

SYNERGIES FOR SUSTAINABILITY IN ALGERIA: A DYNAMIC ARDL AND KRLS ANALYSIS OF RENEWABLE ENERGY AND GREEN GROWTH

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Abstract

This study examines Algeria's green economy and renewable energy sources. The dynamic correlation over time shows people's renewable energy consumption habits, which indicates that the rise in GDP, including the rise in per capita income, reinforces the idea that individuals in Algeria tend to increase the consumption of non-renewable energies and therefore the societal preferences for the consumption of renewable energies decrease, and this is what decision makers should take into account in enhancing the effectiveness of the green economy. Between 2000 and 2021, dynamic ARDL and KRLS models were used to analyze Algeria's GDP per capita in relation to its consumption of renewable energy as a proportion of total energy usage. The results indicate a projected rise in Algeria's per capita GDP that affects negatively renewable energy use in the short-run. By introducing the benefits resulting from the use of renewable energies, especially through various audio-visual means and advertising, Algeria might potentially reduce its dependence on fossil fuels for consumer energy and encourage investment in renewable energy sources.

Keywords: Social behavior, Renewable energy, KRLS, Dynamic interactions, Algeria.

SINERGIJE ZA ODRŽIVOST U ALŽIRU: DINAMIČKA ARDL I KRLS ANALIZA OBNOVLJIVE ENERGIJE I ZELENOG RASTA

Apstrakt

Ova studija istražuje zelenu ekonomiju i obnovljive izvore energije u Alžiru. Dinamička korelacija tokom vremena pokazuje obrasce potrošnje obnovljive energije među stanovništvom, pri čemu rezultati ukazuju da rast bruto domaćeg proizvoda (BDP), uključujući i rast BDP-a po glavi stanovnika, podstiče veću potrošnju neobnovljivih izvora energije. Posledično, društvene preferencije prema korišćenju obnovljivih izvora energije opadaju, što donosi odluku treba da uzmu u obzir kako bi unapredili efikasnost zelene ekonomije. U istraživanju su za period od 2000. do 2021. godine primenjeni dinamički ARDL model i KRLS model radi analize odnosa između BDP-a po glavi stanovnika u Alžiru i potrošnje obnovljive



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energije kao udela u ukupnoj potrošnji energije. Rezultati pokazuju da rast BDP-a po glavi stanovnika u kratkom roku negativno utiče na upotrebu obnovljivih izvora energije. Promovisanje koristi od korišćenja obnovljivih izvora energije, naročito putem različitih audio-vizuelnih medija i reklamnih kampanja, moglo bi doprineti smanjenju zavisnosti Alžira od fosilnih goriva u sektoru potrošnje energije i podstaći ulaganja u obnovljive izvore energije. **Ključne reči:** Društveno ponašanje, obnovljiva energija, KRLS, dinamičke interakcije, Alžir.

INTRODUCTION

It is becoming increasingly difficult for the global economy to deal with the difficulties of climate change, environmental degradation, and resource depletion, which is leading nations to investigate different models of sustainable development. The green economy is one such paradigm that is gaining momentum. Its goal is to support economic growth while simultaneously minimizing environmental dangers and carbon footprints. In the same way that countries all over the world are working to transition away from their dependency on fossil fuels and toward renewable energy sources, Algeria, a country that has traditionally been dependent on oil and gas, is also beginning to see the significance of this change. In this sense, the authorities have been quite vocal about the significance of sustainable energy as a supplement to sources of energy that are not renewable. Renewable sources of energy play an important part in the manufacturing processes, which are necessary for a cleaner environment. In light of this, numerous nations have initiated the process of channeling funds towards the development of technologies that facilitate the transition to renewable energy sources in order to alleviate environmental concerns (Taskin, Vardar, & Okan, 2020, p. 772).

The Algerian energy sector is undergoing substantial changes in the context of global trends towards sustainability. The Algerian government has set ambitious aims to develop renewable energy sources such as solar, wind, and geothermal power. These developments are taking place in the framework of Algeria's energy sector. In contrast to nations like Egypt and Libya, Algeria makes a unique case in the MENA area. Furthermore, Algeria is a crucial case for investigating the connection between the growth of renewable energy and the convergence of the green economy.

The purpose of this study is to analyze the nature of the dynamic link that exists between the rate of GDP per capita in Algeria and the amount of investment in the field of renewable energies that are implemented in Algeria. Due to the fact that the idea of a green economy is connected to the degree to which the standard of living of individuals improves, and the degree to which it is feasible to implement a program in their lives that has a positive impact on the accomplishment of a green economy, the notion of a green economy depends on both of these factors. When it comes to the execution of programs that support investments in a variety of activities that contribute to the sustainability of the green economy, per capita income is another factor that adds further. In our research, we will be relying on the approach of assessing the economy that is characterized by modernity and is represented by DYNAMIC ARDL and KRLS. The social role is manifested through (Deshuai, Hui, & Ullah, 2022)'s study, which illustrated the contribution of renewable energy

consumption, higher education, and the roles of information and communication technology in enhancing environmental quality and green growth in China. The results indicated that, in the long term, renewable energy and higher education significantly reduce carbon dioxide emissions and promote green growth, while the impact of information and communication technology on emissions is mostly negligible. As a result, the social component of individuals or economic actors is closely tied to their spending habits and how they are directed based on their diverse economic needs. Based on this, we can ask the following question: How does individual behavior resulting from their share of the GDP affect the relationship between the green economy and renewable energy consumption in Algeria?

To answer the question, we split our work into three major axes: the first is a description and discussion of many works that addressed the concept of interaction between the green economy and the consumption of renewable energy. With greater specificity, we examined works that addressed both social and economic issues within the context of past literary research. In the second axis, we specified the path of the study's primary variables over the study period. Finally, we used the usual technique to investigate the dynamic connections between per capita GDP and the proportion of renewable energy consumed in Algeria.

Literature review

An investigation by (Bina, 2013) demonstrated the rise of the 'green economy' in reaction to the global economic crisis, with a particular emphasis on its role in sustainable development. The results indicate a polarization of discourses, a tenuous understanding of sustainable development, and persistent discussions over the need to change or radically alter current economic paradigms.

Zeb, Salar, Awan, Zaman, & Shahbaz (2014) examine the causal links between renewable energy output, carbon emissions, resource depletion, GDP, and poverty in SAARC nations from 1975 to 2010. Significant findings reveal bidirectional causality between emissions and resource depletion in Nepal, as well as between energy and poverty in Pakistan. Energy generation alleviates poverty in Bangladesh and India, but poverty propels energy production in Sri Lanka. Panel results indicate that GDP and poverty enhance energy output, which reduces emissions but exacerbates resource depletion and GDP, ultimately elevating emissions in the region. The Green Economy (GE) seeks to harmonize environmental and socio-economic objectives, with renewable energy (RE) regulations serving a pivotal function. Pahle, Pachauri, & Steinbacher (2016) concluded that although renewable energy deployment can provide immediate socio-economic advantages such as job creation and energy accessibility, these benefits may not be sustainable in the long term. Effective GE policies necessitate explicit objectives, rigorous monitoring, and innovative approaches for analyzing multi-objective policies integral to the GE framework.

