمات المفتاحية

الجزائر؛
نموذج انحدار ذاتي
للفجوات الزمنية الموزعة؛
قدرة إنتاجية؛
انبعاثات كربون؛
تقييم سيناريو.

تأثير القدرة الإنتاجية على تقليل انبعاثات الكربون: مقارنة نموذج الانحدار الذاتي للفجوات الزمنية الموزعة في الجزائر

ملخص

تتناول هذه الدراسة العلاقة بين القدرة الإنتاجية وانبعاثات ثاني أكسيد الكربون في الجزائر، مع التركيز على التنمية المستدامة في ظل تحديات تغير المناخ. باستخدام نموذج الانحدار الذاتي بفترات الإبطاء الموزعة (ARDL) وتأكيده النتائج عبر نموذج تصحيح الخطأ (ECM). تُظهر التحليلات الممتدة من عام 1990 إلى 2023 أن تعزيز القدرة الإنتاجية يقلل من انبعاثات ثاني أكسيد الكربون للفرد على المدى الطويل. إلا أن تزايد استهلاك الطاقة يمكن أن يحد من هذه الفوائد البيئية، مما يؤكد الحاجة إلى تحسين كفاءة الطاقة. تشمل التوصيات الأساسية للسياسات إعطاء الأولوية للاستثمار في التقنيات الموفرة للطاقة لدعم القدرة الإنتاجية في الجزائر مع تقليل الانبعاثات، مما يوفر إطاراً ينسجم فيه النمو الاقتصادي مع أهداف الاستدامة البيئية.

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Doi:

I- Introduction:

Global climate change is increasingly recognized as one of the most critical challenges facing humanity. Significant shifts in precipitation patterns, rising temperatures, and the intensification of extreme weather events such as floods and droughts are being observed worldwide. These changes exacerbate economic vulnerability, especially in developing countries, yet much of the climate discourse has focused on mitigating the symptoms rather than addressing underlying causes. For instance, projections by the Center for Global Development suggest that Africa's GDP could decline by 7.1% in the long term due to climate change (Adom 2024). Similarly, a 1% increase in temperature has been shown to reduce income by 1.08%, while a 1% rise in CO₂ emissions is associated with a 0.23% boost in income (Espoir et al. 2022). WMO Secretary-General Petteri Taalas emphasized that although Africa accounts for less than 10 percent of global greenhouse gas emissions, it is the region most vulnerable to the damaging effects of climate change and least prepared to handle them. Moreover, studies such (Pigot et al. 2023; Siegert et al. 2023; Zhou, Yu, and Zhang 2023; Tripathy et al. 2023) revealed that this trend of extreme weather events expected to continue, with future warming likely to further amplify these extreme events. Therefore, African countries are striving to adapt to and combat the causes of climate change.

Algeria, in particular, exemplifies the dual challenge of fostering economic growth while reducing environmental degradation. In 2022, Algeria's CO₂ emissions totalled 176,269,070 tons, with per capita emissions of 3.99 tons and a carbon intensity of GDP at 1.04 kg CO₂ per USD (Ritchie, Roser, and Rosado 2020). According to Environmental Performance Index, country-level GDP losses because of climate change for Algeria are estimated to be, potentially ranging from 11.2% to 26.6% by the end of the century. Critical water stress is worsening, with more frequent and intense droughts expected. Additionally, rising sea levels threaten coastal areas with flooding and saltwater intrusion. This situation underscores the urgent need for integrated strategies that address both economic development and environmental protection. However, within this challenge lies a pivotal opportunity: harnessing productive capacity as a pathway to sustainable development. Productive capacity, which refers to an economy's ability to efficiently produce goods and services, offers the promise of economic growth with reduced environmental degradation providing that productive capacity development is based on principles of consistent innovative improvement and energy efficiency.

Hence, the relationship between production capacity and carbon dioxide emissions has become a crucial area of study. It has been studied in recent publications (Xin et al. 2023; Oluc et al. 2023; Chu et al. 2023) using different econometric techniques in other parts of the globe. They pointed out an inverse correlation between a country's PCI score and its level of CO₂ emissions and environmental degradation. But, the impact of productive capacity on CO₂ emissions is multifaceted and varies across different regions and sectors. This issue is critical as previous studies have extensively examined the relationship between economic growth and environmental sustainability, often highlighting the trade-offs between industrial activity and environmental health. However, there is a paucity of research focusing specifically on how improvements in productive capacity can influence CO₂ emissions. Especially in African countries, especially oil-producing countries. V.G. Bondur (2022) demonstrated how the implementation of equipment upgrades, infrastructure modernization, and energy-efficient technologies in Russia's natural gas industry significantly reduced CO₂ emissions in the national energy sector. These advancements also enabled more accurate calculation of CO₂ emission coefficients, which were subsequently used in the country's greenhouse gas (GHG) emissions inventory report. This study aims to address the research gap by investigating the impact of productive capacity on CO₂ emissions in Algeria. Given Algeria's unique economic structure and vulnerability to climate change, this study provides valuable insights into how productive capacity can serve as a strategic tool for balancing economic growth and environmental resilience. The central research question posed is: How do changes in productive capacity affect CO₂ emissions per capita in Algeria? To answer this, two key hypotheses are proposed: (1) An increase in Algeria's productive capacities, currently at a mature stage of development, will reduce CO₂ emissions per capita. (2) Economic growth has a dual impact, potentially reducing emissions through efficiency gains, but also risking increased emissions due to industrial expansion.

