International Journal of Business & Economic Studies
Year: 2024, Vol: 6, No: 2, pp.90-109
https://doi.org/10.54821/uiecd.1474631

Forecasting the Role of Renewable Energy on Algeria's Economic Stability: ARIMAX Model

Cezayir'in Ekonomik İstikrarı Üzerine Yenilenebilir Enerjinin Rolünün Tahmini: ARIMAX Model

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Received : 27.04.2024
Revised : 24.06.2024
Accepted : 25.06.2024
Type of Article : Research

Keywords:
Algeria,
ARIMAX Model,
Economic Stability,
Renewable Energy
Jel Codes:
C32 O44 Q43

ABSTRACT

This study investigates the impact of integrating renewable energy sources on Algeria's economic stability by 2030. Given Algeria's heavy reliance on fossil fuels, which constitutes 95% of its export revenues, the nation faces significant economic vulnerabilities due to global oil price fluctuations. Utilizing Python 3.12.3 to implement the ARIMAX model, this research analyzes economic data from 1970 to 2022 to forecast GDP growth, considering variables such as inflation, crude oil prices, and the share of renewable energy in the total primary energy supply. The findings suggest that incorporating renewable energy could enhance Algeria's economic resilience, potentially contributing an additional 2% to GDP by 2030. This study underscores the critical need for strategic investments in renewable energy, emphasizing that this shift is not just an environmental imperative but a cornerstone for ensuring sustainable development and long-term economic stability.

Anahtar Kelimeler:
Cezayir,
ARIMAX Modeli,
Ekonomik İstikrar,
Yenilenebilir Enerji
Jel Kodları:
C32 O44 Q43

ÖZET

Bu çalışma, yenilenebilir enerji kaynaklarının entegrasyonunun 2030 yılına kadar Cezayir'in ekonomik istikrarı üzerindeki etkisini araştırmaktadır. Fosil yakıtlara olan yoğun bağımlılığı nedeniyle, Cezayir'in ihracat gelirlerinin %95'ini oluşturmakta ve küresel petrol fiyatlarındaki dalgalanmalara karşı önemli ekonomik kırılganlıklarla karşı karşıya kalmaktadır. Python 3.12.3 kullanarak ARIMAX modelini uygulayan bu araştırma, 1970'ten 2022'ye kadar olan ekonomik verileri analiz ederek enflasyon, ham petrol fiyatları ve toplam birincil enerji arzındaki yenilenebilir enerji payı gibi değişkenleri dikkate alarak GSYİH büyümesini tahmin etmektedir. Bulgular, yenilenebilir enerjinin entegrasyonunun Cezayir'in ekonomik direncini artırabileceğini ve 2030 yılına kadar GSYİH'ye ek olarak %2 katkıda bulunabileceğini göstermektedir. Bu çalışma, yenilenebilir enerjiye yönelik stratejik yatırımların gerekliliğini vurgulayarak, bu geçişin sadece çevresel bir zorunluluk değil, aynı zamanda sürdürülebilir kalkınma ve uzun vadeli ekonomik istikrarın sağlanması için bir temel taşı olduğunu belirtmektedir.

Zemri, B. E. (2024). Forecasting the role of renewable energy on Algeria's economic stability: ARIMAX model. *International Journal of Business and Economic Studies*, 6(2), 90-109, Doi: https://doi.org/10.54821/uiecd.1474631

1. INTRODUCTION

Energy is not merely a commodity; it is the lifeblood of modern economies, shaping the contours of global development and economic stability. As nations strive for growth in the face of rapid industrial expansion, the global appetite for energy has surged. This demand, heavily skewed towards fossil fuels, has seen an inexorable rise. In 2023, fossil fuels accounted for approximately 82% of the world's primary energy consumption, with oil and natural gas being the dominant sources (Yi et al., 2023). This relentless pursuit of traditional energy has precipitated a trio of crises: escalating climate change and the depletion of natural resources (Özmen & Balı, 2024). It is a recognized inevitability that fossil fuels will peak, compelling a global pivot towards renewable energy to safeguard resources and temper climate impacts. Thus, in the last few years there has been a growing interest in diversifying energy portfolios to include renewable sources due to their potential to mitigate the volatility of fossil fuel markets.

