

Energy Transition and Economic Growth Nexus: Empirical Evidence From Algeria

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Abstract:

This research aims to assess the relationship between the energy transition and economic growth in Algeria between 1990 and 2022. Taking into account the researchers' views on the structural changes associated with this transition, we have chosen to use the Fourier Bootstrap ARDL model, which examines long-run relationships between variables while accounting for smooth structural changes in the economy. Our findings reveal that renewable electricity output and carbon dioxide emissions per capita have a positive and significant impact on economic growth, underscoring the pivotal role of renewable electricity in fostering future growth. However, this growth remains dependent on fossil fuels. Conversely, renewable energy consumption has an adverse effect due to technological dependence, which is one of the barriers to expanding renewable energy. The study therefore recommends focusing on domestic technology development by encouraging investment in economic projects that promote innovation in renewable energy.

Key Words: Carbon dioxide emissions, Economic growth, Renewable electricity output, Renewable energy consumption, Fourier Bootstrap ARDL.

JEL Classification : Q43, C32, Q56, O55

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Introduction:

Energy is one of the key resources in the production process. Economic sectors such as agriculture, transport and industry rely on it. Efficient use of energy can boost productivity and economic growth. According to the IEA report (2025a), the global economy now generates a gross domestic product that is 36% higher than in 2000. As economies continue to grow, demand for energy will also increase. However, economic and population growth are also leading to significant levels of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) emissions. These emissions are negatively impacting the environment and climate system due to rising energy consumption (Pachauri & Meyer, 2015).

IRENA (2024) categorised energy sources, outputs, and uses into three main groups: (1) Non-renewable energy comprises all resources that cannot be naturally replenished quickly. This reflects the unsustainable nature of their consumption and includes fossil fuels (oil, coal and natural gas), nuclear energy and the heat and electricity derived from them. (2) Renewable energy encompasses all resources that

can be naturally and rapidly replenished, making them sustainable. This includes bioenergy and energy generated from natural sources such as wind, water, geothermal heat and the sun. (3) Energy storage is not considered a source of energy, but rather a technology that allows energy to be stored for later use. Storage durations range from seconds to years. This category was introduced due to the difficulty of tracing the original source (non-renewable or renewable) of the stored energy. It includes both hydrogen and electricity storage, but not conventional fuel storage.

Based on the above classifications, we can conclude that the energy transition is an attempt to shift towards a more sustainable, low-carbon energy system. The energy transition relies on renewable energy sources, which are considered environmentally friendly and allow for a reduction in the negative environmental impact of conventional energy sources. According to the OECD and UNDP (2025), the energy transition offers economic benefits as well as environmental ones. Investment in clean energy and its efficient use fosters innovation through the development of new technologies and products, leading to increased productivity and economic growth. According to the latest IRENA report (2026), in 2024, 31.7% of global electricity production came from renewable sources, while no more than 1.4% came from non-renewable sources. The top three regions were Asia with 4 589 TWh, Europe with 1 758 TWh, and Eurasia with 411 TWh. Meanwhile, Africa recorded 227 TWh. These figures reflect the growing importance of the energy transition at an international level, while also highlighting regional disparities in production volumes.

The energy sector is considered a cornerstone of Algeria's economic growth strategies, driving development across all sectors given its contribution of 93% to hard currency revenues. However, in light of recurring oil crises, the country has embarked on an energy transition policy, adopting the "National Programme for Renewable Energy and Energy Efficiency 2011–2030 (NPREEE)" in 2011 (Kessaissia, 2022). In 2015, Algeria adopted an updated version of the programme for the period 2015–2030, aiming to improve energy efficiency, achieve the energy transition and promote sustainable development, while mitigating the impacts of climate change through the energy, waste, forestry, transport, housing and industry sectors. It is expected that renewable electricity will account for 27% of total electricity consumption by 2030 (Bouznit, 2022). Algeria's potential in renewable energy, particularly solar energy, motivated the decision to pursue a policy of energy transition. The Algerian Sahara is considered the largest source of solar energy, which prompted the German Space Agency to request investment from the German government in the Algerian Sahara (Maaskri & Yamani, 2020).

However, Algeria's energy transition faces a number of challenges. The most prominent of these are outlined by Bouteraa and Aouissi (2025). (1) High costs and limited local industrial capacity are causing delays to energy projects. The first tender under the NPREEE aimed to install 22 GW of renewable energy capacity by 2023, but only achieved 90 MW due to stringent local ownership and industrial content requirements. (2) The limited number of solar panel manufacturing plants (three) necessitates imports to meet project requirements. (3) The limited transfer of

knowledge and technology from developed countries leaves importing countries dependent on them. (4) Research centres and universities have limited success in translating their outputs into practical industrial innovations. (5) Continued reliance on a mono-product economy based on traditional resources means that importing countries are subject to various international crises and their domestic repercussions. An assessment of the NPREEE's progress revealed that it was falling behind its planned targets. Consequently, its deadlines have been extended to 2035 and additional partners have been brought on board with the aim of accelerating progress and achieving 15 000 MW by the end of 2035 (Bouarroudj, 2022).

Our study aims to determine the impact of the energy transition, as represented by renewable energy consumption and renewable electricity output, on long-run economic growth. We use carbon dioxide emissions per capita as a control variable to account for the impact of non-renewable energy, and we take into account structural changes during the period 1990-2022. To this end, we employed the Fourier Bootstrap ARDL model, which examines long-term relationships between variables while accounting for smooth structural changes in the economy through the inclusion of Fourier functions. This is particularly important given that the period under study witnessed several economic and political shifts. We also used the Bootstrap technique to provide more accurate estimates, particularly for small samples.

This research is structured as follows: Section I presents studies that have addressed energy transition and economic growth. Section II is devoted to presenting the study variables and their data sources, as well as the various stages of the methodology that were followed to arrive at the final results. Section III presents and discusses the findings, comparing them with the existing literature. The conclusion offers some recommendations and identifies the study's limitations, which may open avenues for future research.