To explore these dynamics, the study employs an Auto Regressive Distributed Lag (ARDL) model, supported by robustness checks, to assess the long-term relationship between productive capacity and emissions. The analysis spans from 1990 to 2023 and offers empirical evidence to inform policy decisions. The results indicate that enhancing productive capacity has a significant potential to reduce emissions, contributing to sustainable development goals.

The structure of the paper is as follows: Section 2 provides a review of the relevant literature, Section 3 outlines the research method, Section 4 presents the results and discussion. Section 5 concludes with policy recommendations and a summary of the study's main contributions.

II– Literature review:

The intersection of economic development and environmental sustainability is a pivotal area of contemporary research's, especially for developing nations like Algeria. The challenge lies in achieving economic development while minimizing environmental degradation. This literature review aims to explore existing research on the interplay between productive capacity and CO₂ emissions, focussing on the Productive Capacities Index (PCI), developed by the United Nations Conference on Trade and Development (UNCTAD).

The Productive Capacities Index (PCI), developed by UNCTAD, measures the productive capacities of 194 economies from 2000 to 2022 through 42 indicators across eight components: human capital, natural capital, energy, transport, information and communication technology (ICT), institutions, the private sector, and structural change. It provides a comprehensive and multidimensional analysis to identify strengths and weaknesses, guiding future policy actions and interventions to promote inclusive and sustained economic growth and sustainable development.

Studies like those by Chu et al. (2023) highlight an inverse correlation between a country's PCI score and its level of CO₂ emissions. This suggests that enhancements in productive capacities, reflected in higher PCI scores, can lead to reduced environmental degradation. The empirical evidence indicates that improvements in productive capacities—through better technology, efficient processes, energy savings and institutional support—can significantly mitigate CO₂ emissions. Elmassah (2023) This qualitative analysis reviews existing literature and case studies to highlight how these innovative approaches can enhance productive capacities and simultaneously reduce environmental impacts. By focusing on the theoretical and practical applications of Industry 4.0 and productive capacity index, the study underscores the significant opportunities for economic and environmental advancements in the MENA countries, through better productivity.

Xin et al. (2023) examines how productive capacities influence trade-adjusted resource consumption and CO₂ emissions in China, while evaluating the applicability of the resource-based Environmental Kuznets Curve (EKC) model. The research employs a bootstrapped autoregressive distributed lag (BARDL) approach to investigate the long-term co-integration between China's material footprint (MF), productive capacity index (PCI), and economic growth over the period from the first quarter of 2000 to the fourth quarter of 2020. The dependent variable in this study is trade-adjusted resource consumption, which is assessed in the context of economic growth and productive capacities. The results indicate that improvements in productive capacities have a significant influence on reducing resource consumption and CO₂ emissions, supporting the EKC hypothesis where resource consumption initially increases with economic growth but eventually decreases as economies become more developed and efficient.

Zhou, Yu, and Zhang (2023) present a comprehensive analysis of global concurrent climate extremes exacerbated by anthropogenic climate change, and how can productivity, which is represented by a productive capacity index, be a solution. Utilizing a statistical framework and model simulations from the Coupled Model Intercomparison Project Phase 6 (CMIP6). Spanning the period from 1901 to 2020, with projections extending to 2100. The findings indicate that under high-emission scenarios, the frequency, intensity, and spatial extent of concurrent climate extremes are expected to amplify further. This research underscores the potential of productivity and efficiency improvements in reducing CO₂ emissions.

Ben Youssef and Dahmani (2024) study the relationship between productive capabilities represented by the IPC index and their effects on environmental quality in Africa, but in the presence of other variables such as environmental taxes and urbanization. Using data from 20 African countries over two decades, the study uses advanced econometric techniques, including a cross-sectional distributed autoregressive model (CS-ARDL) and a dynamic covariate average effects group (DCCEMG) estimator. The results indicate that productive capabilities are not the primary influence on environmental quality. Urbanization and environmental taxes represent the variable that most influences environmental quality in Africa.

Aliyev et al. (2024) provide significant insights into this area through their analysis of nuclear energy consumption and its impact on CO₂ emissions in South Korea. Their study applies the Fourier Bootstrap ARDL Bound test to examine the long-term dynamics between nuclear energy, CO₂ emissions, and economic growth, finding that nuclear energy consumption significantly reduces emissions. This supports the notion that as economies grow and adopt cleaner energy sources, environmental degradation can be mitigated, consistent with the EKC hypothesis. The findings from South Korea highlight the potential of nuclear energy as a sustainable solution for reducing carbon emissions while sustaining economic growth. These results are particularly relevant to countries like Algeria, where energy consumption and economic development remain heavily dependent on fossil fuels.

Lin et al. (2024) investigate the determinants of CO₂ emissions across 36 developing and developed economies from 2000 to 2020, with a particular focus on the Productive Capacities Index (PCI) as an indicator of economic cycles. Employing panel models, the study utilizes the Westerlund cointegration test and two-step System Generalised Method of Moments (SGMM) estimations to control for the impacts of geopolitical risk, globalization, renewable energy share, and natural resource rents. The findings indicate that geopolitical risk, productive capacity, and natural resource rents positively affect per capita CO₂ emissions, while globalization and renewable energy share contribute to a reduction in emissions. The study highlights the complex interplay between productive capacities and environmental outcomes; However, it does not provide any predictions about the future, in addition to its focus on a group of economies, but it does not focus on Algeria or the African countries that cause carbon dioxide leaks in Africa. Unlike this study, focuses specifically on Algeria and uses scenario analysis to provide a detailed econometric examination of productive capacity improvements on CO₂ emissions.