Today, Algeria stands at a critical juncture. Predominantly reliant on non-renewable resources, the nation faces profound environmental, economic, and societal challenges—a scenario exacerbated by its heavy dependency on the volatile oil market. As of 2023, oil and gas exports account for approximately 95% of Algeria's total export revenues (Kurt & Bayram, 2024), underscoring a stark dependence on fossil fuel incineration for economic vitality. This linkage is evident as the hydrocarbon sector represents about 20% of Algeria's GDP and over 60% of budget revenues (Rey & Hazem, 2020; Camporeale et al., 2021), making the national economy highly susceptible to global oil price fluctuations. For example, the 2014 collapse in oil prices from over $100 per barrel to below $50 dramatically reduced state revenues (Stocker et al., 2018; Patidar et al., 2024), leading to economic contractions and social unrest. The country's external debt ratio and unemployment rates are also closely tied to these fluctuations. When oil prices are high, Algeria experiences a surge in foreign exchange reserves and reduced unemployment, but the reverse is true when prices decline (Bouamra et al., 2023). In response to these vulnerabilities, Algeria is increasingly gravitating towards renewable energy sources like solar, wind, and hydropower. This transition also aligns with global energy trends, which could significantly contribute to both national energy needs and potential exports in renewable energy. Based on this context, the study problem can be formulated as follows: What are the implications of integrating renewable energy in Algeria on its economic stability by 2030?

While considerable research has been conducted on the broad economic impacts of renewable energy, there remains a conspicuous gap in studies specifically analyzing the effects of renewable energy integration on the economic stability of oil-dependent economies such as Algeria. Furthermore, existing studies often lack comprehensive model-based analyses that forecast the medium-term economic outcomes of transitioning towards renewable energy using sophisticated methodologies like the ARIMAX model. The core hypothesis posits that Algeria's economic fluctuations are intricately tied to the global oil and gas markets, making it vulnerable to external economic shocks. This research proposes that a strategic embrace of renewable energy could significantly bolster Algeria's economic resilience. Utilizing the ARIMAX model, this study will dissect the impacts of renewable energy deployment on economic parameters from 1970 to 2022. This comprehensive analysis will guide strategic policy formulations aimed at fostering sustainable development, ensuring energy security, and nurturing long-term economic resilience in Algeria.

The significance and urgency of this study arise from a conspicuous gap in current research: While many studies have highlighted the general economic impacts of renewable energy, few have specifically analyzed the intersection of renewable energy deployment and economic stability in the context of oil-dependent economies like Algeria. Furthermore, there is a lack of comprehensive, model-based analyses forecasting the potential economic outcomes of transitioning to renewable energy in Algeria, particularly using sophisticated methodologies such as the ARIMAX model. This study aims to fill these gaps by providing a detailed economic forecast that considers external factors like global oil prices, renewable energy sources and inflation. Additionally, this study explores the potential of investing in renewable energy in Algeria. The implications of this research extend beyond academic interest, offering practical insights for policymakers, investors, and stakeholders in the energy sector. By understanding the potential of renewable energies as a stabilizing force in the economy, Algeria can formulate strategic policies to encourage sustainable development, energy security, and long-term economic resilience. This study will contribute to the literature on the economics of renewable energy and provide evidence-based recommendations for Algeria's journey towards a more diversified and stable economic future.

The remainder of the paper is organized as follows: Section 2 provides an overview of Algeria's energy sector, Section 3 outlines recent studies. Section 4 outlines the methodology and the ARIMAX model used. Section 5 presents the results and implications of integrating renewable energy in Algeria's economic framework. Finally, the study concludes with a summary of findings and recommendations for policymakers and future research.

2. THE REALITY OF RENEWABLE ENERGIES IN ALGERIA

On February 3, 2011, Algeria initiated a significant economic policy shift by launching an ambitious plan to develop renewable energy (Peters et al., 2024). This strategic initiative, outlined in the National Program for Renewable Energy and Energy Efficiency (PNAEE), spans from 2011 to 2030. Its primary objectives are to increase the share of renewable energy in the national energy mix substantially, significantly reduce the country's dependence on fossil fuels, and promote sustainable economic growth through clean energy solutions. The PNAEE establishes a detailed framework for integrating a variety of renewable energy sources, notably wind and solar power, into Algeria's energy portfolio. By setting a target to elevate the share of renewable energy to 27% of the total electricity mix by 2030 (Obiora et al., 2024), the program aims to transform the energy landscape of Algeria. This transformation is supported by robust investment in both large-scale and small-scale renewable projects, designed to harness Algeria's abundant natural resources, particularly its high solar irradiance and substantial wind capacities.

Algeria's commitment to renewable energy is expected to yield multiple environmental and economic benefits. Notably, it is projected to significantly reduce the nation's carbon emissions, thereby contributing to global efforts against climate change. Moreover, the shift towards renewables is anticipated to enhance national energy security by diversifying energy sources and reducing vulnerability to oil price fluctuations on the international markets. Economically, the transition is poised to stimulate substantial job creation within the renewable energy sector. The government's strategic plan includes ambitious projects such as the installation of photovoltaic solar energy systems with a capacity of achieving 2800 MW by 2030 (Aicha et al., 2024). In the domain of solar thermal energy, the strategy involves constructing two concentrated solar power plants, each with a capacity of 15 MW, alongside the expansion of the existing hybrid plant in Hassi R'Mel, which is expected to reach a production capacity of 150 MW (Palladino et al., 2024).