Tien, Phuc, Thoi, Duc, & Thuc, (2020) discussed the green economy as a response to climate change, rising sea levels, and the global economic recession. Following the 2011 climate change conference in South Africa, which established a Green Climate

Fund, countries have focused on reducing greenhouse gas emissions and transitioning to low-carbon economies. The paper highlights the need for renewable energy sources, such as wind, solar, geothermal, and biomass, to meet global energy demands. It explores the opportunities for Vietnamese businesses in promoting renewable energy development and identifies key challenges hindering the exploitation of these resources in Vietnam.

Another study by (Taskin, Vardar, & Okan, 2020) uses multivariate panel data to investigate renewable energy usage, trade openness, and green economic growth in OECD nations from 1990–2015. Renewable energy usage and trade openness both boost green economic growth, but trade openness has a longer-term effect. Bidirectional causality between renewable energy and green economic growth fosters feedback. The findings urge governments to encourage renewable energy markets with laws and regulations that minimize environmental damage to achieve sustainable economic growth. The analysis of the criteria for balancing endeavors for green economic development between pollution reduction, efficiency, and growth reveals their connection to renewable energy through technological reliance. The findings of (Xie, Liu, Guan, & Wang, 2020)'s study revealed an inverse link in the form of the value of renewable energy benefits on green growth falling between 0.67% and 10.87% of total energy consumption. The emergence of new technology reinforces this relationship, while current advancements fail. Policies that encourage innovation, ecologically benign transformations, and reduced reliance on fossil fuels are critical. The function of financial regulation in attaining a sustainable green economy was examined in another study by (Cigu, Petrisor, Nută, Nută, & Bostan, 2020). It examines the literature on the value of regulation using a conventional method, in which a linear regression model covering pre-, during-, and post-crisis periods was created in order to analyze the effects of financial regulation in 25 EU nations (2000–2018). The findings demonstrated how sound financial regulation may support sustainable and growth-oriented green economies. Ye et al (2022) explored the impact of green finance (green credit, investment, and securities) and corporate social responsibility on renewable energy investment in the rising economy (1976-2020) using econometric measurement via the error correction model. The findings revealed strong positive connections between these parameters and renewable energy investment, providing policymakers with insights into green financing and sustainable energy in developing countries.

Using panel ARDL analysis (Younas, Shoukat, Awan, & Arslan, 2023) explore the impact of renewable energy, green innovations, employment, and technology on South Asia's Green Economy (GE) from 1972 to 2021. Green inventions, employment, and technology have limited impact owing to cost and awareness hurdles; however, renewable energy has a favorable effect on GE. Training, education, and awareness initiatives are among the policies that have been proposed to promote long-term economic expansion. (Gorji & Martek, 2023) Examined the problems of the impacts of renewable energy technologies on green growth in 20 developed and 20 developing countries from 2010 to 2021, utilizing the team's data estimators. The findings indicate varied contributions: solar, wind, and biomass energy facilitate growth in developed nations, whereas hydropower does not; in

developing nations, most sectors, excluding wind, also provide contributions. Moreover, effective policies promote innovation and sustainability. Nejad (2023) introduced the Green Economy Index and examined the significance of renewable energy in Egypt's green transformation. The primary findings indicate that renewable energy fosters the advancement of the green economy, but non-renewable energy exerts a detrimental impact. Augmented capital expenditure and employment enhance the green index. Furthermore, governmental policies ought to incentivize investment in renewable energy and engage corporations to propel the expansion of the green economy. To fight environmental challenges, the globe requires renewable energies. Furthermore, the involvement of vocational and university programs in training skilled people is critical to achieving a green workforce, as is the establishment of legislation to create jobs in the renewable energy sector (Karakul, 2016).

In their paper (Ashfaq, et al., 2024) focused on the renewable energy-green growth nexus in G-20 countries, demonstrating long-term cointegration, emissions persistence, and the need for effective policies that promote sustainability, green jobs, innovation, and climate change mitigation. A recent study by (Murshed, 2024) examined green growth, focusing on renewable energy transition, governance, and other factors. The results showed that renewable energy alone does not drive green growth without improved governance, which mediates the relationship. Urbanization, industrialization, trade, and financial development hinder green growth, while financial globalization has no effect. This investigation also highlights differences between lower-middle and upper-middle income countries and suggests tailored policies to promote green growth. Phan (2024) assessed the impact of clean energy, green bonds, and green economic progress on environmental, social, and cultural governance practices, as well as sustainable development goals in Asian economies from 2011 to 2020. The main findings illustrate that these factors are the primary determinants of environmental, social, governance, and sustainable development practices. The linkages remain stable when accounting for variables such as FDI and GDP, offering valuable insights for stakeholders and policymakers in the promotion of sustainable business practices. The existence of varied effects in terms of geography and resource utilization was proven by (Hwang & Diez, 2024)'s study on the influence of renewable energy transition on green economic growth in 14 Latin American nations (2003-2020). These effects may be categorized into five intermediary factors: capital investment, dependence on hydropower, per capita electricity consumption, human capital, and employment development. This research validates the complex characteristics of renewable energy transitions in enhancing green development.

While a growing body of literature has explored the relationship between renewable energy and the green economy at the global and regional levels, limited attention has been paid to this relationship in the Algerian context, particularly from a socio-economic perspective. Most current studies tend to focus on the environmental or technical dimensions, often ignoring the broader socio-economic implications of renewable energy adoption. Moreover, few studies use advanced econometric techniques that can capture the dynamic and asymmetric nature of this relationship over time. So far, no study has used DYNAMIC ARDL and KRLS models to analyse

how renewable energy can contribute to Algeria's transition towards a green economy, taking into account the country's unique structural, institutional and developmental characteristics. This study aims to bridge this gap by providing an accurate understanding of the socio-economic interaction between renewable energy and the green economy in Algeria.