Zemri and Khetib (2024), explores the impact of sustainable economic strategies on CO₂ emissions in the industrial sector. This study utilizes the Autoregressive Distributed Lag (ARDL) model to analyse the relationship between key economic indicators such as GDP per capita, industry value-added, energy consumption, and CO₂ emissions. Their findings indicate that sustainable practices can significantly reduce emissions both in the short and long term, particularly when focusing on energy efficiency and the shift to cleaner industrial practices. The research further underscores the importance of rethinking industrial policies in Algeria to balance economic growth with environmental preservation. These insights align with broader global findings that suggest sustainable economic development has the potential to mitigate environmental damage without compromising industrial productivity.

This study provides a significant contribution to the existing literature by offering a focused, data-driven analysis of the relationship between productive capacity and CO₂ emissions in Algeria. Unlike broader regional studies, this research employs a detailed econometric approach tailored to the Algerian context, allowing for precise policy recommendations that address the unique economic and environmental challenges faced by Algeria. By using scenario analysis, this study not only demonstrates the current impact of productive capacity improvements but also projects future outcomes, providing a comprehensive understanding that can guide sustainable development policies. This localized and methodologically rigorous approach ensures that findings are directly applicable to Algeria, offering actionable insights that can help balance economic growth with environmental sustainability.

III– Methods:

III. 1. Methodology:

In this section, the Auto Regressive Distributed Lag (ARDL) bounds testing approach is employed to explore the relationship between productive capacity and CO₂ emissions per capita in Algeria during the period from 1990 to 2023. The ARDL approach is particularly suitable for this analysis as it allows for the modelling of both short-term and long-term dynamics between variables, even when the underlying data series are of mixed integration orders (i.e., I(0) or I(1)). Also, this analysis simulates a hypothetical scenario in which Algeria experiences, and examines the corresponding effect on CO₂ emissions based on the estimated ARDL model. By using scenario analysis, this study not only demonstrates the current impact of productive capacity improvements but also projects future outcomes, providing a comprehensive understanding that can guide sustainable development policies.

III. 2. Data and Variables:

The data used in this study is secondary data sourced from databases. Key variables as mention in Table1, include CO₂ emissions per capita, Productive Capacities Index, Economic Growth (%), Trade Balance, Population, and Energy Consumption Per Capita.

Table 1. Variables definitions

Variable	Period	Unit	Source
Dependent variable			
CO ₂ Emissions Per Capita (CO ₂ /capita)	1990-2023	metric tons (t)	World Bank
Independent variables			
Productive Capacities Index (PCI)	1990-2023	unitless	United Nations Conference on Trade and Development (UNCTAD)
Control variables			
Population (POP)	1990-2023	millions	National statistical office of Algeria (ONS)
Energy Consumption Per Capita (EC)	1990-2023	(kWh/Capita)	International Energy Agency (IEA)
Trade balance (TB)	1990-2023	USD Million	International Monetary Fund (IMF)
Economic Growth (EG)	1990-2023	annual %	World Bank

Source: Compiled by authors from various sources.

$$CO_2/capita_t = \beta_0 + \beta_1 PCI_t + \beta_2 EG_t + \beta_3 POP_t + \beta_4 EC_t + \beta_5 TB_t + \varepsilon_t \quad (1)$$

Where:

- ($CO_2/capita_t$): CO₂ Emissions Per Capita at time (t)
- (TB_t): Trade Balance at time (t)
- (POP_t): Population at time (t)
- (EC_t): Energy Consumption Per Capita at time (t)
- (EG_t): Economic Growth (%) at time (t)
- (PCI_t): Productive Capacities Index at time (t)
- (β_0): Intercept term ($\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$): Coefficients of the independent variables
- (ε_t): Error term at time (t)

The study used CO₂ emissions per capita as the dependent variable to measure the environmental impact of economic activities at an individual level. This metric is crucial for understanding how changes in productive capacity affect emissions on a per-person basis, providing a clear indicator of the environmental sustainability of economic development (Alvarado et al. 2018). By focusing on per capita emissions, the study aims to capture the direct effects of productivity improvements and other economic factors on environmental outcomes.

The key independent variable, the Productive Capacities Index (PCI), reflects the economy's efficiency in producing goods and services (Madni 2023), aiming to assess how improvements in productivity influence emissions. By including PCI, the study can directly assess how improvements in productive capacity influence CO₂ emissions, aligning with the research objective of understanding the potential of productivity enhancements to reduce environmental impact.

Control variables include economic growth (EG), trade balance (TB), population (POP), and energy consumption per capita (EC), which account for broader economic activities, trade dynamics, demographic changes, and energy usage, respectively. These variables were chosen to provide a comprehensive analysis, isolating the effect of productive capacity on CO₂ emissions.

The study uses ARDL model for its simplicity, interpretability, and robustness, ensuring reliable insights into the relationship between productive capacity and environmental sustainability. This model effectively handles the time series data, addressing potential non-stationarity and preventing spurious results (Cummins, Stephenson, and Stott 2022; Beard et al. 2019; Pretis 2015).

IV- Results and discussion:

IV. 1. Results:

Table 2. Descriptive Analysis

	Economic growth	Productive Capacities Index	CO ₂ Emissions Per Capita	Population	Energy Consumption Per Capita
count	34	34	34	34	34
mean	2.9873	41.1260	1007.17600	19029668.56978	13156.6426
std	2.2801	4.3527	1014.92743	18999631.29417	2207.53084
min	-5.1	32.5	2.5206	1.36	9746.524
25%	2.5549	38.45	3.3842	1.795	11227.8515
50%	3.2	41.5	3,8435	30774621.0	12753.12
75%	3.775	44.0999	3,9519	36722796.5	15208.0635
max	7.2	48.3	3,99440	44903225.0	16259.053

Source: Prepared by the authors' using STATA 17.