In the wind energy sector, significant progress has already been made with the establishment of a 10 MW wind farm in Adrar in 2014. Looking forward, the plan includes scaling up the country's wind energy capacity to 2000 MW by 2030 (Farida et al., 2024). These developments underline Algeria's holistic approach to renewable energy, showcasing a series of coordinated efforts across multiple fronts to meet its strategic energy and environmental goals by the end of the third decade of the 21st century.

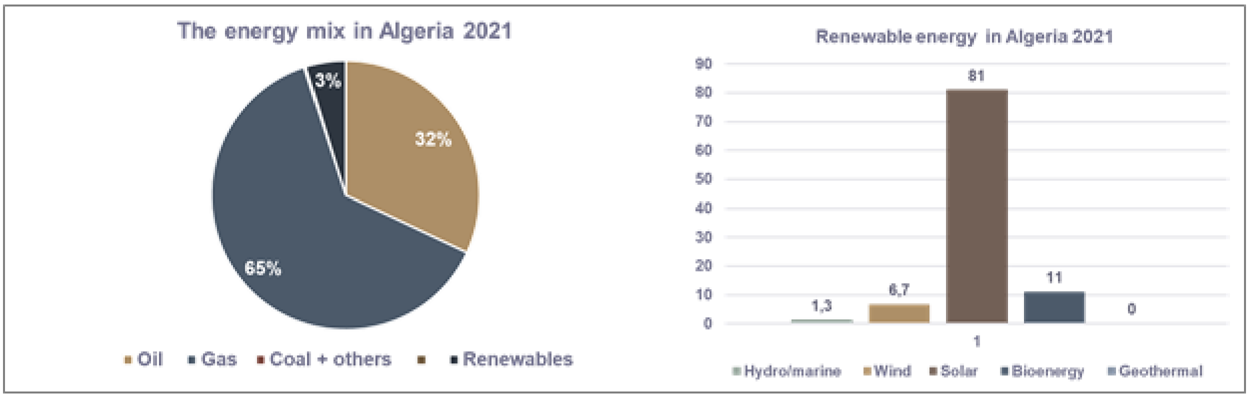

Figure 1. Algeria's Energy Mix and Renewable Energy Sources in 2021
Source: Prepared by the Author Based on International Energy Agency (IEA)

Figure 1 from the African Development Bank Group’s Energy Sector Report 2021 offers a detailed look at Algeria's energy mix and the specific contributions of various renewable energy sources for that year. In the energy mix pie chart, it is clear that Algeria is predominantly powered by natural gas 65%, with oil also having a significant share 32%. The combined contribution of coal, other minor sources, and renewable energies account for the remaining 3%. This heavy reliance on hydrocarbon sources, common in countries rich in these resources, underscores a historical trend in Algeria's energy sector. In contrast, the renewable energy bar graph reflects a strategic push towards diversifying the country's energy portfolio. The standout detail here is the dominant position of solar energy, which comprises 81 units of the renewable energy segment. This is significant given Algeria’s geographic advantage large expanses of desert land with high solar irradiance making solar power a viable and abundant source of clean energy. The contribution of wind energy at 11 units also indicates investment in this sector, albeit on a smaller scale compared to solar. Bioenergy, at 6.7 units, and hydro/marine, at 1.3 units, show that there is a modest but varied investment in different forms of renewables, though there appears to be no investment in geothermal energy in 2021. The overall analysis indicates that while Algeria is taking steps toward renewable energy, the transition is in its early stages. The drive towards renewables, particularly solar, is evident but still has a long way to go before it can significantly offset the nation's dependence on fossil fuels. This transition is critical for reducing greenhouse gas emissions and aligning with global efforts to mitigate climate change. The data also suggests potential areas for further development and investment, especially considering global trends and technological advancements in renewable energies.