THEORETICAL BACKGROUND

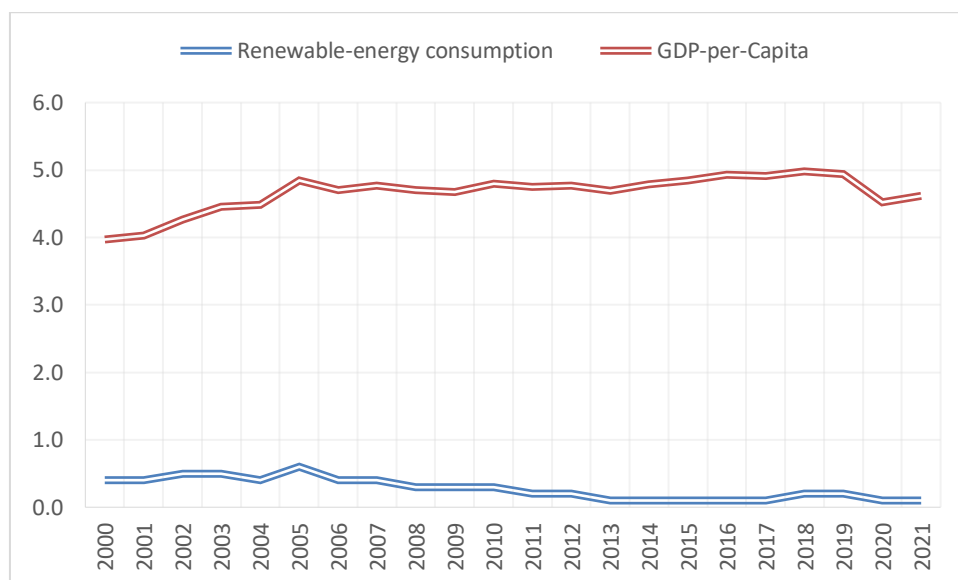
GREEN ECONOMY AND RENEWABLE ENERGY STATUS IN ALGERIA.

The concept of a global transition towards a green economy has emerged as a strategic response to growing environmental challenges, resource depletion, and socio-economic inequality. The green economy, in essence, promotes economic growth and reduces environmental risks and ecological scarcity, and this is considered one of the most important statements of the United Nations Environment Program for the year 2011. More than that, green economics emphasizes low-carbon development, efficient use of resources, social inclusion, and offering renewable energy as a cornerstone of sustainable economic transformation. Renewable energy technologies such as solar, wind, biomass, and hydropower, for example, have a very positive role not only in mitigating the effects of climate change, but also in stimulating job creation, energy security, and economic diversification, especially in resource-dependent countries such as Algeria.

In the framework of Algeria's hydrocarbon-dominated economy, the move to renewable energy is both a necessity and an opportunity. Algeria has significant solar potential, but green energy adoption is restricted owing to institutional, organizational, and financial impediments (Boudghene Stambouli, Khiat, Flazi, & Kitamura, 2012). In this section, we will discuss the theoretical foundations of two key variables related to the situation of the green economy and renewable energy paths in the Algerian economy. We will discuss per capita production based on the available statistics, and these variables are the proportion of renewable energy consumption each year from 2000 to 2021. Figure 01 analyzes the paths of Algeria's per capita output and the proportion of its energy consumption that originates from renewable sources.

Figure 1

Algeria renewable energy consumption (% of total energy consumption) and GDP per capita (thousand U.S. dollars) during 2000-2021.



Source: tradingeconomics.com (seen on 25/05/2025).

The use of renewable energy in Algeria has demonstrated a declining tendency from the year 2000 to the year 2021, which indicates that the country has not made significant progress in diversifying its energy portfolio. At the beginning of the twenty-first century, the percentage of total final energy consumption that was comprised of renewable energy was roughly 0.6%. This number, on the other hand, experienced a major decline after the year 2008 and has remained at values lower than 0.2% following the year 2010. Because of this impasse, Algeria's renewable energy infrastructure has made very limited progress, despite the fact that the world is moving toward more sustainable energy sources.

Algeria's gross domestic product (GDP) per capita exhibited a variety of trends over the same period. As a result of robust hydrocarbon exports and cheap oil prices, the gross domestic product (GDP) per capita increased consistently between the years 2000 and 2014. Nevertheless, the oil price fall that occurred after 2014 introduced an element of uncertainty into the economy, resulting in a significant shift in GDP per capita. Algeria's dependence on fossil fuels and its susceptibility to shocks from the international oil market were brought into sharper focus by the fact that this economic crisis occurred at the same time as the rise of renewable energy did not progress.

When the use of renewable energy is not considered in conjunction with the expansion of GDP, significant policy and structural deficiencies are revealed. It would appear that there was a failure to diversify the energy sector by spending only a small amount on renewable energy throughout times of economic expansion. Inadequate funding, outdated infrastructure, and weak regulatory frameworks that inhibit the expansion of renewable energy sources are some of the factors that have contributed to this situation.

THEORETICAL PILLARS OF THE NEXUS BETWEEN GREEN ECONOMY AND RENEWABLE ENERGY CONSUMPTION

Green investments in renewable energy, as viewed through the lens of internal growth theory, may be significant engines of innovation and technological advancement. Classical growth models, on the other hand, consider technological change external. Internal models propose that governmental policies and R&D spending have a direct impact on economic growth trends (Romer, Oct.1990). More than that, renewable energy sectors, especially in emerging economies like Algeria, represent great potential for knowledge spillovers, green job creation, and industrial diversification. Because of the above, it has a great role in promoting sustainable growth. Thus, the transition to a green economy is not only an environmental necessity, but also a strategic tool for economic progress, especially in countries seeking to reduce dependence on limited natural resources such as oil and gas (Bibri, 2018).

Renewable energy, according to the United Nations Environment Program's (2011) green economy model, is not simply a technology, but also a catalyst for systemic transformation that improves resource efficiency, lowers carbon emissions, and promotes equitable economic growth (UNEP, 2011). The connection between the green economy and renewable energy is rooted in the larger context of sustainable development theory, which emphasizes the importance of balancing economic growth, environmental protection, and social justice. Renewable energy also plays a crucial part in attaining this balance by providing clean and sustainable alternatives to fossil fuels, therefore lowering environmental degradation and helping to long-term economic stability (Brundtland Report, 1987).

Furthermore, the Environmental Kuznets Curve (EKC) hypothesis sheds light on the dynamic relationship between income levels, environmental deterioration, and green energy uptake. According to the Environmental Knowledge Center, economic expansion is initially associated with a rise in environmental pollutants. However, beyond a certain wealth level, societies begin to invest in cleaner environmental technology and policies, resulting in better environmental outcomes (Grossman and Kruger, 1995). That concept may be applied to Algeria's economy. Because they believe that economic expansion, along with deliberate political interventions and the deployment of renewable energy, may eventually lead to the decoupling of growth from environmental degradation. As a result, the theoretical underpinning for this connection underlines the importance of integrated policy frameworks that support green economic goals while also accelerating the deployment of renewable energy technology.

Socio-Economic Implications

The shift to renewable energy promotes the establishment of green jobs as well as social integration by offering opportunities based on skill level and geographic location. Furthermore, green occupations like solar panel installation and energy efficiency services boost local economies and eliminate inequities between urban and

rural regions (La Camera & Ryder, 2021). Furthermore, investment in human capital and vocational training related to clean technology fosters broad economic involvement. These dynamics also reflect an equitable transition framework, ensuring that they do not exacerbate social inequities and, instead, support equitable development (UNDP, 2022).