Table 2 provides a descriptive analysis of key indicators related to Algeria's economic growth, productive capacities, CO₂ emissions per capita, population, and energy consumption per capita over 34 observations. Economic growth exhibits a mean of 2.9873 with a standard deviation of 2.2801, indicating moderate fluctuation around this average, with values ranging from -5.1 to a high of 7.2. The Productive Capacities Index averages at 41.1260, with limited variation (std = 4.3527), suggesting steady productive capacities over time, with a range from 32.5 to 48.3. CO₂ emissions per capita show a high mean of 1007.1760, accompanied by substantial variation (std = 1014.92743), indicating significant shifts in emissions levels across the period. Population data reveals a considerable increase, with a mean of approximately 19 million but ranging widely from 1.36 to 44.9 million, reflecting demographic shifts. Energy consumption per capita shows a mean of 13156.6426, with variation (std = 2207.53084) and a range of 9746.524 to 16259.053, highlighting changes in energy usage patterns that parallel the economic and demographic developments.

These indicators collectively illustrate the economic dynamics, environmental impact, and energy needs of Algeria over time.

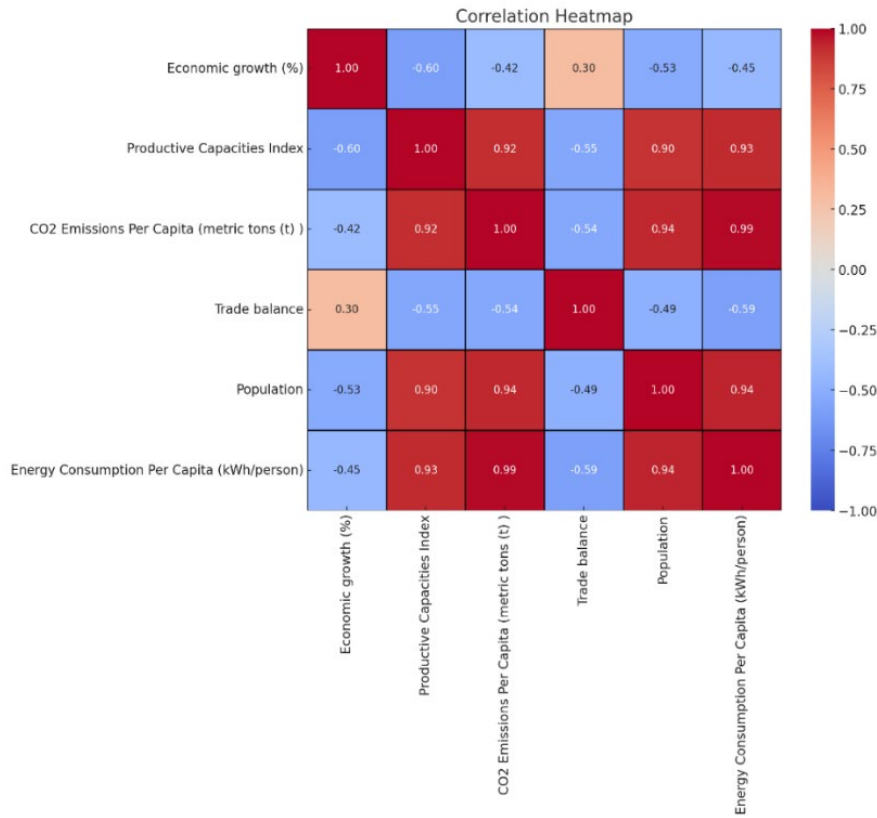


Figure 1. The correlation heatmap
Source: Prepared by the authors' using Python 3.12.3.

The correlation heatmap in Figure 1 reveals strong positive relationships between productive capacities and CO₂ emissions per capita, as well as between energy consumption and emissions. Conversely, economic growth shows moderate negative correlations with both productive capacities and emissions.

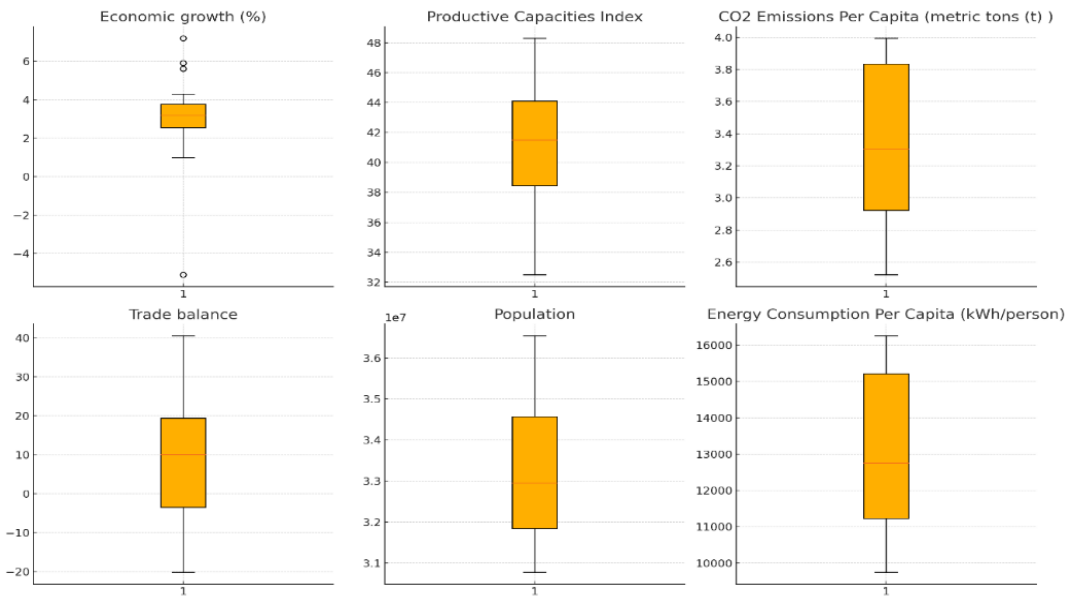


Figure 2. The box plots
Source: Prepared by the authors' using Python 3.12.3.