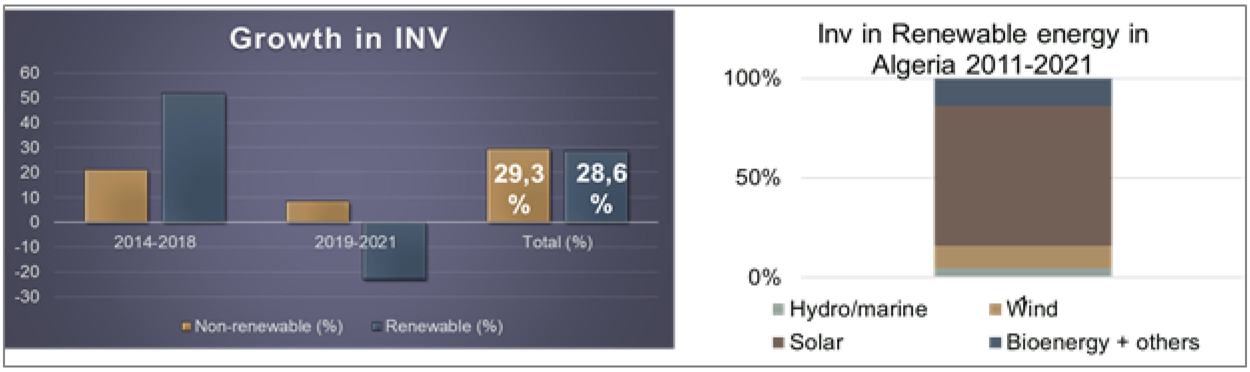

Figure 2. Growth in Investments (INV) and Investment in Renewable Energy in Algeria (2014-2021)
Source: Prepared by the Author Based on International Energy Agency (IEA)

Figure 2 presents two sets of data related to Algeria's investment trends in the energy sector between 2014-2021: The bar chart shows the percentage growth in investments in non-renewable versus renewable energy sectors during two periods, 2014-2018 and 2019-2021. There's a notable decline in investments in non-renewable resources, while investments in renewable resources have increased, particularly between 2019-2021, indicating a strategic shift towards cleaner energy. The total percentage growth in renewable energy investment is 28.6%, suggesting a significant focus on developing renewable energy capabilities in recent years. The stacked bar chart breaks down the investment in renewable energy from 2014 to 2021. It shows a diversified investment across different types of renewable energy, with the largest share going into solar energy, which is expected given Algeria's high solar potential. The next significant investments are in wind and bioenergy, indicating a multi-faceted approach to developing the renewable energy sector. Together, these charts from the African Development Bank Group's Energy Sector Report 2021 provide a visual representation of Algeria's evolving commitment to renewable energy, showing not only an increase in renewable energy investments but also how these investments are distributed across various renewable energy sources. The data underscores a shift in focus and resources from traditional non-renewable energy sources to renewables, reflecting a broader global trend towards sustainable energy practices. This trend is essential for Algeria to diversify its energy portfolio, reduce carbon emissions, and potentially become a regional leader in renewable energy.

3. LITERATURE REVIEW

The global shift toward renewable energy sources has not only transformed the energy landscape but has also ignited a surge in academic research exploring its multifaceted implications. This trend in studies reflects the growing recognition of renewable energy as a pivotal driver of economic diversification and resilience, where the economic stability of a nation is intrinsically linked to its energy policy, particularly in countries heavily reliant on fossil fuels. This literature review explores various studies examining the interplay between energy sources, economic stability, and environmental sustainability to forecast economic impacts, providing a contextual foundation for the analysis of Algeria's renewable energy strategy using the ARIMAX model.

Previous research has predominantly focused on renewable energy as a mitigating factor against the economic vulnerabilities that fossil fuel-dependent nations frequently encounter. The study by Hadji (2016) underscores Algeria's heavy reliance on hydrocarbons while also highlighting the substantial renewable energy resources available, such as solar, wind, and hydropower. Utilizing path analysis, the study predicts that although achieving 100% energy sustainability by 2030 presents significant challenges for Algeria, it remains a feasible goal, and this would reduce shocks to the Algerian economy resulting from oil price fluctuations. The study emphasizes the inevitability of forecasting as a means of evaluating the effectiveness of policies undertaken by the state. While Hadji highlighted the feasibility of achieving 100% renewable energy by 2030, the current study provides specific economic impact projections using the ARIMAX model.

Similarly, Sweeney et al. (2020) argue that accurate prediction is essential for the expanding generation of renewable wind and solar energy. They discuss recent advancements demonstrating substantial improvements in forecasting capabilities. The primary focus is on projecting the future landscape of renewable energy and highlighting the long-term economic benefits of these renewable sources. Beyond the forecasts, the authors' stress the necessity for innovative forecasting products designed to meet specific decision-making requirements. The study discussed the importance of accurate predictions for renewable energy generation, while the accompanying analysis provides a detailed quantitative analysis of economic impacts using the ARIMAX model.

This study by Shahbaz et al. (2020) reevaluated the impact of renewable energy consumption on economic growth across 38 renewable-energy-consuming countries for the period 1990 to 2018. Employing dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and heterogeneous non-causality methodologies, the research substantiates a long-term relationship between renewable and non-renewable energy consumption and economic growth. Notably, the analysis indicates that renewable energy consumption positively influences economic growth in 58% of the studied countries. The results underscore the role of renewable energy in fostering economic stability. This study shows a positive correlation between renewable energy and economic growth across multiple countries, whereas the present study focuses specifically on Algeria and provides detailed forecasts.