From the lens of Income Redistribution and Energy Poverty Reduction, Renewable energy deployment is critical for eliminating energy poverty and fostering wealth redistribution, particularly in low-income and neglected communities. Distributed solar energy systems and off-grid solutions cut home energy expenses, enhance living conditions, and free up revenue for other essential requirements (Pachauri, et al., May 2013). Renewable energy programs serve as tools for economic empowerment and long-term poverty alleviation by democratizing energy access and supporting small-scale entrepreneurship.

Model specification

Model Description

This section lays out the methodology of the study, including the steps taken to collect, analyze, and interpret data in a way that guarantees the reliability and validity of the study's findings. We aim to provide a strong basis for our findings by meticulously selecting and employing these strategies.

Furthermore, we shall assess the impact of GDPPERCAPITA on REC (renewable energy consumption) in Algeria. At its heart, the standard process is based on three primary variables that use dynamic ARDL, a novel standard method that lets us apply various shocks to independent variables and monitor their evolution through simulation models given and created by the "Dynardl program" developed by (Philips, January 2018); (Jordan & Philips, 2018). This method accurately depicts the REC path in the event of GDP per capita shocks to the economy. Table No. 01 shows the various variables, their sources, and nature

Table 1

Variables characteristics

variables	Designation	Type	Data type	source
GDPPERCAPITA	Annual per capita GDP according to the US dollar	Independent (Regressor)	Annual	https://tradingeconomics.com
REC	The ratio of consumption of renewable energies to total energy consumption	Dependent	Annual	https://tradingeconomics.com

Source: made by authors.

The ARDL model in error correction form could be written as follows: (Jordan & Philips, 2018, p. 904)

$$\Delta y_t = \alpha_0 + \theta_0 y_{t-1} + \theta_0 x_{1,t-1} + \dots + \theta_k x_{k,t-1} + \sum_{i=1}^q \alpha_i \Delta y_{t-1} + \sum_{j=0}^{q1} \beta_{1j} \Delta x_{1,t-j} + \dots + \sum_{j=0}^{qk} \beta_{kj} \Delta x_{k,t-j} + \epsilon_t \dots (1)$$

in which the change of the dependent variable is associated with a constant, its value at t-1 (which is presented in levels), the values of all regressors at t-1 (which is also presented in levels), and the first differences between the dependent variable and the regressors up to p and q_k lags, respectively.

y_t : Dependent variable.

x_k : Regressors (independent variables).

α_0 : Constant.

The following is a reformulation of the equation for the study model that takes into account the factors included in the study:

$$\begin{aligned} \Delta REC_t = & \alpha_0 + \theta_0 REC_{t-1} + \theta_0 GDPPERCAPITA_{1,t-1} + \dots \\ & + \theta_k GDPPERCAPITA_{k,t-1} + \sum_{i=1}^q \alpha_i \Delta REC_{t-1} \\ & + \sum_{j=0}^{q1} \beta_{1j} \Delta GDPPERCAPITA + \dots \\ & + \sum_{j=0}^{qk} \beta_{kj} \Delta x GDPPERCAPITA_{k,t-j} + \epsilon_t \dots (2) \end{aligned}$$

In order to simulate the dynamic link between the percentage of renewable energy consumption in Algeria and the GDP per capita as an indicator of an individual's potential to contribute to the achievement of a green economy, we will explore various tests and models using equation No. 02, which gives us the opportunity to study the dynamic relationship.

The descriptive data analysis is shown in Table 2:

Table 2
Data descriptive analysis

Variables	REC	GDPPERCAPITA
Mean	0.2727	4.3822
Median	0.25	4.46
Maximum	0.6	4.83
Minimum	0.1	3.57
Std. Dev.	0.1579	0.3732

Skewness	0.3873	-0.8644
Kurtosis	1.9628	2.7792
Jarque-Bera	1.5360	2.7844
Probability	0.4639	0.2485
CV	0.5790	0.0851
Sum	5.9999	96.4099
Sum Sq. Dev.	0.5236	2.9257
Observations	22	22

Source: calculated by authors.

Data indicate an average renewable energy consumption (REC) of 0.2727, accompanied by a standard deviation of 0.1579 and a coefficient of variation of 0.579. This trend indicates significant annual volatility. The mean GDP per capita is 4.3822 (thousands of USD), accompanied by a standard deviation of 0.3732 and a coefficient of variation of 0.085. This aligns with Algeria's relatively stable per capita income trajectory during this era. The distribution of REC is somewhat right-skewed (skewness 0.3873) and slightly platykurtic (kurtosis 1.9628), indicating a prevalence of years with moderate to high uptake over those with dramatic spikes. The Jarque–Bera statistic of 1.536 with a p-value of 0.4639 fails to reject normalcy, hence endorsing conventional inference in regressions utilizing REC. The GDP per capita distribution exhibits left skewness (skewness -0.8644), with a kurtosis of 2.7792 and a Jarque–Bera statistic of 2.7844 ($p=0.2485$), indicating a general compatibility with normality. Economically, this left tail corresponds to the oil-cycle dynamics from the mid-2000s to 2014 and subsequent downturns that resulted in several years falling below the median of 4.46, despite a maximum of 4.83 and a minimum of 3.57, reflecting Algeria's hydrocarbon-related income fluctuations as documented in the World Bank/TE series. The data indicates that REC increased but remained a minor, fluctuating proportion (from 0.1 to 0.6), but living standards exhibited greater stability. From a policy perspective, the relative stability of GDP per capita in comparison to REC is noteworthy. Indicating that REC shocks likely do not significantly affect overall well-being immediately. Nevertheless, expanding renewable energy sources could assist in decoupling revenue from the fluctuations of oil prices, which are crucial for Algeria's economic development.

DYNAMIC ARDL steps and tests

This model requires the dependent variable to be at Level I (1) and the independent variables to be no more stable than Level 1 (I (0) or I (1)). A series' sequence of integration can be determined by unit root tests like Kwiatkowski-Phillips-Schmidt-Shin, Elliott-Lothenberg-Stock, Dickey-Fuller, and Phillips-Perron. Cointegration requires a non-stationary dependent variable (Jordan & Philips, 2018, p. 903). The results of the unit root tests (see Table 3) show that the independent variable REC is stable of degree I(0) (PP test p-value 0.01; DF test 0.02) and the dependent variable is independent of the first degree I(1) (PP test p-value 0.82; DF test 0.29). Therefore, we can apply dynamic simulations to the ARDL model.