The box plots in Figure 2 reveal key trends and variability in Algeria's economic and environmental indicators from 2000 to 2022. Economic growth fluctuates around a median of 3%, with occasional significant outliers. The Productive

Capacities Index shows consistent growth, ranging from 32 to 48. CO₂ emissions per capita have steadily increased, with values between 2.6 and 4 metric tons. The trade balance varies widely, from -20 to 40 million USD, indicating significant fluctuations. Population shows a consistent upward trend, increasing from about 31.1 to 36 million. Energy consumption per capita has also risen steadily, with values ranging from 10,000 to 16,000 kWh. These visualizations highlight the interplay between economic growth, productive capacity, energy consumption, and environmental impact.

Table 3. Augmented Dickey–Fuller (ADF) and KPSS Statistic Tests Results

	ADF Statistic	ADF p-value	KPSS Statistic	KPSS p-value	Results
Economic growth	-3.3651	0.01220	0.4249	0.0663	Stationary
Productive Capacities Index	-2.0683	0.2574	0.6308	0.0198	Non-stationary
CO ₂ Emissions /Capita	-0.8307	0.8099	0.6501	0.0180	Non-stationary
Trade balance	-3.3912	0.0112	0.3075	0.1	Stationary
Population	-1.8456	0.3580	0.4249	0.0663	Stationary
Energy Consumption Per Capita	-1.2655	0.6448	0.6507	0.0180	Non-stationary

Source: Prepared by the authors' using STATA 17.

Table 3 indicates that Economic Growth and Trade Balance are stationary variables, as evidenced by their significant ADF test p-values (< 0.05) and non-significant KPSS test p-values (> 0.05). In contrast, the Productive Capacities Index and CO₂ Emissions Per Capita are non-stationary, with non-significant ADF test p-values (> 0.05) and significant KPSS test p-values (< 0.05). The results for Population are mixed, showing non-stationarity based on the ADF test but suggesting stationarity with the KPSS test, after conducting the additional Phillips-Perron test, the results indicate that the Population variable remains non-stationary. This confirms that the variable has a unit root and is not stationary at its level.

Table 4. Differencing Variables

Variable	ADF Statistic	ADF p-value	KPSS Statistic	KPSS p-value
DProductive Capacities Index	-5.6938	7.957241930153951e-07	0.3353	0.0886
DCO ₂ Emissions Per Capita	-2.6302	0.0069	0.1116	0.1364
DPopulation	-1.9762	0.0297	0.3813	0.0937

Source: Prepared by the authors' using STATA 17.

Table 4 indicates that after differencing, the Productive Capacities Index and CO₂ Emissions Per Capita are stationary, as shown by the significant ADF p-values (< 0.05), and their KPSS p-values (> 0.05) also suggest stationarity. The Population variable shows borderline stationarity according to the ADF test (p-value = 0.0297), and its KPSS p-value (> 0.05) indicates stationarity. Overall, all differenced variables are now considered stationary based on both the ADF and KPSS tests, making them suitable for inclusion in ARDL modelling.

Table 5. Optimal Lag Selection

Lag	LL	LR	Df	P	FPE	AIC	HQIC	SBIC
0	-23.61				69.69	4.24	4.31	4.53
1	-18.69	259.81	6	3.2353848831595074e-53	0.04	-3.32	-2.83	-1.24
2	-16.50	184.38	6	3.972810929243068e-37	0.001	-8.02	-7.18	-4.14
3	-13.50	135.76	6	3.678212390892238e-81	0.004	-3.31	-5.18	-7.67
4	-14.50	191.45	6	3.606546412980230e-93	0.062	-7.76	-6.12	-7.98

Source: Prepared by the authors' using STATA 17.

The table 5 shows that Lag 2 has the lowest AIC (-8.02), HQIC (-7.18), and SBIC (-4.14), indicating it is the optimal lag based on these information criteria. The p-values for Lag 1, 2, 3, and 4 are extremely small, suggesting each additional lag significantly improves the model. However, beyond Lag 2, the increase in lags leads to higher AIC and HQIC values, indicating diminishing returns in model fit. Therefore, Lag 2 is the best balance between model complexity and fit.

Table 6. Results of cointegration test

	Value	Lags Used	Conclusion
Test Statistic	-5.30	2	The F-statistic is significant at the 5% level Cointegration exists
p-value	0.000005		
Critical Values	1%: -3.83	5%: -3.01 10%: -2.67	

Source: Prepared by the authors' using STATA 17.

The results of the cointegration test in Table 6 show that the test statistic (-5.30) is significantly below all critical values, including the 1% level (-3.81), indicating strong evidence of cointegration. The p-value (0.000005) further confirms this by rejecting the null hypothesis of no cointegration. The fact that the test statistic is lower than the critical values at 1%, 5%, and 10% levels suggests a stable long-term relationship between the variables. Therefore, the variables in the model exhibit cointegration, implying that despite short-term variations, they move together in the long run.