I. Literature Review

The energy transition is a contemporary issue that has attracted the attention of researchers in many countries. Several studies have been carried out, covering both developed and developing countries. These studies range from single-country case studies to analyses of groups of countries.

In the European context, Lu et al. (2025) conducted an empirical study analysing the contribution of technological innovation and renewable energy consumption to green growth. The study was conducted across a group of European countries categorised by income level. The results of the cross-sectional autoregressive distributed lag (CS-ARDL) model revealed that, across all income categories, renewable energy consumption has a positive and statistically significant impact on green growth, particularly in high-income economies. This highlights the importance of renewable energy in promoting green growth. However, the impact of technological innovation and globalisation varied according to income level: their impact was more pronounced in high-income economies, but they had no significant effect in low- and middle-income countries. The researchers suggest that this variation is due to

differences in institutional strength and the development of green innovation ecosystems. The outcomes of policies and investments in renewable energy vary across countries depending on institutional and economic factors; the results are stronger in countries with robust institutional frameworks and resilient economies. Meanwhile, in emerging economies, Hutajulu and Indrawati (2023) assessed the effect of renewable and non-renewable energy on economic growth in Indonesia. The study used an error correction model based on annual data for economic growth, biomass energy, natural gas, oil, fuel and electricity. The results showed that, in the short and long term, renewable energy, represented by biomass energy, does not contribute to economic growth; this is due to constraints relating to its production, as well as limited availability. Natural gas is considered a non-renewable energy source. The study found that its impact on economic growth in the short and long term was negligible due to inadequate infrastructure and insufficient investment in its management. Fossil fuels have a significant negative long-term impact on growth due to several factors, such as declining reserves and rising government subsidy costs. In contrast, electricity contributes to boosting Indonesia's economic growth in both the long and short term, particularly when generated from renewable energy sources. However, Hutajulu and Indrawati (2023) argue that Indonesia's heavy reliance on non-renewable energy sources means that renewable energy is still unable to drive economic growth.

Regarding Arab countries, a study by Sedqy et al. (2026) investigated the influence of the expansion of renewable energy on economic diversification in Egypt, using the Non-Linear Autoregressive Distributed Lag (NARDL) model. The study revealed a long-term relationship between the variables under investigation, including economic diversification, renewable energy, carbon intensity, oil rents, and foreign direct investment. The results showed a negative long-term relationship between economic diversification and renewable energy, for both positive and negative renewable energy shocks. This is consistent with the green dependency paradox, which operates through technology-related capital flight and deindustrialisation resulting from public procurement policies. Conversely, oil revenues have been shown to positively affect economic diversification. The study suggests a link between these findings and Egypt's current institutional context: renewable energy is not the direct cause of the lack of economic diversification, but rather the surrounding institutional environment. This is because the majority of the value generated by energy projects flows abroad. This is due to the import of most equipment and technologies, which stems from the absence of productive linkages between the renewable energy sector and other industries.

At the local level, Zakraoui and Ratiat (2024) investigated the impact of renewable energy investment on economic growth in Algeria. They used electricity output from gas and renewable energy sources as independent variables. The results of the ARDL model showed that, in the long run, electricity output from renewable energy sources had a positive and statistically significant effect on economic growth. In contrast, electricity output from natural gas had a negative and statistically significant effect due to the decline in production observed during the study period (2000–2020).

Despite the positive impact of renewable energy, the researchers concluded that investment in this sector remains constrained by the significant challenges facing the Algerian economy. Similarly, Soualili and Belghai (2019) analysed the impact of renewable and non-renewable energy consumption on economic growth in Algeria, incorporating fixed capital and labour as an extension of the neoclassical production function. Using the ARDL methodology, the study concluded that neither renewable nor non-renewable energy consumption impacts economic growth, with the effect stemming solely from fixed capital and labour. A causality test revealed a one-way causal relationship from gross domestic product to fixed capital. Despite improvements in its mix, the study highlighted the weakness of renewable energy production; furthermore, non-renewable energy consumption is primarily derived from gas and is rising steadily, leading to an increase in carbon dioxide emissions. The study concluded that promoting renewable energy requires adequate support and encouragement.

II. Data and Methodology

The objective of this research is to assess the effect of the energy transition on economic growth in Algeria by analysing the relationship between gross domestic product per capita and variables relating to renewable and non-renewable energy, using econometric modelling. We use gross domestic product per capita to represent economic growth, and employed two variables: renewable energy consumption as a percent of total energy consumption, and renewable electricity output as a percent of total energy production as a proxy for energy transition, and carbon dioxide emissions per capita as a control variable to account for the impact of non-renewable energy sources.

1 .Presenting the study variables

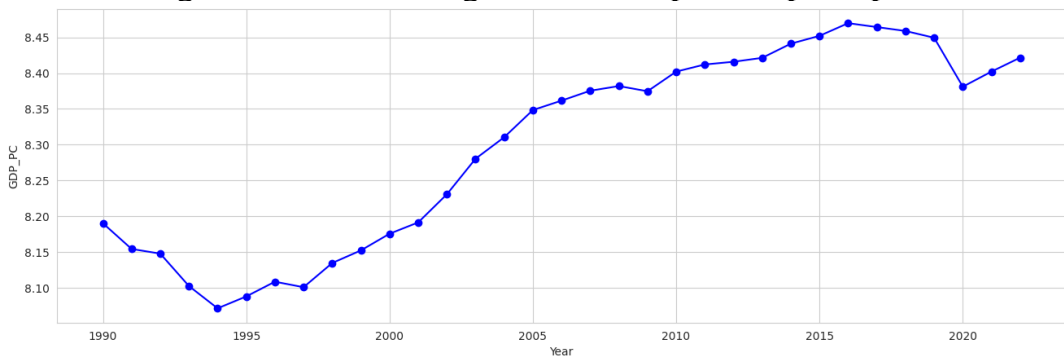
Annual time-series data were obtained for the period 1990–2022; the sample ends in 2022, as this is the most recent year for which complete and consistent data were available in World Development Indicators (WDI) of the World Bank at the time of the study. We have listed the variables in Table (1), which provides their detailed specifications: their abbreviations, descriptions, units and sources. We transformed the economic growth variable, expressed by gross domestic product per capita measured in monetary values, into logarithmic form in order to avoid heteroscedasticity.