Table 3

Phillips-Perron and dicky-fuller tests for unit root

Phillips perron test for unit root					Number of Obs= 21									
Variable : ln-GDPPERCAPITA Newey-West lags = 3														
H0 : Random walk without drift, d = 0														
Critical values			Dickey-Fuller											
1% critical value 5% critical value 10% critical value			z (rho) test statistic =-3.366				z (t) test statistic = - 3.311							
			- 17.200				- 3.750							
			- 12.500				- 3.000							
			- 10.200				- 2.630							
DF-GLS test for unit root										Number of Obs = 17				
Variable : ln-GDPPERCAPITA														
Lag selection : maximum 4 lags														
Lags		DF-GLS tau	Critical values											
			1%		5%		10%							
4		-0.837	- 3.770		- 3.043		- 2.654							
3		-1.250	- 3.770		- 3.188		- 2.805							
2		-1.179	- 3.770		- 3.349		- 2.963							
1		-0.843	-3.770		-3.498		-3.103							
Opt Lag (Ng-Perron seq t) =0, option max lag (0)														
Min SIC =- 7.23453 at lag 1 with RMSE = 0.0227333														
Min MAIC =- 7.309366 at lag 1 with RMSE = 0.0227333														
Phillips-Perron test for unit root					Number of Obs= 21									
Variable : ln-REC					Newey-West lags = 3									
H0: Random walk without drift, d = 0														
Critical values			Dickey-Fuller											
1% critical value 5% critical value 10% critical value			z (rho) test statistic =-1.677				z (t) test statistic = - 0.778							
			- 17.200				- 3.750							
			- 12.500				- 3.000							
			- 10.200				- 2.630							
DF-GLS test for unit root					Number of Obs= 17									
Variable : ln-REC														
Lag selection : maximum 4 lags														
Lags		DF-GLS tau	Critical values											
			1%		5%		10%							
4		-2.340	- 3.770		- 3.043		- 2.654							
3		-2.213	- 3.770		- 3.188		- 2.805							
2		-1.896	- 3.770		- 3.349		- 2.963							
1		-1.871	-3.770		-3.489		-3.103							
Opt Lag (Ng-Perron seq t) =0, option max lag (0)														
Min SIC =- 2.107241 at lag 1 with RMSE = 0.2951474														
Min MAIC =- 1.727981 at lag 1 with RMSE = 0.2951474														

Source: calculated by authors using stata17.

Attributes of the ARDL model:

Based on the data presented in Table 4, the results from the P-tests indicate that the p-value is less than the critical values at the 1%, 5%, and 10% significance levels. Consequently, this suggests that the model demonstrates statistical quality. Therefore, there are no issues related to cointegration in the short-run. More than that, Table 05 and Table 06 indicate the power of the nexus between the two variables; this is where it reached 30% in the model with a constant and 32% in the model with absence of the constant.

Table 4

Pesaran, Shin and Smith (2001) cointegration test.

PESARAN, SHIN AND SMITH (2001) cointegration test		
Obs : 21		
No. Regressors (K) : 1		
Case : 3		
F-test		
	I (0)	I (1)
10% critical value	4.290	5.080
5% critical value	5.395	6.350
1% critical value	8.170	9.285
F-stat =	3.570	

Source: calculated by authors using Stata 17.

DYNAMIC ARDL simulations

In our study, we run a simulation to assess the impacts of GDP per capita changes on renewable energy consumption in Algeria using DYNAMIC ARDL, analyzing short, medium, and long-term shocks (20, 50, 80 years) within a 100-year range. This study aims to examine the compatibility pattern between the two variables over a 100-year simulation range.

Model01:

The initial model articulates the regression outlined in tables5 and 6. This model will involve the creation of negative shocks (- 1) for the independent variable. We will use a simulation capacity of 100 periods (results shown in table06) and implement shocks at various intervals (20, 50, and 80). The two independent variables and the dependent variable are lagged by one period, and the first differences of the independent variables are presented. The subsequent equation represents the model:

$$\Delta \ln - REC_t = \ln_REC_{t-1} + \Delta \ln_GDP_PERCAPITA_t + \ln_GDP_PERCAPITA_{t-1} \dots (3)$$

Table 5

Regression test with constant

Source	SS	df	MS	Number of Obs = 21	
Model	0.6180	3	0.2060	F (3,18) =	2.49
Residual	1.4073	17	0.0827	Prob > F =	0.0953
Total	2.0253	20	0.1012	R-squared =	0.3052
				Adj R-squared =	0.1825
				Root MSE =	0.2877
dlN-REC	Coefficient	Std.err	T	P> t	[95%conf, interval]

ln- REC						
ln- GDPPERCAPITA	L1.	-0.2653	3.3863	-1.74	0.099	-0.58
	D1.	5.3636	3.3863	1.58	0.132	0.055
	L1.	-0.9266	1.2625	-0.73	0.473	-1.78
	-cons	0.8548	1.7330	0.49	0.628	12.50
						-3.59
						1.73
						-2.80
						4.51
With constant.						

Source: calculated by authors using Stata 17.

Table 6
Regression test without constant

Source	SS	df	MS	Number of Obs	=	21
Model	0.6894	3	0.2298	F (3.18)	=	2.90
Residual	1.4274	18	0.0793	Prob > F	=	0.0635
				R-squared	=	0.3257
Total	2.1169	21	0.1008	Adj R-squared	=	0.2133
				Root MSE	=	0.2816
dln-REC	Coefficient	Std.err	t	P> t	[95%conf, interval]	
ln- REC	L1.	-0.2171	0.1141	-1.90	0.073	-0.45 -0.022
ln- GDPPERCAPITA	D1.	6.3701	2.6451	2.41	0.027	0.81 11.92
	L1.	-0.3072	0.1271	-2.42	0.027	-0.57 -
						0.04
No constant.						

Source: calculated by authors using Stata 17.

By applying a simulation (see Figure 02), we can track the trend of the dependent variable behavior at specific points. Shaded lines show the 75%, 90%, and 95% confidence intervals, from darkest to lightest; dots show the average predicted values.