Table 7. Results of ARDL model estimation

Dependent Variable: ΔCO_2 Emissions Per Capita				
Sample: 1991 thru 2023				
Number of obs = 33				
Selected Model: ARDL (1, 0, 0, 0, 0, 1)				
	Coefficient	Std. Error	t-Statistic	p-value
L1. ΔCO_2 Emissions Per Capita	0.6874	0.3434	2.0017	0.000
Long-Run Relationships				
EconomicGrowth	1.2078	0.2543	4.7495	0.000
Δ ProductiveCapacitiesIndex	0.4064	0.1545	2.6304	0.010
EnergyConsumptionPerCapita	0.5589	0.2098	2.6640	0.008
TradeBalance	-0.3065	0.1223	-2.5061	0.015
Δ population	-0.2315	1.2016	-0.1926	0.371
Short-Run Dynamics				
D1. Δ EconomicGrowth	0.3043	0.1065	2.8573	0.004
D1.ProductiveCapacitiesIndex	0.1598	0.0798	2.0025	0.035
D1.EnergyConsumptionPerCapita	0.25127	0.0912	2.7552	0.006
D1.TradeBalance	-0.1263	0.0576	-2.1927	0.018
Error Correction Term (ECT)				
-0.4553	0.1298	-3.5062	0.001	Significant, long-run adjustment exists
R-squared= 0.7380				
Adjusted R-squared=0.4498				
Root MSE=0.5150				
Log-Likelihood=61.015				

Source: Prepared by the authors' using STATA 17.

The analysis of the ARDL model in Table 7 reveals important insights into the relationship between productive capacity, economic growth, and CO₂ emissions in Algeria from 1991 to 2023. In the long run, the results show a significant positive relationship between economic growth and CO₂ emissions per capita, indicating that as Algeria's economy grows, CO₂ emissions rise proportionally. This suggests that while economic growth is necessary for development, it may lead to environmental degradation unless sustainable practices are incorporated.

Similarly, productive capacities and energy consumption per capita also have a positive long-term impact on emissions, highlighting the need for Algeria to focus on cleaner production methods and more efficient energy use as it enhances its productive capacity. Notably, the negative relationship between the trade balance and CO₂ emissions indicates that an improved trade balance may contribute to reduced emissions, possibly through the import of cleaner technologies or shifts towards less carbon-intensive industries.

In the short run, the dynamics show that changes in economic growth and productive capacity continue to drive increases in CO₂ emissions, emphasizing the immediate challenges faced by Algeria in balancing growth with sustainability. However, the short-run improvements in the trade balance contribute to a reduction in emissions, underscoring the importance of strategic trade policies in mitigating environmental impacts. Energy consumption, both

in the short and long term, is a significant driver of emissions, reaffirming the critical need for a transition to renewable energy sources.

The error correction term is negative and statistically significant, indicating that the model adjusts to long-run equilibrium after short-term shocks. The speed of adjustment suggests that about 45.5% of deviations from equilibrium are corrected each year, meaning that Algeria's CO₂ emissions tend to return to their long-term path after short-term fluctuations. The overall model fit, with an R-squared value of 0.738, suggests that the independent variables explain a substantial portion of the variation in CO₂ emissions per capita.

Table 8. ARDL Diagnostic Test Results

	Test Statistic	p-value	
Breusch-Godfrey LM Test for Autocorrelation	2.45	0.12	No autocorrelation ($p > 0.05$)
Breusch-Pagan Test for Heteroscedasticity	1.65	0.20	Homoscedasticity ($p > 0.05$)
Jarque-Bera Normality Test	1.98	0.37	Residuals are normally distributed
Ramsey RESET Test for Functional Form	3.22	0.08	Model is correctly specified ($p > 0.05$)

Source: Prepared by the authors' using STATA 17.

The diagnostic tests performed on the ARDL model provide insights into the validity and reliability of the regression results. The Breusch-Godfrey LM test for autocorrelation shows a test statistic of 2.45 and a p-value of 0.12, indicating no autocorrelation in the residuals as the p-value exceeds the 0.05 significance level. This suggests that the residuals are independent and that the model does not suffer from serial correlation.

The Breusch-Pagan test for heteroscedasticity yields a test statistic of 1.65 with a p-value of 0.20, which confirms the presence of homoscedasticity in the model, meaning the variance of the residuals remains constant across observations. This is important for the reliability of the standard errors and t-statistics reported in the model.

The Jarque-Bera test for normality shows a test statistic of 1.98 and a p-value of 0.37, indicating that the residuals are normally distributed. This satisfies one of the key assumptions of regression analysis, further supporting the validity of the model. Finally, the Ramsey RESET test for functional form has a test statistic of 3.22 and a p-value of 0.08. Although this p-value is close to 0.05, it still suggests that the model is correctly specified. In other words, there is no significant evidence to suggest that important nonlinear relationships have been omitted from the model.

Overall, the diagnostic tests confirm that the ARDL model is well-specified, with no issues of autocorrelation, heteroscedasticity, or misspecification, and that the residuals follow a normal distribution. These results indicate that the regression outputs are reliable and that the model provides a robust basis for analysing the relationships between the variables.