Table 1: Specification of data and sources

Variable	Short form	Description and unit	Source of data
Economic Growth	GDP_PC	GDP per capita (constant 2015 US\$)	WDI
Renewable energy consumption	REC	Renewable energy consumption (% of total final energy consumption)	WDI
Renewable electricity output	REO	Renewable electricity output (% of total electricity output)	WDI
Carbon dioxide emissions per capita	CO ₂ _PC	Carbon dioxide (CO ₂) emissions excluding LULUCF per capita (t CO ₂ e/capita)	WDI
<i>Note :</i> WDI : World Development Indicators (https://databank.worldbank.org/source/world-development-indicators#)			

1.1. Gross domestic product per capita

Gross Domestic Product (GDP) represents a country's total income derived from goods and services over a specific period, and gross domestic product per capita (GDP_PC) refers to the amount that corresponds to each individual in the country; it is calculated by dividing GDP by the population (World Bank, n.d.). GDP_PC is used to measure economic performance, as it is considered an important indicator of the standard of living and economic well-being of a country's population (OECD, 2018).

Fig 1: Annual trend in gross domestic product per capita

Source: Author's using Python 3.12

Fig (1) shows the trend in GDP_PC, which has risen steadily throughout the study period. This is due to Algeria's focus on this indicator, particularly following the introduction of the economic recovery programme. Its evolution can be divided into two phases: the first phase, from 1990 to 1994, during which it remained at low levels due to the economic and political circumstances Algeria was experiencing at the time; its lowest value was estimated at USD 3 202 per capita in 1994. The second phase, from 1995 to 2016, witnessed continuous growth due to rising government revenues driven by increased income from hydrocarbons and development projects

implemented to boost economic growth, reaching a peak of USD 4 769 in 2016. However, the slump in oil prices in 2014 began to impact GDP_PC, and this was exacerbated by the repercussions of the 2020 pandemic, when the indicator fell to USD 4 364 per capita. It then recovered in the subsequent period. During this period, the government set out a new economic growth model with the aim of increasing the contribution of non-oil sectors to GDP between 2020 and 2030, which will raise GDP_PC.

1.2. Renewable energy consumption

Renewable Energy Consumption (REC) is defined as the proportion of energy produced from renewable sources within total final energy consumption. In other words, it is the amount of energy consumed by end users from renewable sources compared to the total amount of energy consumed. The main sources of renewable energy in Algeria are as follows:

Solar energy technologies convert solar irradiance into usable energy. While some solar energy technologies are still in the research and development stage, such as producing fuel from solar energy, concentrated solar power (CSP), solar panels and solar heating are considered more advanced. However, solar energy production is considered unstable due to its dependence on the climate (IPCC, 2012). Algeria is considered one of the richest countries in the Mediterranean basin in terms of this resource, with an estimated potential four times the total global consumption and 60 times the electricity needs of European countries. In this context, Algeria is developing several hybrid projects combining solar energy and natural gas (Rahmane, Bentafat, & Sallami, 2019).

Water utilisation projects can take various forms, including run-of-river power stations and dams with reservoirs. These projects not only generate electricity, but also provide drinking water, support irrigation activities and mitigate the risks of flooding and drought (IPCC, 2012). The drought experienced by Algeria in 2021 prompted the search for solutions to supply large cities with water. Seawater desalination, a process requiring significant energy, emerged as a viable economic and technical alternative to rainwater harvesting (Kessaissia, 2022).

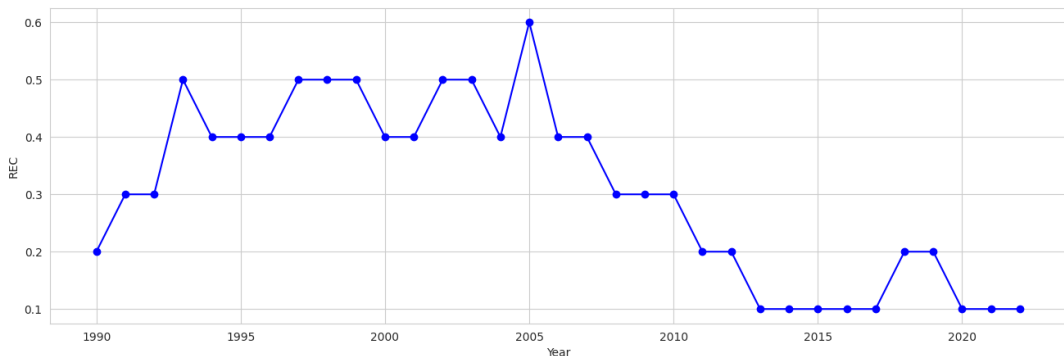
Biomass is the third-largest source of renewable electricity output. This includes wood and wood waste, agricultural crops and residues, livestock manure, municipal solid waste, and food industry waste. Recent studies have shown that Algeria's potential for recovering energy from various types of waste amounts to 1 700 GWh per year (Haddoum, Bennour, & Zaid, 2024).

Furthermore, wind power is considered a strategic option for mitigating the impacts of climate change and reducing dependence on fossil fuels. This involves converting the kinetic energy of the wind into electrical energy using specialised turbines. The potential for wind energy in Algeria varies across different geographical regions, increasing towards the south to reach 4 m/s. In 2017, the Centre for Renewable Energy Development published a new national wind atlas. The semi-regular network of monitoring stations enabled more accurate estimates of wind resources, particularly in the Sahara. The atlas also highlighted the promising potential of these

areas, with the average wind speed at the Hassi al-Raml site reaching 5.6 m/s (Layachi & Mokhtar, 2023).

Geothermal energy is characterised by its low cost and year-round production. Geothermal technology extracts heat from the Earth's interior and is found in tectonically active regions. It can be used for heating and cooling purposes, or converted into electrical energy (IRENA, 2025). Algeria has around 200 geothermal sources, most of which are in the north. A third of these exceed 45C°, and temperatures of around 118C° are reached in some areas, such as the wilaya of Biskra.