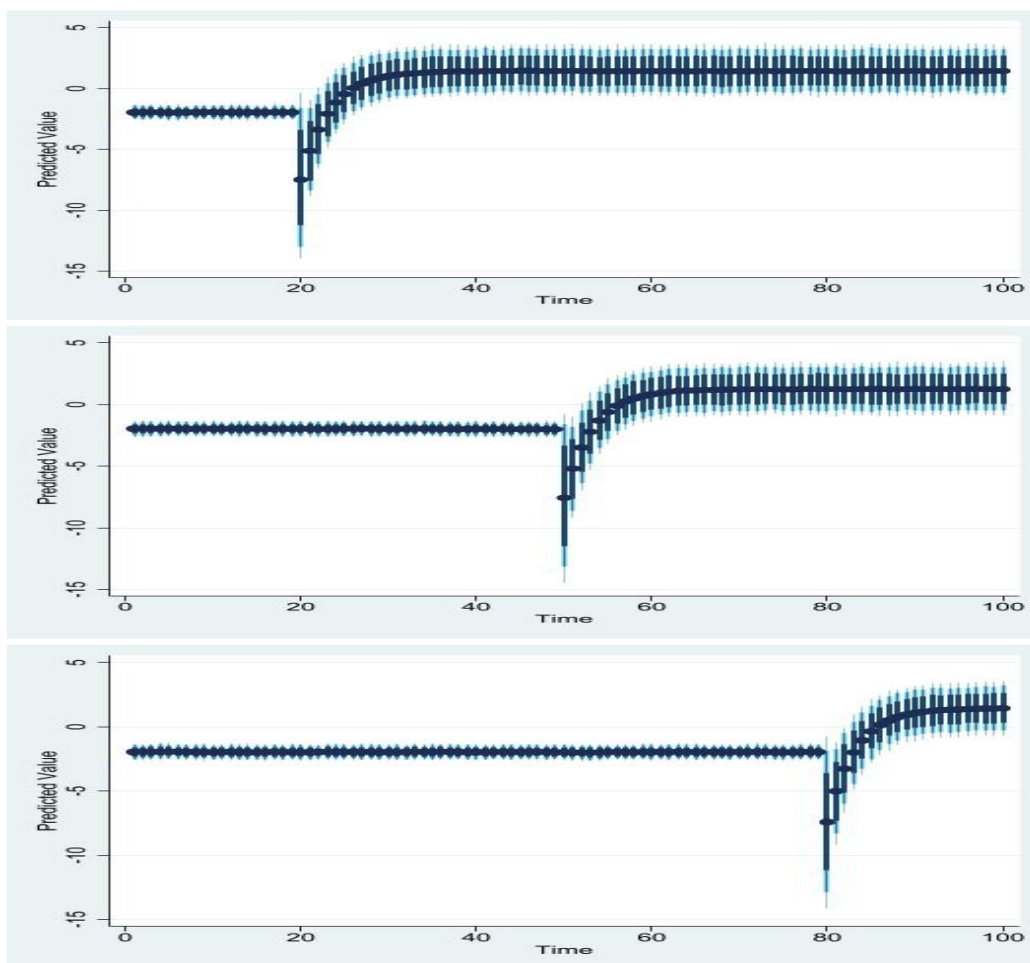
Table 7
DYNAMIC ARDL simulation 1000 real change

Source	SS	Df	MS	Number of Obs	=	17
Model	0.6180	3	0.2060	F(3.17)	=	2.49
Residual	1.4073	17	0.0827	Prob> F=		0.0953
				R-squared	=	0.3052
Total	2.0253	20	0.1012	Adj R-squared	=	0.1825
				Root MSE	=	0.2877
dln-REC	Coefficient	Std.err	t	P> t	[95%conf, interval]	
L1-ln- REC	-0.2653	0.1522	-1.74	0.099	-0.58	-
D-ln- GDPPERCAPITA	5.3636	3.3863	1.58	0.132	0.05	
L1- ln- GDPPERCAPITA	-0.9266	1.2625	-0.73	0.473	-1.78	
-cons	0.8548	1.7330	0.49	0.628	12.58	
					-3.59	
					1.73	
					-2.89	
					4.51	

(1.000 real changes made) ; dependent variable to be run in differences

Source: calculated by authors using stata17.

Figure 2: Shocks (-1) on *GDPPERCAPITA* “periods 20; 50; 80” 1 lag for each variable.



Source: stata17 outputs.

Model02:

Various scenarios that can be applied by Dynardl can be utilized to evaluate economic results. The model will be adjusted for scenarios that are more complex in this second model. So, it requires more dynamics to be developed and simulated. As shown in Figure 03, this model's characteristics indicate that the dependent variable REC appears as a lagged first difference alongside its lagged-level form at $t-1$. *GDPPERCAPITA* now manifests at the first, second, and third lags rather than contemporaneously. Equation (4) delineates model No. 02.

$$\Delta \ln_REC_t = \ln_REC_{t-1} + \Delta \ln_REC_{t-1} + \ln_GDPPERCAPITA_{t-1} + \ln_GDPPERCAPITA_{t-2} + \ln_GDPPERCAPITA_{t-3} \dots (4)$$

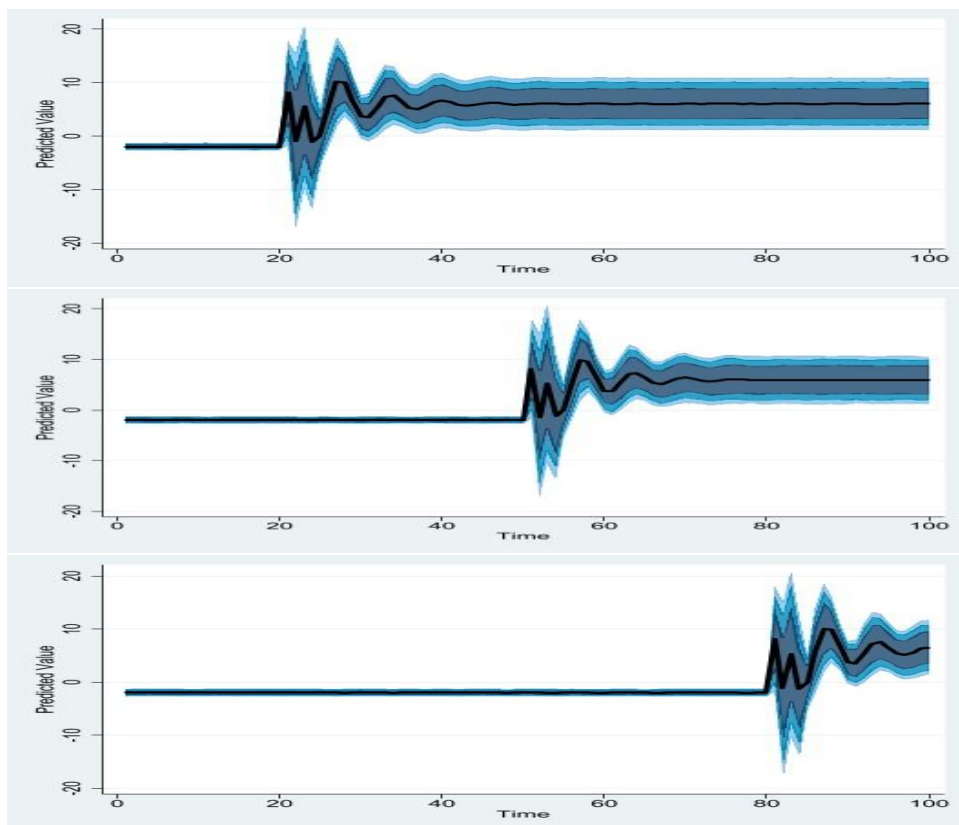
Table 8
DYNAMIC ARDL simulation 5000 real change

Source	SS	Df	MS	Number of Obs =	18
Model	1.2185	7	0.1740	F(7.9) =	2.28
Residual	0.6856	9	0.0761	Prob >F =	0.1235
				R-squared =	0.6399
				Adj R-squared =	0.3599
				Root MSE =	0.2760
dln-REC	Coefficient	Std.err	t	P> t	[95%conf,interval]
L1-ln- REC	-0.8145	0.3126	-2.61	0.028	-1.52 -0.10
L1D-ln- REC	0.7178	0.3916	1.83	0.100	-0.16 1.60
L1- ln- GDPPERCAPITA	-10.1039	4.9532	-2.04	0.072	-21.30 1.10
L2- ln- GDPPERCAPITA	18.3405	9.0012	2.04	0.072	-2.02 38.70
L2- ln- GDPPERCAPITA	-22.1665	10.7130	-2.07	0.068	-46.40 2.06
L3- ln- GDPPERCAPITA	8.2781	5.7044	1.45	0.181	-4.62 21.18
-cons					

(5.000 real changes made) ; dependent variable to be run in differences

Source: calculated by authors using stata17.