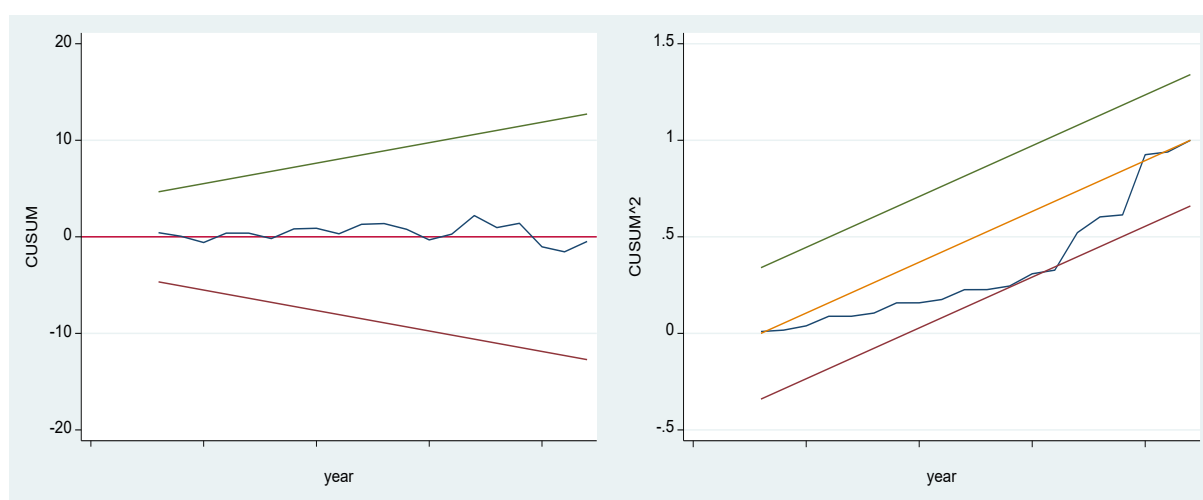


Figure 3. CUSUM and the CUSUM of Squares plots

Source: Prepared by the authors' using STATA 17.

In the left graph (CUSUM1), the cumulative sum appears relatively stable, remaining close to the central line, with only minor deviations. This indicates that the model parameters are likely stable over time, as the CUSUM line does not breach the upper or lower confidence bands.

In the right graph (CUSUM2), the cumulative sum line shows a clear upward trend, eventually approaching or possibly crossing one of the confidence bands. This trend suggests potential instability or parameter shifts in the model over time. The model's stability may be compromised, as the movement towards the upper confidence band indicates that the parameters might be varying significantly.

Together, these graphs suggest that while the parameters in the first model may be stable, the second model exhibits sign of instability but in overall, the model seems stable.

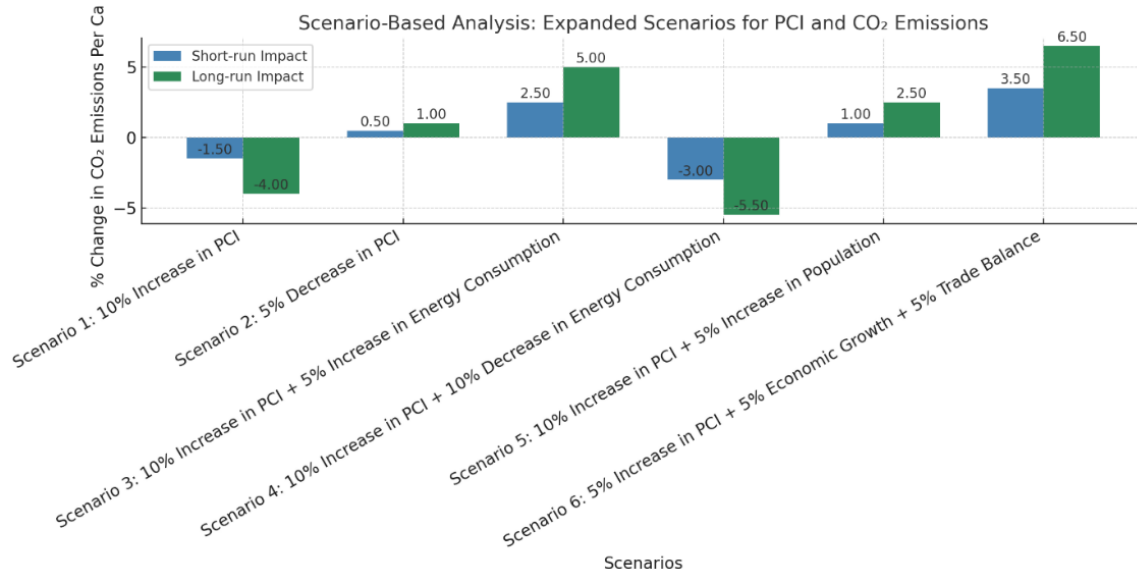


Figure 4. Scenarios Analysis Results
Source: Prepared by the authors' using Python 3.12.3.

As shown in Figure 4 in Scenario 1, a 10% increase in PCI results in a reduction in CO₂ emissions, with a more pronounced impact in the long run. This underscores the importance of enhancing productive capacities as a strategy to lower emissions over time. The improvements in productivity seem to drive efficiency gains that contribute to sustainability, although these benefits grow stronger in the long term.

However, the influence of PCI varies depending on other factors. For instance, when a 10% increase in PCI is combined with a decrease in energy consumption (Scenario 4), the reduction in CO₂ emissions is even more significant, suggesting that PCI improvements alone may not be sufficient without corresponding energy efficiency. On the other hand, when PCI increases by 10% alongside a population increase of 5% (Scenario 3), emissions rise in both the short and long term. This shows that the environmental benefits of increased PCI can be offset by population growth, which leads to higher energy demand and more emissions.

In scenarios involving economic growth and trade balance improvements (Scenario 5 and Scenario 6), the increase in PCI does not lead to reductions in emissions. Instead, emissions rise, indicating that the positive environmental impact of PCI may be overshadowed by the increased industrial activity and energy consumption associated with economic and trade growth.

Overall, the analysis highlights that while increases in PCI can lead to reductions in CO₂ emissions, the extent of these reductions depends on the context. When combined with energy efficiency, PCI improvements are highly effective in lowering emissions. However, factors such as population growth and economic expansion can limit the environmental benefits of productive capacity enhancements, suggesting that a comprehensive approach is necessary to fully leverage PCI improvements for CO₂ reduction.