Fig 2: Annual trend in renewable energy consumption



Source: Author's using Python 3.12

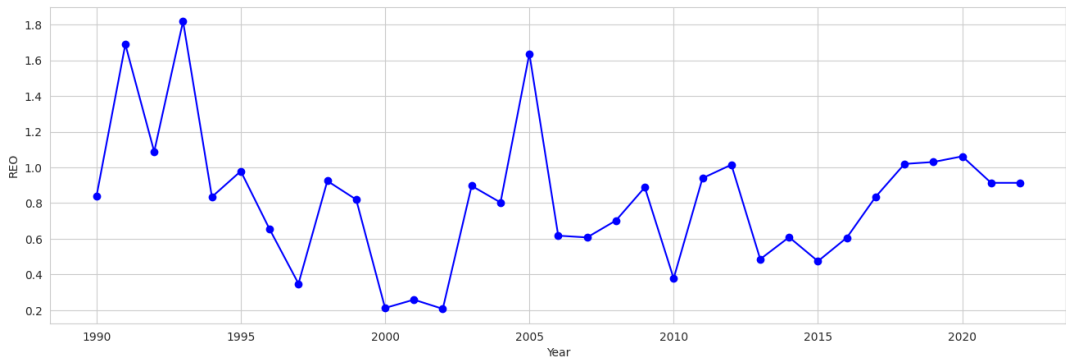
Figure (2) illustrates the trend in renewable energy consumption (REC) as a proportion of total energy consumption. Although REC has increased in recent years due to government programmes designed to promote clean energy sources, the aim is to reach 22 000 MW by 2030 (11 000 MW for domestic consumption and 10 000 MW for export) (IEA, 2025b). However, this increase has not been reflected in the proportion of total energy consumption; the proportion of renewable energy consumption ranged from 0.3% to 0.5% between 1990 and 2004. The highest proportion was recorded in 2005 at 0.6%, reflecting the dominance of renewable energy over fossil fuels. The subsequent period (2006-2022) saw a steady decline until stabilising at around 0.1-0.2%. This decline is due to the significant increase in non-renewable energy consumption (electricity and gas), which exceeds the rate at which renewable energy projects are being implemented.

1.3. Renewable electricity output

Renewable Electricity Output (REO) refers to the proportion of electricity generated from renewable sources out of the total electricity generated, whether from conventional or renewable sources. There are two ways to generate electricity: the first is conventional, involving the conversion of heat produced by fuel combustion or nuclear reactions into steam (thermal power generation); the second is renewable, using energy sources found in nature, such as solar, hydro and wind power. In Algeria, the largest source of electricity generation is gas, accounting for 99% in 2023, followed by solar energy at 0.7%, with production reaching 686 GWh. Wind power and hydropower are among the renewable sources of electricity generation. Wind power generation stood at 15 GWh in 2022, with the highest figure for the

period 2015-2022 being recorded in 2016 at 29 GWh. Meanwhile, electricity generation from hydropower reached 16 GWh in 2022. During the period 2000-2022, the highest figure was 622 GWh in 2012 (IEA, Electricity, 2026a).

Fig 3: Annual trend in renewable electricity output



Source: Author's using Python 3.12

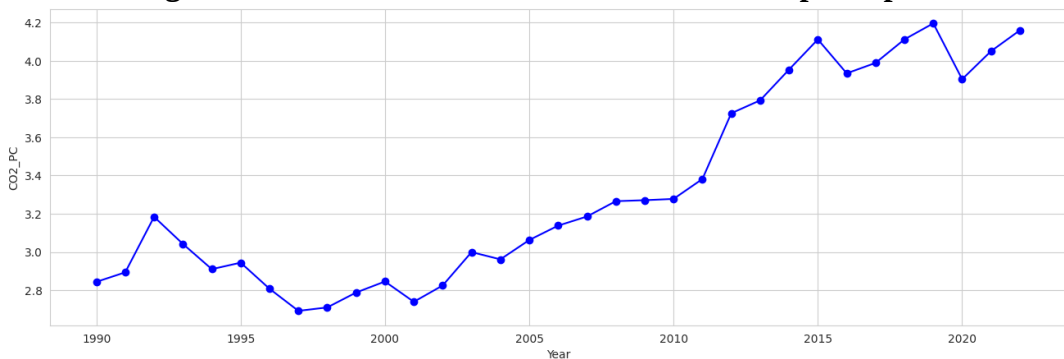
Fig (3) shows the trend in electricity output from renewable sources as a proportion of total electricity output. We can see that this proportion was high during the period 1990-1993, reaching 1.82% in 1993. However, it then declined during the subsequent period 1994-2010, reaching its lowest levels 0.2% between 2000 and 2002 due to a decline in rainfall. During this time, Algeria relied primarily on hydropower for electricity generation. Following the commissioning of the hybrid solar and natural gas power station at Hassi R'mel in 2011, however, electricity production gradually increased, reaching 1.02% in 2019 and 1.06% in 2020 (ICA, 2011).

1.4. Carbon dioxide emissions per capita

Annual carbon dioxide emissions per capita (CO_2_{PC}) are one of the greenhouse gases covered by the Kyoto Protocol. These emissions arise from energy production, agriculture, industry and forestry, but not from land use, land use change and forestry (LULUCF). These emissions are converted to CO_2e and divided by the country's population.

Reports from the IEA (2026b) indicate that the majority of carbon dioxide emissions are linked to the use of fossil fuels (coal, oil and natural gas), with the combustion of these fuels being a significant driver of climate change. Algeria's share of total global emissions was 0.4% in 2023, up 151% from 2000, reflecting the country's reliance on fossil fuels for economic activity.

Economic literature uses this variable to analyse the relationship between economic growth and carbon dioxide emissions in order to examine environmental sustainability. The aim of including this variable is to identify the true effect of renewable energy on economic growth after controlling for the impact of non-renewable energy use. The study's model will enable us to measure the extent to which economic growth in Algeria is linked to fossil fuel consumption.