Figure 3: Shocks (-1) on GDPPERCAPITA (5lags) “periods 20; 50; 80” 1 lag for dependent variable REC.



Source: Stata 17 outputs.

5-Applying Kernel-Based Regularized Least Squares (KRLS): The application of KRLS, a machine learning technique introduced by Hainmueller & Hazlett(2014), will reduce parametric constraints and uncover nonlinearities, interactions, and heterogeneous effects. This may offer additional validation and improved comprehension of causal relationships.

Table 9

Krls iteration

Iteration	Looloss
1	2.09282
2	1.781646
3	1.508485
4	1.304857
5	1.178082
6	1.115514
7	1.103107
8	1.100933

Source: Computed by authors

The KRLS iteration results (see table 9) show a consistent and substantial decrease in Leave-One-Out loss (Looloss) from 2.09 in the first iteration to 1.10 by the eighth iteration, indicating that the model is effectively minimizing prediction error and converging well. In addition, most of the improvement occurs in the first few iterations, with loss reductions becoming marginal after the sixth iteration. All demonstrating that the model has reached a stable solution and further iterations would yield little additional benefit. This pattern suggests successful optimization and good generalization capability.

Table 10

krls summary

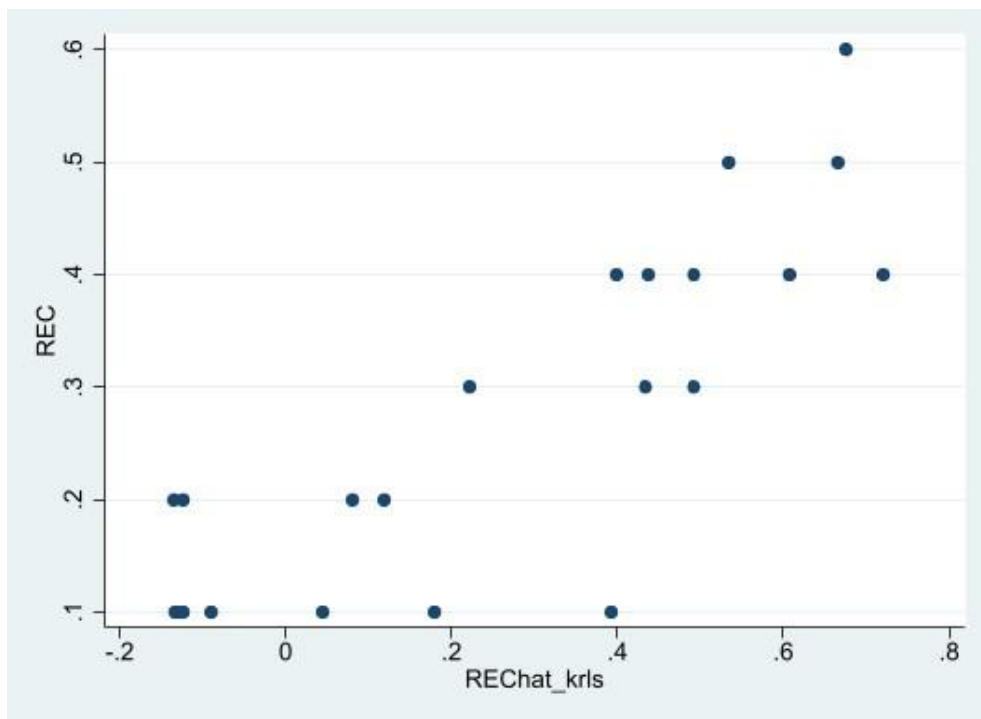
Pointwise Derivatives					Number of Obs	22	
					Lambda	0.5305	
					Tolerance	0.022	
					Sigma	1	
					Eff. Df	4.124	
					R-square	0.775	
					Looloss	1.097	
REC	Avg	SE	t	P> t 	P25	P50	P75
GDPPERCAPITA	-0.2873	0.0488	-5.880	0.00	-0.7310	-0.2657	0.1493

Source: Computed by authors

The KRLS summary output in Table 09 indicates a strong and statistically significant negative relationship between GDP per capita and REC, with an average marginal

effect of -0.2873 (SE = 0.0488, $t = -5.88$, $p < 0.01$), meaning that, on average, a one-unit increase in GDP per capita is associated with a 0.29 unit decrease in REC, holding other variables constant. The 25th, 50th, and 75th percentiles of the marginal effects (-0.7310, -0.2657, and 0.1493, respectively) reveal some heterogeneity in the effect across observations, though the negative association predominates. Model fit is high, with an R-squared of 0.775, indicating that approximately 78% of the variance in REC is explained by the model, and the low Looloss (1.097) further supports good predictive performance. Overall, the results are robust and suggest a meaningful, reliably estimated impact of GDP per capita on REC in the sample.

Figure 4: *KRLS Scatter Plot Results.*



Source: Stata 17 outputs.

The scatter plot displays the relationship between the observed values of REC (on the y-axis) and the predicted values from the KRLS model (REChat_krls, on the x-axis). This plot is useful for diagnosing model fit. If the points were randomly scattered with no pattern, it would suggest poor predictive power. The observed positive trend supports the model's validity.

Figure 4 reveals the Principal Insights of the krls scatter are as follows:

- ✓ **Positive Association:** The anticipated and observed values are usually related in a good way. The observed values of REC also tend to go up when the anticipated values (REChat_krls) go up. This means that the KRLS model is picking up on the data's rising trend.

- ✓ **Spread and Fit:** The data points are not exactly aligned along a 45-degree line, which would signify flawless prediction; nonetheless, they exhibit a tendency to cluster, indicating that greater forecasts correlate with higher observed values.
- ✓ **Potential Outliers:** There are certain points where the actual value of REC is higher than the anticipated value, and there are other points where the opposite is true. This shows that the model's predictions and the real data don't always match up, which is normal in real life.
- ✓ **Range of Predictions:** The projected values (REChat_krls) span from just below zero to around 0.8, but the observed REC values span from approximately 0.1 to 0.6, with a particularly high value at 0.6.