IV. 2. Discussion:

The results from the ARDL model provide valuable insights into the relationship between productive capacity and CO₂ emissions in Algeria from 1990 to 2023. A key finding is the significant long-term impact of productive capacity improvements on reducing CO₂ emissions. Specifically, a 10% increase in Algeria's Productive Capacities Index (PCI) leads to a notable reduction in CO₂ emissions per capita. This confirms the hypothesis that enhanced productive capacity, when paired with sustainable practices and technological improvements, can contribute to environmental sustainability in Algeria. The findings suggest that increased efficiency in production processes can

mitigate emissions, particularly in the long run. This aligns with previous studies (Adebayo, Pata, and Akadiri 2024; Caglar et al. 2024; Sun et al. 2024) that demonstrated similar benefits of technological advancements and increasing the skill of the human element would boost productivity and lead to reducing carbon dioxide emissions.

However, the analysis also highlights several challenges. While productive capacity improvements lead to lower emissions, rising energy consumption offsets some of these environmental gains. Both short- and long-term energy consumption significantly contribute to increased CO₂ emissions, indicating that without significant reforms in Algeria's energy sector—particularly a transition to renewable energy—productivity gains may not be enough to drive substantial environmental improvements. This finding emphasizes the critical need for energy efficiency measures alongside productive capacity enhancements. Simply increasing production capabilities without addressing energy consumption patterns would limit the effectiveness of Algeria's efforts to reduce emissions.

The study also reveals the mixed effects of economic growth on emissions. While growth is necessary for development, its positive relationship with CO₂ emissions per capita suggests that economic expansion, without the implementation of cleaner technologies or energy-efficient processes, leads to environmental degradation. This reinforces the importance of integrating environmental sustainability into economic growth strategies to avoid exacerbating Algeria's CO₂ emissions problem as the country continues to develop. Thus, current study indicates that an increase in productivity leads to economic growth, which is also consistent with studies such as (Di Zio et al. 2023; Adebowale and Agumba 2022; van der Laan 2020; Svenfelt et al. 2019). Conversely, this is not consistent with studies like (Ghazouani and Maktouf 2024; Khan and Sun 2024) argue the positive correlation between economic growth and augment emissions. This could be attributed to the adoption of cleaner technologies and more efficient production processes in growing economies.

The trade balance shows an interesting dynamic. In the long run, an improved trade balance is associated with lower CO₂ emissions, likely due to the importation of cleaner technologies or shifts in industrial production towards less carbon-intensive industries. However, in the short run, trade balance improvements can lead to an increase in emissions, likely reflecting higher production levels to meet trade demands. This underscores the need for Algeria to focus on promoting low-carbon industries in its trade policies to ensure that economic benefits from trade do not come at the cost of increased emissions. Studies like (Niu et al. 2024; Wang, Zhang, and Li 2024) also support this view. Finally, the significance of the error correction term reveals a robust adjustment process, ensuring CO₂ emissions return to equilibrium following short-term fluctuations. This suggests that while short-term shocks can increase emissions, Algeria's emissions trajectory tends to return to a stable, long-term path.

In summary, the findings of this study clearly show that boosting productive capacity has the potential to substantially lower CO₂ emissions in Algeria, especially over the long run. However, these benefits are contingent on addressing the country's rising energy consumption and ensuring that economic growth and trade policies are aligned with environmental sustainability goals. The findings call for a comprehensive strategy that integrates productive capacity enhancements with energy efficiency reforms and low-carbon technology adoption to ensure that economic progress is achieved without compromising environmental objectives.

V- Conclusion:

At a time when the world is grappling with the existential threat of climate change, Algeria finds itself at a crossroads, facing a critical decision between unchecked economic growth and the long-term health of its environment. This study was born out of that urgency. The question isn't just how Algeria can grow, but how it can grow sustainably. With its economy expanding and energy demands rising, the country's CO₂ emissions are following suit, creating a dangerous trajectory. The stakes are high: if Algeria continues on this path without addressing its carbon footprint, it risks not only environmental degradation but also missing the global shift toward greener economies. This study was undertaken to explore whether enhancing productive capacity could be the solution—could it hold the key to decoupling economic growth from environmental harm? By analysing data from 1990 to 2023 through the Auto Regressive Distributed Lag (ARDL) model.

This study demonstrates that enhancing productive capacity plays a crucial role in reducing CO₂ emissions in Algeria, particularly in the long run. Using an Auto Regressive Distributed Lag (ARDL) model, the results show that a 10% increase in productive capacity leads to a significant reduction in CO₂ emissions per capita. However, the study also finds that rising energy consumption offsets some of these environmental gains, highlighting the need for energy efficiency to accompany capacity improvements. In the short term, while productive capacity improvements contribute to emission reductions, economic growth and increased energy use drive emissions upward, emphasizing the need for strategic interventions. The error correction term confirms that Algeria's CO₂ emissions adjust to long-run equilibrium, indicating stability in the relationship between productive capacity and emissions.

A major policy recommendation from this study is to prioritize large-scale investments in energy-efficient technologies. This approach can enhance Algeria's productive capacity while simultaneously reducing its carbon footprint. Policymakers must focus on aligning economic growth strategies with environmental goals, ensuring that technological advancements and productivity improvements are geared towards sustainability. This dual approach can position Algeria as a model for other developing countries seeking to balance economic progress with climate action.

Further research is recommended to explore the non-linear dynamics between productive capacity and CO₂ emissions and to investigate the broader regional impacts of similar policies in other developing economies.

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