Fig 4: Annual trend in carbon dioxide emissions per capita

Source: Author's using Python 3.12

Fig (4) shows the trend in carbon dioxide emissions per capita. The period from 1990 to 1999 saw low levels due to the economic conditions prevailing at that time. Rising levels were seen between 2000 and 2015 due to increased manufacturing activity and urban expansion, both of which contributed to higher energy demand. Following the fall in oil prices after 2015, the pace of economic activity slowed and, consequently, emission levels fell. This was followed by the onset of the 2020 pandemic, which led to a decline in industrial activity and transport, resulting in lower emissions. However, production activities quickly recovered in 2021 and 2022.

2. Methodology

We follow a series of steps to analyse the relationship between the energy transition and economic growth in Algeria. These steps are as follows:

- Retrieving data representing the study variables from the World Bank database and analysing their characteristics through descriptive analysis and graphical representations;
- Examining the stationarity of the time series using unit root tests, followed by assessing of the potential for cointegration among the variables using the Bootstrap technique;
- Estimating the effect of the energy transition on economic growth using a Fourier Bootstrap ARDL model, and assessing the model's validity;
- Analysing and discussing the empirical results.

2.1. Unit root tests

We use the Augmented Dickey–Fuller (ADF) test (1981), alongside the Fourier Augmented Dickey–Fuller (FADF) test by Enders and Lee (2012), which is considered an extension of the ADF test. The FADF test emerged following the introduction of the concept of Fourier functions by Gallant (1981), which offers a significant advantage in stability tests by enabling the detection of structural changes without the need for knowing the dates on which they occurred. The test takes the following form:

$$d(t) = \alpha_0 + a_k \sin\left(\frac{2\pi kt}{T}\right) + b_k \cos\left(\frac{2\pi kt}{T}\right) \dots\dots\dots (1)$$

$$y_t = \alpha_0 + a_k \sin\left(\frac{2\pi kt}{T}\right) + b_k \cos\left(\frac{2\pi kt}{T}\right) + \sum_{j=1}^p \phi \Delta y_{t-j} + \varepsilon_t \dots\dots\dots (2)$$

$$y_t = \alpha_0 + \alpha_1 t + a_k \sin\left(\frac{2\pi kt}{T}\right) + b_k \cos\left(\frac{2\pi kt}{T}\right) + \sum_{j=1}^p \phi \Delta y_{t-j} + \varepsilon_t \dots\dots\dots (3)$$

Equation (1) represents the Fourier term in the case of a single frequency. Equation (2) tests the null hypothesis of the presence of a unit root with a constant term, whereas equation (3) tests the null hypothesis of the presence of a unit root with both the constant term and the trend term.

2.2. Cointegration test

The cointegration test determines whether there is a long-run equilibrium relationship among the variables under study, using the ARDL bounds test approach developed by Pesaran et al. (2001). However, this test can leave researchers uncertain when the F-bound is between $I(0)$ and $I(1)$, as it is unclear whether cointegration exists. McNown et al. (2018) introduced a bootstrap technique that generates new critical values to avoid this region of uncertainty. Furthermore, this technique is highly efficient in producing accurate results even with small sample sizes. Subsequently, Bertelli et al. (2022) further developed the technique to provide more accurate results with more than two variables. The test is based on testing the following hypotheses:

$$H_0 (F_Overall): \alpha y = \alpha_1 = \dots = \alpha_k = 0 \text{ (all regressors)} \dots\dots\dots (4)$$

$$H_0 (T_dependent): \alpha y = 0 \text{ (the lag of dependent variable)} \dots\dots\dots (5)$$

$$H_0 (F_independent): \alpha_1 = \alpha_2 = \dots = \alpha_k = 0 \text{ (the lag of independent variable)} \dots\dots\dots (6)$$

We say that there is mutual integration between the variables if the values of the statistics calculated for the tests of all null hypotheses are greater, in absolute terms, than the critical values generated by bootstrapping.

2.3. Model estimation

The Fourier Bootstrap ARDL model is a robust approach to addressing structural changes, providing more realistic interpretations of long-run relationships. To this end, Yilanci et al. (2020) incorporated Fourier functions into the Bootstrap ARDL model to estimate the long-run relationship between variables in cases there were break points in the time series. The long-run equation for measuring the effect of the energy transition on economic growth is given as follows:

$$\Delta GDP_PC_t = \alpha_0 + a_k \sin\left(\frac{2\pi kt}{T}\right) + b_k \cos\left(\frac{2\pi kt}{T}\right) + \alpha_1 GDP_PC_{t-1} + \alpha_2 REC_{t-1} + \alpha_3 REO_{t-1} + \alpha_4 CO_2_PC_{t-1} + \sum_{i=1}^{p-1} \gamma_i \Delta GDP_PC_{t-i} + \sum_{i=0}^{p-1} \tau_i \Delta REC_{t-i} + \sum_{i=1}^{p-1} \theta_i \Delta REO_{t-i} + \sum_{i=1}^{p-1} \mu_i \Delta CO_2_PC_{t-i} + \varepsilon_t \dots\dots\dots (7)$$

Where Δ denotes the first difference operative; “p” indicates the lag length which is chosen according to the Akaike information criteria (AIC); “ $\alpha_1 - \alpha_4$ ” represents the coefficient of the lagged levels of the dependent and independent variables; “ $\gamma_i, \tau_i, \theta_i, \mu_i$ ” are the parameters of the lagged differenced regressors; and “ ε_t ” denotes the disturbance term with a mean of zero and finite variance.

III. Results and discussion

This section illustrates the results obtained after applying the methodology described above to the study variables. The results of the estimates have been organised into tables to facilitate their reading and analysis.

1. Descriptive statistics

The descriptive statistics presented in Table (2) deliver an overview of the characteristics of the study variables in Algeria. The mean GDP_PC, REC, REO, and CO₂_PC during the period (1990–2022) were 8.299, 0.306, 0.821, and 3.324, respectively. GDP_PC and REC recorded low standard deviations of 0.137 and 0.156, respectively, indicating the homogeneity of their data. These were followed by REO, with a standard deviation of 0.382, reaching its lowest value in 2002 and its highest in 1993. In contrast, CO₂_PC recorded the highest standard deviation compared with the other variables, with the lowest and highest values recorded in 1997 and 2019, respectively.