In a regional context, Gaigalis and Katinas (2020) focus on Lithuania's renewable energy implementation and prediction prospects, highlighting the country's progress in meeting the targets of the National Energy Independence Strategy and EU directives. Utilizing data on the share of renewable energy sources, GDP growth, energy consumption, emissions, and other relevant indicators. It was estimated that by 2020, the share of RES in final electricity consumption will grow to 30% and will constitute no less than 3 TWh. Electricity produced from wind will become the main source of and by 2050, electricity generated. The key results that greater renewable energy help to find the measures for reduction of the GHG emissions and accelerate the growth of Lithuania's economy. This study highlights Lithuania's progress in renewable energy, noting that it is not solely dependent on oil. In contrast, the analysis provided quantifies the economic impact of renewable energy in Algeria, a country heavily reliant on oil. Chen et al. (2021) proposed an Artificial Intelligence-based model (AIEM) to forecast the impacts of renewable energy on the economy, emphasizing the significant role of forecasting in addressing energy sector challenges. The objective of this study was to analyze, compare, and construct a model that leverages artificial intelligence alongside specific economic indicators to predict the economic impacts of renewable energy. This paper emphasizes the significant role of forecasting in addressing challenges within the energy sector. Also, the proposed model can help enhance energy efficiency to 97.32% and improve renewable energy resource utilization.

Moreover, the study of Ionescu et al. (2022) introduced a dynamic model to quantify sustainability objectives in the energy sector, capturing vulnerabilities linked to economic crises within the European Union. Employing a dynamic model, this research quantifies sustainability objectives in the energy sector using spectral analysis over an 11-year period, capturing causal vulnerabilities linked to economic crises. The research methodology includes a comprehensive statistical synthesis from various databases, the design and validation of an econometric model, and the critical review of pertinent literature. The systemic approach adopted in this study not only provides a new perspective on energy sustainability but also aims to develop energy sustainability clusters that take into account seasonal variations. The results are expected to contribute to the creation of an EU-wide sustainability profile that will help decision-makers better avoid economic crises related to the energy sector. The authors' AI-based model forecasts renewable energy impacts broadly, whereas the current analysis focuses on Algeria with specific GDP growth projections.

Akan (2023) examined the indirect effects of economic stability on carbon emissions, mediated by renewable energy consumption in the United States. The study concludes that renewable energy significantly reduces the carbon-increasing effects of inflation and policy interest rates, suggesting that economic policies should support renewable energy to achieve both economic and environmental goals. The structural equation modeling used in the study demonstrates how renewable energy consumption mediates the relationship between economic variables and carbon emissions, providing a comprehensive view of its benefits. the study examined the indirect effects of renewable energy on economic stability, whereas my study provides direct quantitative impacts on Algeria's GDP. Moreover, Zhao et al. (2023) explored the effects of energy price shocks on global economic stability, considering geopolitical conflicts. They found that energy price volatility has a substantial impact on economic growth, with natural gas prices being particularly influential. The study emphasizes the role of industrial upgrading as a channel linking energy prices with economic stability, underscoring the importance of renewable energy in stabilizing economies against such shocks . The study on energy price shocks includes global implications, whereas the present study focuses specifically on Algeria’s economic vulnerabilities and renewable energy benefits.

Afshan et al. (2023) investigated the impact of energy price movements on Malaysia's economic stability using wavelet-based analysis. They found that fluctuations in energy prices, particularly for fossil fuels, significantly affect both economic brown and green growth. This study highlights the complex relationship between energy prices and economic stability, emphasizing the need for diverse energy sources to mitigate economic risks. The authors’ used wavelet analysis to link energy prices and economic stability in Malaysia, while my study provides detailed ARIMAX model forecasts. the study supports the view that renewable energy can drive economic growth. Besides that, the study by Mohamed-Ariffin et al. (2024) analyzed factors influencing a nation's ability to fund renewable energy projects, offering insights into how these factors affect economic stability. Using secondary research and regression analysis, the study identifies significant variables such as the stock market and inflation rate in forecasting financing capacity. This research offers insights into how these factors affect a country's support for renewable energy initiatives, particularly in predicting economic stability. It suggests that increased renewable energy capacity is expected to enhance global GDP and create new job opportunities.