RESULTS AND DISCUSSION

Dynardl model results

A simulation was conducted to analyze the dynamics of renewable energy consumption in Algeria, focusing specifically on REC and GDPPERCAPITA. The findings suggest that renewable energy consumption (REC) is negatively affected by the shock impacting GDPPERCAPITA in the initial model. The simulation initially indicated a reduction in renewable energy consumption (REC) (refer to Figure 1). The shape of the shock curve suggests a high level of confidence in the field. The anticipated values of renewable energy consumption stabilize within a defined range. Additionally, the correlation strength between the two variables is 30.52%, with a correlation coefficient of -0.26% at the initial divergence, which subsequently returns to 5.36% after this divergence. A 75% confidence interval can be established. Refer to Table 05.

The first model's output agrees with the second model's outcomes, as shown by the second model's simulations. This model seems more realistic since it incorporates the idea of five lags of the independent variable. That is to say, the effects of the GDP per capita shock will take some time to materialize. The reality that people can always fall back on their savings when times get tough. This is why the second model's explanation of individual behavior's actuality helps to explain its realism.

After performing 5000simulations (see Table 8) of the GDPPERCAPITA shocks in the framework of 3 lags, the correlation strength between the two variables in this model became equal to 63.99%. The correlation coefficients between the two variables also became larger than the previous one, reaching -10.10 at the first slowdown period, then 18.34% at the 02 period, and then -22.16 at the 3rd slowdown period. Then it becomes 19.16% in period 04, to decrease slightly at period 05 with a value of -11.76%. In the end, the final impact on the consumption of renewable energies remained negative with a value of -22.1665% in the forecast values of the second model.

Krls model results

- ✓ **Model Performance:** The KRLS model seems effective as it illustrates the general trend of the relationship between the independent variables and

REC. However, the dispersion indicates that there remains unexplained variance, since not all points are proximate to a singular line.

- ✓ **Nonlinearity and Flexibility:** KRLS is designed to manage nonlinear and intricate interactions. The distribution of the points indicates that the model may be reflecting some subtleties; yet, there is potential for improvement, either via the incorporation of further predictors or by further optimization of the model.

CONCLUSIONS

This work combines the KRLS model with dynamic ARDL simulations to not only validate the strength of the predicted linkages, but also to provide deeper policy-relevant insights into how economic development and renewable energy use affect each other in Algeria in the short-run. This hybrid method makes sure that both linear and nonlinear patterns are included, which gives a complete and more dependable basis for future choices on energy and economic policies. The main findings reveal: Negative shocks in per capita GDP in Algeria have an immediate negative impact, which then influences individuals' behavior, leading them to increase their consumption of renewable energy.

The reality reflected by the second model further clarifies that individuals, in light of the shocks affecting their share of the GDP in Algeria, will behave in a manner that reflects their interest in staying towards the consumption of non-renewable energy, which poses obstacles to supporting the green economy in Algeria. Algeria has to make use of its great renewable energy potential, especially solar and wind power, to overcome these obstacles. With over 2,500 hours of sunshine annually, the country finds solar energy to be a viable option for both small and major projects. Encouraging private and international investment depends on policy changes, including feed-in tariffs, tax benefits, and streamlined licensing processes. Moreover, Algeria might use climate funds and create international collaboration to address technological and budgetary limitations.

Algeria is poised to gain from the integration of its renewable energy into regional and worldwide markets. Closeness to Europe presents a chance to export renewable energy to the EU, which is progressively pursuing sustainable energy sources. Concurrently, domestic public awareness initiatives and workforce development programs could enhance acceptance and capacity building within renewable energy sectors.

In conclusion, while Algeria has ambitious renewable energy goals, there exists a significant gap between policy formulation and implementation. Algeria can transition to a more diverse and sustainable energy future by prioritizing investments, strengthening legislation, and engaging in international collaboration, thereby reducing its dependence on hydrocarbons and enhancing economic resilience. More specifically:

- ✓ Introducing the benefits resulting from the use of renewable energies, especially through various audio-visual means and advertising

- ✓ Incorporate renewable energy into national resilience and economic planning.
- ✓ Introduce targeted incentives and reform energy subsidies.
- ✓ Establish a National Green Investment and Innovation Fund.
- ✓ Simplify Regulatory Systems for Renewable Deployment.
- ✓ Increase both local and international green energy cooperation.
- ✓ Start a National Awareness & Skills Development Program.
- ✓

Limitations of the study:

In the framework of our study, we were unable to obtain a larger sample of data on the variables. But this did not prevent us from applying the DYNAMIC ARDL approach, which is considered a sophisticated measurement method.

Future research recommendations:

For future research, it is possible to apply study variables with larger samples that may add to our results and provide a larger analysis.

Declaration of competing interests:

The authors declare that any known competing financial interests or personal relationships could have influenced none of the work reported in this study.

Contribution of authors:

Each author has made an equal contribution to the research planning, idea or design of studies, data gathering and computation, and paper writing. The final manuscript was read and approved by every author.

Funding:

No funding.

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REZIME

Cilj istraživanja jeste da ispita dinamički odnos između ekonomskog rasta i potrošnje obnovljive energije, kao i da utvrdi na koji način promene u ekonomskim pokazateljima utiču na obrasce potrošnje energije u zemlji. Posebna pažnja posvećena je promenama u ponašanju potrošača i društvenim preferencijama u pogledu korišćenja obnovljivih i neobnovljivih izvora energije, kako bi se obezbedila pouzdana osnova za kreiranje efikasnijih javnih politika u oblasti energetske tranzicije. Empirijska analiza zasniva se na podacima za period od 2000. do 2021. godine, pri čemu su za ispitivanje kratkoročnih i dugoročnih odnosa primenjeni dinamički autoregresivni model sa distribuiranim vremenskim docnjama (Dynamic ARDL) i metoda Kernel Regularized Least Squares (KRLS). Analizirana je povezanost između bruto domaćeg proizvoda (BDP) po stanovniku i potrošnje obnovljive energije izražene kao udeo u ukupnoj potrošnji energije. Primena ova dva metodološka pristupa omogućila je detaljnije sagledavanje složenih i nelinearnih odnosa između ekonomskog razvoja i energetske potrošnje. Rezultati istraživanja pokazuju da rast BDP-a po stanovniku u kratkom roku negativno utiče na potrošnju obnovljive energije. Povećanje dohotka stanovništva povezano je sa većom potrošnjom energije iz fosilnih goriva, što ukazuje na to da ekonomski rast sam po sebi ne podstiče prelazak na održivije izvore energije. Pored ekonomskih podsticaja i regulatornih mera, značajnu ulogu mogu imati informativne i edukativne kampanje, posebno putem audio-vizuelnih medija, digitalnih platformi i drugih oblika javne komunikacije, koje bi povećale svest građana o ekonomskim, ekološkim i društvenim koristima obnovljive energije. Takve mere mogle bi doprineti smanjenju zavisnosti Alžira od fosilnih goriva, povećanju investicija u sektor obnovljivih izvora energije i ubrzanju tranzicije ka održivijem i otpornijem modelu ekonomskog razvoja.