Table 2: Descriptive statistics

	GDP_PC	REC	REO	CO ₂ _PC
count	33.00000	33.00000	33.00000	33.00000
mean	8.299227	0.306061	0.821558	3.324307
std	0.137407	0.156004	0.382288	0.515921
min	8.071396	0.100000	0.207610	2.691845
25%	8.154359	0.200000	0.607807	2.893424
50%	8.361618	0.300000	0.835473	3.183930
75%	8.415922	0.400000	0.978950	3.904231
max	8.469836	0.600000	1.818275	4.196519

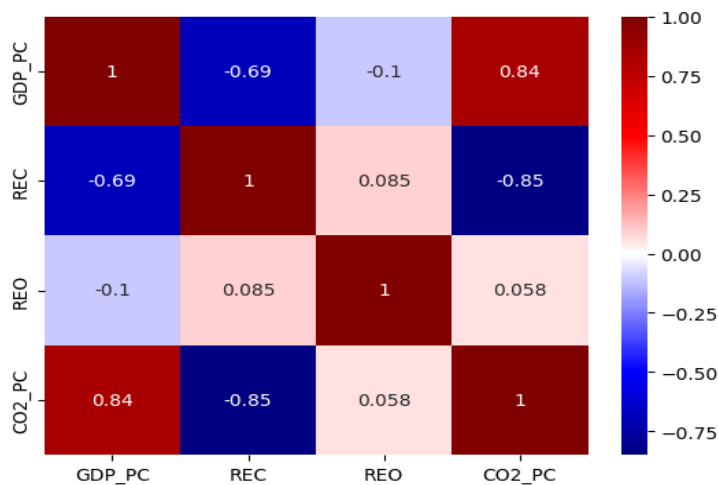
Source: Author's using Python 3.12

2. Correlation Matrix among the Variables

Figure (5) shows the heat map of the correlation matrix between the variables. The results indicate a strong positive correlation between GDP_PC and CO₂_PC with a coefficient of 0.84. Conversely, GDP_PC is strongly inversely correlated with REC with a coefficient of -0.69, and weakly inversely correlated with REO with a coefficient of -0.1.

On the other hand, we observe a weak positive correlation between CO₂_PC and REO, with a coefficient of 0.058, and a weak positive correlation between REC and REO, with a coefficient of 0.085. Meanwhile, we observe a strong inverse correlation between CO₂_PC and REC, with a correlation coefficient of -0.85.

Fig 5: Heat map of correlation matrix



Source: Author's using Python 3.12

3. Unit root test results

Table (3) presents the unit root test results using the ADF test and the FADF test. The ADF test showed that the REO series is stationary at level $I(0)$, while the FADF test showed that both REC and REO are stationary at level $I(0)$. The remaining variables are stationary after the first difference, indicating that they are first-order integrated $I(1)$. The stationarity of the time series was determined by considering P-values below the 5% and 1% significance levels, which implies the rejection of the null hypothesis that the time series are non-stationary.

The results of the stationarity tests indicate that the variables have different orders of integration, $I(0)$ and $I(1)$; consequently, the FARDL model can be used in this study.

Table 3: Results of the ADF and FADF stationarity tests

ADF Unit Root test						
	At Level			At First Difference		
	<i>ADF-Stat</i>	<i>P-Value</i>		<i>ADF-Stat</i>	<i>P-Value</i>	
GDP_PC	-0.4230	0.9062		-3.9051	0.0020***	
REC	-0.6159	0.8674		-7.9915	0.0000***	
REO	-4.1392	0.0008***		-3.7184	0.0039***	
CO ₂ _PC	-0.0881	0.9506		-5.5442	0.0000***	
Fourier ADF Unit Root test						
	At Level			At First difference		
	<i>FADF-stat</i>	<i>Frequency</i>	<i>P-Value</i>	<i>FADF-stat</i>	<i>Frequency</i>	<i>P-Value</i>
GDP_PC	-3.5599	1	0.1817	-4.0909	3	0.0314**
REC	-4.5495	1	0.0015***	-3.6029	5	0.0086***
REO	-2.3701	5	0.1348	-11.6004	5	0.0010***
CO ₂ _PC	-4.9204	1	0.0120**	-6.2492	1	0.0010***
Note: **, *** indicate rejection of H_0 at the 5% level and 1% level respectively.						

Source: Author's using Stata 19.5

4. Cointegration test results

After confirming that the degree of integration of the time series does not exceed $I(1)$, we proceed to test for cointegration between the variables to ascertain whether there exists a long-run equilibrium between them. Table (4) provides the results of the cointegration test using the Bootstrap technique. As the test statistics F_{Overall} and $F_{\text{independent}}$ (in absolute terms) exceed the critical values at a 5% significance level, and the statistical value of the $T_{\text{dependent}}$ test (in absolute terms) exceeds the critical value at a 1% significance level, we reject the null hypothesis that there is no cointegration. This implies the existence of a long-run equilibrium among the variables; in other words, GDP_{PC} , REC , REO and CO_2_{PC} move together in the long run.

Table 4: Results of the cointegration test using the Bootstrap technique

Test H_0 : No cointegration	Statistic	P- value	Bootstrap Critical Values			Decision
			1%	5%	10%	
F_{Overall}	61.4659	0.0417	105.826	38.361	21.885	Reject H_0^{**}
$T_{\text{dependent}}$	-11.1547	0.0000	-4.752	-4.752	-3.819	Reject H_0^{***}
$F_{\text{independent}}$	79.7599	0.0417	129.087	47.358	28.934	Reject H_0^{**}
Note: ** and *** indicates rejection of H_0 at the 5% and 1% level						

Source: Author's using Stata 19.5

5. Discussion of the long-run results

Table (5) presents the results for the error-correction coefficient and the long-run relationship between economic growth and energy transition variables in Algeria. The error-correction coefficient ($L.GDP_{PC}$) must be negative and statistically significant, which is the case given that the P-value is below the 1% significance level. This result shows effective adjustment toward equilibrium, with the adjustment rate exceeding 100%, indicating rapid convergence. We note that all explanatory variable coefficients are statistically significant at the 1% significance level.