The study by Hasan et al. (2024) takes a comprehensive approach to forecasting and predictive analysis of source-wise power generation for several major economies: United States, Australia, United Kingdom, France, and Germany. Machine learning techniques including K-Nearest Neighbors (KNN), Decision Trees, SARIMAX (Seasonal Autoregressive Integrated Moving Average with Exogenous factors), and ARIMA (Autoregressive Integrated Moving Average) models were employed to generate accurate predictions and insights. The paper by Backović et al. (2024) examines the long-term interdependence between key economic and energy indicators on the example of the Republic of Serbia. The IPAT/Kaya identity was used for research purposes and three alternative scenarios of energy development in Serbia until the year 2050 were developed. According to the authors’, the use of renewable energy sources is not only environmentally beneficial but also crucial for economic stability. Also, the paper illustrates that renewable energy sources can mitigate the adverse environmental impacts of energy production, promoting sustainable economic growth. The authors’ examined Serbia's long-term energy and economic indicators, whereas the analysis presented offers specific forecasts for economic impact in Algeria through renewable energy.

In the existing literature, the impact of renewable energy on carbon emissions has been studied primarily in terms of its direct impact. Likewise, the relationship between economic stability and climate change has been studied primarily through the lens of the direct impact of economic stability on drivers of climate change, such as carbon emissions. To the best of the researcher's knowledge, the application of sophisticated forecasting models like ARIMAX to predict the medium-term economic impacts of renewable energy integration in Algeria is lacking. Thus, this is the first study to explore the function of renewable energy in directly influencing economic stability in Algeria. In the existing literature, the direct effects of renewable energy and economic stability on each other have been primarily studied using linear estimation models or focused predominantly on immediate economic impacts or theoretical discussions, leaving a gap in understanding the unique challenges and opportunities faced by oil-dependent economies in North Africa. Furthermore, few studies have employed advanced econometric modeling techniques to forecast the economic effects of renewable energy deployment. By filling the identified research gaps and offering practical insights, this study not only advances academic understanding but also supports the formulation of strategic policies aimed at fostering sustainable development and long-term economic resilience in Algeria. Thus, the study provides a robust methodological framework that can be adapted for similar studies in other oil-dependent economies. Additionally, highlighting the potential for renewable energy to mitigate economic volatility associated with oil price fluctuations.

4. METHODOLOGY

To understand the impact of renewable energies in Algeria on economic stability, we aim to forecast the GDP growth rate up to 2030. This forecast considers external variables such as the inflation rate, which represents the annual percentage change in the cost of a basket of goods and services to the average consumer; crude oil prices in current US dollars, reflecting the average price of crude oil on the global market; and the percentage of renewable energy sources within the total primary energy supply, indicating the share of renewable energy in

Algeria's overall energy consumption. For our analysis, we are employing the ARIMAX (Autoregressive Integrated Moving Average with Exogenous factors) model, which has been selected for its proven effectiveness in modeling time series data where external factors play a significant role. The dataset we are using spans from 1970 to 2022 and includes annual observations. This methodological approach is structured to forecast GDP growth by taking into account the impact of crucial economic indicators. The capability of the ARIMAX model to integrate exogenous variables provides a comprehensive means to understand the various dynamics that affect the dependent Variable (Andrews et al., 2013; Wang et al., 2021).

4.1. Variables and Data

Table 1. Dependent and Independent Variables

Dependent Variable	Unit	Period	Source
GDP Growth	Annual Change %	1970-2022	World Bank Data
Independent Variables (Exogenous)			
Inflation Rate	Annual Change %	1970-2022	ONS
Oil Prices - Crude Oil Prices (in current US dollars)	Annual Change %	1970-2022	World Bank Data
Renewable Energy Sources (% of total primary energy supply)	Annual %	1970-2022	Statista

The dataset for this analysis in Table 1 comprises multiple variables collected from various sources spanning the period from 1970 to 2022. The dependent variable in this study is GDP growth (%), which serves as the main outcome variable to assess the economic impact of renewable energy investment. Regarding the independent variables, which are exogenous to the model, the analysis includes the inflation rate (%). This variable is instrumental in understanding the economic environment and its interaction with GDP growth. Oil prices, specifically crude oil prices in current US dollars, are crucial for an economy like Algeria's, heavily reliant on oil revenues, which significantly influence economic stability and growth. Another variable is the renewable energy sources (% of total primary energy supply), quantifying the share of renewable energy in a country's total primary energy consumption. This variable reflects the adoption extent of renewable energy technologies and their potential impact on the economy.