The results of the long-term analysis revealed that an increase in REC by one percentage point leads to a 0.776% decrease in economic growth, indicating a negative impact of REC on economic growth. This finding is consistent with the results of numerous applied empirical studies. In his study of OECD countries, Matei (2017) found that REC has a negative impact on economic growth. This is either due to insufficient funding for renewable energy technologies, or because the renewable energy sector is still in its early stages of development. However, Hutajulu and Indrawati (2023) attributed this to constraints relating to renewable energy production and the scarcity of renewable energy in Indonesia.

Our findings are also consistent with those of Sedqy et al. (2026), who argued that the negative impact was due to the outflow of technology-related capital given that renewable energy equipment and technologies are imported. The negative relationship between REC and GDP_{PC} does not reflect any shortcomings in renewable energy itself, but rather the high investment costs associated with it. Most projects rely on importing modern equipment and technologies (e.g. solar panels,

control systems and batteries) from overseas markets. This results in an increase in the import bill and a depletion of foreign exchange reserves. Sedqy et al. (2026) emphasised that the lack of production linkages between the renewable energy sector and other industries has contributed significantly to this negative impact. Limited local manufacturing of renewable energy components leads to weak production linkages between this sector and the rest of the economy, reducing opportunities for local knowledge development and the creation of high-skilled jobs. As technological dependence persists, some of the economic returns leave the local economy rather than being channelled into investment, production, and local income.

Soualili and Belghait (2019) observed that the REC has no impact on economic growth in Algeria. This is because renewable energy is not considered one of the main drivers of economic growth and levels of renewable energy are low. However, this does not mean that renewables are unimportant for economic growth. On the contrary, investment in renewable energy should be encouraged, given its importance for environmental protection. Researchers have demonstrated that renewable energy sources are still in their infancy (Bedrina & Bourennane, 2022) and that their positive impact will only become apparent once a certain threshold has been surpassed. Before this threshold is reached, depending on the strength of the economies in question and whether they are developed or developing, the impact is negative (Bhuiyan, et al., 2022; Eyuboglu, 2022).

Our results show that REO has a positive impact on economic growth, albeit a relatively weak one compared to CO₂_PC: a one percentage point increase in REO is followed by a 0.081% increase in economic growth. This finding is consistent with the conclusions of Zakraoui and Ratiat (2024), who determined that electricity generation from renewable sources positively impacts economic growth in Algeria, in contrast to electricity generation from natural gas. Ishouf and Satour (2021) emphasised that solar and hydroelectric power generation contributes to economic growth. Solar energy is one of Algeria's most important renewable energy sources, placing the country among the world leaders due to the vast expanse of the Algerian Sahara. Although hydroelectric power production capacity is limited due to its dependence on precipitation, it nevertheless plays a positive role in achieving economic growth. Similarly, a study by Ohler and Fетters (2014) on OECD countries demonstrated a long-term relationship between economic growth and electricity generation from hydropower, biomass, wind power, and waste. The study revealed that electricity generation from hydropower and waste has the greatest impact on economic growth compared to other sources. It also revealed that the impact on economic growth and the environment varies from one renewable source to another. This means that decision-makers must consider this variation when formulating policies and investment programmes for renewable energy.

The results suggest that an increase in CO₂_PC has a positive impact on economic growth, with a one-unit increase in CO₂_PC leading to a 0.3% increase in economic growth. This finding reflects the positive effect of fossil fuel use on economic growth and is consistent with the structure of the Algerian economy, which relies on hydrocarbons to finance economic activity. This finding is consistent with the

conclusion of numerous studies that energy from non-renewable sources has a positive impact. Matei (2017) observed that energy support policies can stimulate economic growth due to the positive effect of non-renewable energy sources on economic growth. However, Soualili and Belghait (2019) argue that despite the positive impact of non-renewable energy sources, their increased consumption will lead to higher carbon dioxide emissions, negatively impacting the environment and quality of life.

Table 5: Speed of adjustment and long-run relationship

ADJ — Speed of Adjustment			
<i>Variable</i>	<i>Coefficient</i>	<i>T-stat</i>	<i>P-Value</i>
L.GDP_PC	-1.052844	-11.1547	0.0000 ***
Long Run Relationship			
<i>Variables</i>	<i>Coefficient</i>	<i>T-stat</i>	<i>P-Value</i>
REC	-0.776663	-6.3362	0.0000***
REO	0.081166	5.9089	0.0000***
CO ₂ _PC	0.300030	28.0855	0.0000***
Note: *** means that all parameters are significant at the 1% level			

Source: Author's using Stata 19.5

6. Diagnostic tests

Table (6) provides the results of the diagnostic tests for the estimated model; the tests indicate that the model is statistically acceptable. The normality tests show that the residuals follow a normal distribution, and the serial correlation tests indicate no autocorrelation among the errors. Heteroscedasticity tests reveal that the variance of the residuals is constant, and the model does not suffer from specification issues based on the Ramsey test. Furthermore, the stability of the model's coefficients is demonstrated by the results of the stability tests (CUSUM and CUSUM-SQ), which support the reliability of the findings and their use in interpreting the relationship between the energy transition and economic growth.