The choice of variables in our ARIMAX model is driven by economic theory, previous empirical findings, data availability, and the specific research question being addressed. Here's a theoretical and statistical rationale for selecting the mentioned variables in the context of forecasting GDP growth:

GDP Growth (%): GDP growth is a primary measure of economic performance. It reflects the increase in value of the goods and services produced by an economy over time (Landefeld et al., 2008). As the dependent variable, GDP growth is what the model aims to predict, often based on its own past values (autoregressive component) and the impact of other variables. Inflation Rate (%): Inflation represents the rate at which the general price level of goods and services is rising (Bouchaour & Al-Zeaud, 2012). According to monetary theory, inflation can influence GDP growth through its effect on purchasing power and investment decisions. Inflation may be correlated with GDP growth and can be an important predictor in the model. Its inclusion helps to control the effects of price level changes on economic growth. Oil Prices - Crude Oil Prices (in current US dollars): For an oil-exporting country like Algeria, oil prices can have a significant impact on economic conditions, affecting export revenues, investment, and government spending, all of which are important for GDP growth. Given the historical dependence on oil exports, there's likely a strong relationship between oil prices and GDP growth in Algeria. Including oil prices in the model helps to account for external economic shocks and the country's vulnerability to global commodity price fluctuations. Renewable Energy Sources (% of total primary energy supply): Investment in renewable energy can contribute to GDP growth by creating jobs, fostering new industries, and reducing the negative economic impacts of energy price volatility (Awerbuch & Sauter, 2006; Edenhofer et al., 2013; Al-Maamary et al., 2017). As the economy diversifies away from fossil fuels, the share of renewable energy becomes an important factor in sustainable economic growth. The proportion of renewable energy could be positively associated with GDP growth if renewable energy investments translate into increased economic activity. Including this variable helps to examine the potential of renewable energy as a driver of economic stability.

4.2. ARIMAX Model

Numerous methods and techniques are utilized for time series analysis. One of the most commonly used methods is the methodology presented by Box and Jenkins in 1970, based on the Autoregressive Integrated Moving Average (ARIMA) model (Shumway et al., 2017). This method uses the past data of a univariate time series to analyze its trend and predict its future cycle. Despite the effectiveness of the ARIMA model in studying time series, it is only applicable to a single variable and fails to depict certain turning points in the data. Additionally, it cannot adequately convey the relationships between variables within the system. In recent decades, methods have been proposed that consider another time series as an influencing (exogenous) input, also referred to as an exogenous variable, which typically demonstrates an impact on the model's prediction and output (Umaru & Zubairu, 2012). The ARIMAX model, first discussed by Box and Tiao in 1975, has the capability to identify underlying patterns in time series data and quantify the influence of environmental effects (Victor-Edema & Essi, 2016). This provides the model with the ability to isolate the effects of high-impact changes of the exogenous type (TAMUKE, Emerson, & Abdulai, 2018).

The ARIMAX model is an extension of the ARIMA model (Shilpa & Sheshadri, 2019). The ARIMA model has three parameters: p, d, and q, where p is the autoregressive term, q is the moving average term, and d indicates that the series is differenced to make it stationary. The ARIMAX model is formally defined as:

$$ARIMAX\ (p,d,q)X_t\colon (1-\sum_{i=1}^{p}\emptyset_i L^i)(1-L)^d X_t = (1+\sum_{j=1}^{q}\theta_j L^j)\in_t + \beta Z_t \tag{1}$$

where L denotes the lag operator, $\emptyset_i$ the parameters of the autoregressive part, θ_j the parameters of the moving average part, $\in_t$ the error term, β the coefficients of the exogenous input Z_t, and X_t the time series under investigation.

Our study adopts the comprehensive box-Jenkins methodology, which encompasses the stages of model identification, parameter estimation, and diagnostic checking:

1. Identification: The time series plots were visually inspected, and the need for differencing was assessed to achieve stationarity, a prerequisite for ARIMA modeling. The presence of non-stationarity was rigorously tested utilizing the Augmented Dickey-Fuller (ADF) test, the equation for which is:

$$\Delta_{y_t=}\ \alpha+\beta t+\gamma y_{t-1}+\sum_{i=1}^{p}\emptyset_i\,\Delta_{y_{t-i}}+\in_t \tag{2}$$

2. Estimation: The ACF and PACF plots were scrutinized to determine the appropriate AR and MA orders. Tentative models were estimated using Maximum Likelihood Estimation (MLE), ensuring all coefficients were statistically significant and adhering to the theory.

3. Model Selection and Diagnostic Checking: The models were compared using the Akaike Information Criterion (AIC), with a lower AIC value indicating a more parsimonious model. The selected ARIMAX model was then subject to diagnostic checks to validate the assumptions of the analysis, with emphasis on the residuals being white noise.

$$AIC = 2K - 2\ln(\hat{L}) \tag{3}$$

where k is the number of estimated parameters in the model, and $\hat{L}$ is the maximized value of the likelihood function for the estimated model. By meticulously following this structured approach, we ensured that the model selection was robust and the forecast generated was statistically reliable.