Table 6: Diagnostic tests

Category	Test	Statistic	P-Value
Normality Tests	Jarque-Bera	0.0073	0.9964
	Shapiro-Wilk W	0.9766	0.7471
	Shapiro-Francia W	0.9766	0.6542
Serial Correlation Tests	BG LM(1)	0.5293	0.4669
	BG LM(2)	1.0243	0.5992
	BG LM(3)	3.0374	0.3859
	BG LM(4)	6.2797	0.1792
Heteroskedasticity Tests	ARCH LM(1)	0.1081	0.7450
	ARCH LM(4)	0.5897	0.6739
Functional Form	Ramsey RESET	0.3029	0.8228
Stability Tests	CUSUM (5%)	Stable	
	CUSUM-SQ (5%)	Stable	
Note: H ₀ (normality): normally distributed residuals H ₀ (serial): no serial correlation H ₀ (heterosk.): homoscedastic errors			

Source: Author's using Stata 19.5

7. Fourier Term test

Table (7) provides the results of the Fourier terms test, which indicate the presence of structural changes in the study variables data, based on the F-statistic at a 1% significance level. This highlights the need to include Fourier functions in the ARDL model, as they are statistically valid, rather than using the standard ARDL model.

Table 7: Fourier Terms Joint Significance F-test

Test	Statistic	P-Value
F-statistic	18.8183 ***	0.0000
Note: *** indicates rejection of H_0 at the 1% level. H_0 : $\lambda_1 = \lambda_2 = 0$ (no structural break)		

Source: Author's using Stata 19.5

8. Cumulative Fourier-Frequency Toda-Yamamoto Causality Test

Table (8) presents the results of the Cumulative Fourier-Frequency Toda–Yamamoto causality test (Nazlioglu, Soytas, & Gormus, 2019), which assesses long-run causality between variables while accounting for structural changes in the economy. The findings suggest that there is no bidirectional causal relationship between GDP_PC, REC and REO. This supports the long-term findings regarding the relationship between economic growth and energy transition variables. This implies that investment in renewable energy has not yet reached a sufficient level to establish

a causal relationship with economic growth, given that renewable energy is still in its infancy and the economy continues to rely on fossil fuels. Furthermore, the findings suggest that economic growth is not currently driven by renewable energy, as growth is primarily directed towards other sectors. The analysis reveals no evidence of bidirectional causality between GDP_PC and CO₂_PC, as economic growth in Algeria depends heavily on oil revenues, which are influenced by global market prices. However, the results demonstrate a unidirectional causal relationship from CO₂_PC to REC and REO. This indicates that increasing carbon dioxide emissions incentivise the adoption of energy transition policies. Consequently, the energy transition in Algeria is closely linked to environmental considerations, as evidenced by Algeria's ratification of the Paris Agreement (Bouznit, 2022) and subsequent amendments to the National Renewable Energy Programme (NREP) draft.

Table 8: The Cumulative Fourier-Frequency Toda-Yamamoto Causality Test results

<i>Null Hypothesis</i>	GDP_PC	REC	REO	CO₂_PC
GDP_PC	-	0.163 (0.931)	3.166 (0.245)	2.612 (0.309)
REC	0.156 (0.914)	-	3.450 (0.220)	0.691 (0.711)
REO	0.004 (0.998)	0.181 (0.903)	-	0.358 (0.845)
CO₂_PC	0.096 (0.947)	7.440 (0.049) **	5.856 (0.082) *	-
<i>Note: *, ** indicate rejection of H₀ at the 10% level and 5% level respectively based on bootstrap p-values between brackets. Optimal Fourier Frequency= 3. Lag = 2</i>				

Source: Author's using Stata 19.5

Conclusion:

This study aims to evaluate the effect of the energy transition on economic growth in Algeria. To achieve this, the Fourier Bootstrap ARDL model is applied to annual data from 1990 to 2022. The energy transition is measured by renewable energy consumption (REC) and renewable electricity output (REO), both expressed as a percentage of total consumption and output, respectively. Additionally, carbon dioxide emissions per capita (CO₂_PC) are included as a control variable to account for the impact of non-renewable energy. Meanwhile, gross domestic product per capita (GDP_PC) is used as the dependent variable to represent economic growth. Our findings revealed that, while renewable electricity output (REO) has a positive impact, albeit relatively weak, on economic growth, renewable energy consumption (REC) has a negative impact. Our results are consistent with those of numerous previous studies that have concluded that renewable energy has a negative impact on economic growth, while renewable electricity output has a positive impact. One of the main reasons for these results is that the energy transition is still in its early stages and is facing obstacles. The most significant of these are reliance on foreign

technology and the high cost of acquiring it, particularly when revenues and returns from renewable energy projects do not cover these costs.

The literature has highlighted variations in the outcomes of the energy transition, with the impact on different countries varying according to the strength of their economies and their potential for renewable resources. Even developed countries experience a negative impact on their economic growth at the outset of the transition, but once a certain threshold is crossed, the positive impact on their economic growth becomes apparent. We also concluded that carbon dioxide emissions per capita (CO_2_PC) have a positive impact on economic growth. This finding confirms the economy's dependence on fossil fuels and hydrocarbons for its activities. Furthermore, the results of the Cumulative Fourier-Frequency Toda-Yamamoto causality test indicated a unidirectional causal relationship from CO_2_PC towards both renewable energy consumption (REC) and renewable electricity output (REO). No causal relationship was found between the remaining variables.

These findings do not imply that the energy transition is unimportant for achieving growth. On the contrary, they highlight the need to continue developing renewable energy projects, given that they are still in their infancy. The positive impact of renewable electricity output is clear evidence that we must continue to focus on achieving greater efficiency in the production and use of renewable energy if we are to reach a level that will allow the energy transition to have a positive impact on economic growth. There is an urgent need to encourage the domestic market to develop alternatives to imported technologies by raising awareness among economic institutions, researchers and students of economic projects that promote innovation in renewable energy and encourage the domestic adoption of technology. In addition, incentives and benefits should be provided for innovative renewable energy entrepreneurs to encourage participation in this sector, particularly with regard to access to funding and support. This also involves reducing the obstacles and bureaucracy associated with obtaining the necessary licences, as well as encouraging public-private partnerships to make renewable energy more competitive compared with fossil fuels.

The study has some limitations that could be addressed in future research. Although the model included three independent variables due to data limitations and a desire to avoid overcomplicating it, other explanatory variables that contribute to economic growth could be included. Given the importance of the energy transition at the international level, future research could address these shortcomings and extend the study to a wider range of countries.

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