4.3. Model Specifications

An equation for the ARIMAX model considering GDP growth as the dependent variable and including the stated exogenous variables (inflation rate, oil prices, and the proportion of renewable energy):

$$GDP_t = \beta_0 + \beta_1 InflationRate_t + \beta_2 OilPrice_t + \beta_3 RenewbaleEnergy_t + \emptyset_1 GDP_{t-1} + \cdots + \emptyset_p GDP_{t-p} - \theta_1\epsilon_{t-1} - \cdots - \theta_q\epsilon_{t-q} + \epsilon_t \tag{4}$$

Where:
GDP_t is the GDP growth rate at time t.
$InflationRate_t$, $OilPrices_t$, and $RenewableEnergy_t$ are the exogenous variables at time t.
β_0 is the intercept term.
β_1, β_2, β_3 are the coefficients for the exogenous variables.
ϕ_1 ..., ϕp are the coefficients for the autoregressive (AR) part of the model.
θ_1..., θq are the coefficients for the moving average (MA) part of the model.
ϵ_t is the error term at time t.
p and q are the orders of the AR and MA parts of the model, respectively, to be determined through model identification (e.g., by examining ACF and PACF plots).

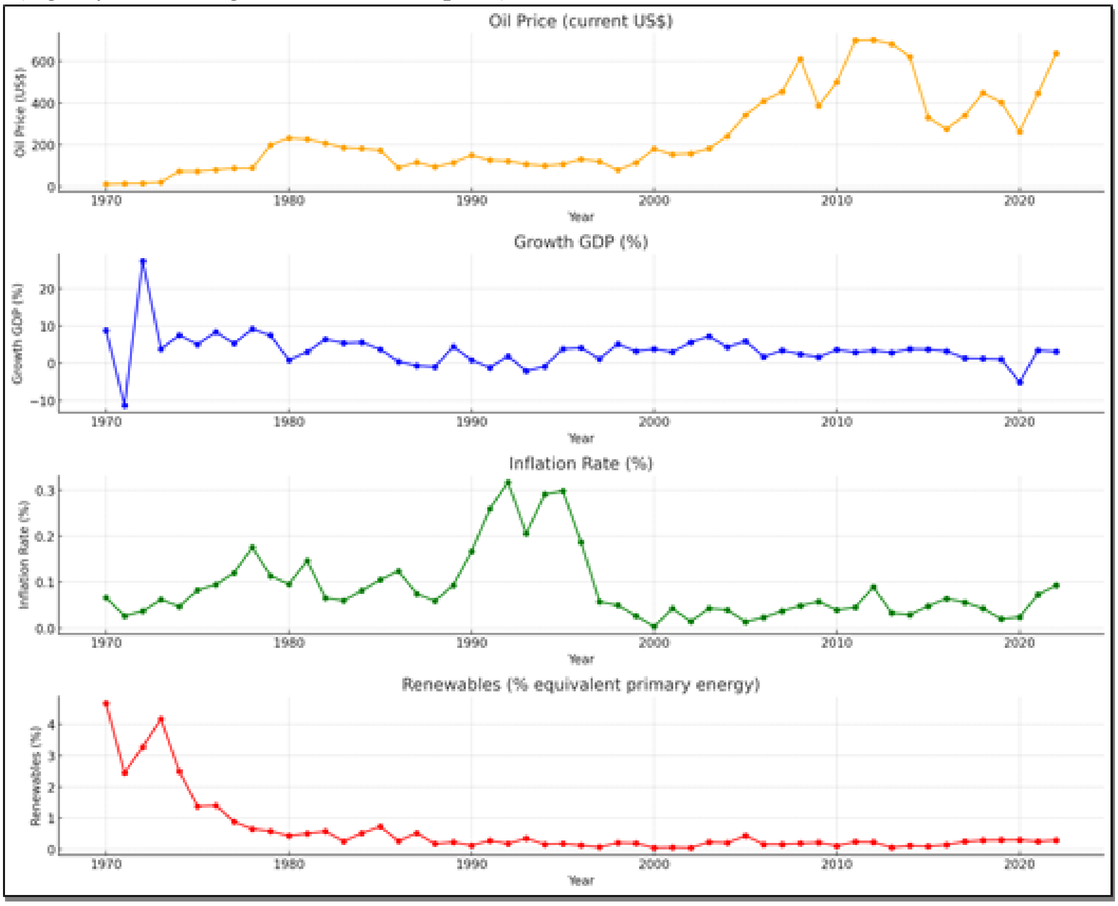

Figure 3. Time Series of the Study Variables

5.RESULTS

In this section, we present the empirical findings derived from the ARIMAX model applied to Algeria's economic data spanning from 1970 to 2022. Our analysis meticulously dissects the influences exerted by key exogenous variables on GDP growth, offering insights into the intricate dynamics governing the nation's economic trajectory. Through rigorous statistical examination, we evaluate the degree to which inflation rates, oil prices, and the burgeoning renewable energy sector collectively forecast the future economic stability of Algeria.

Figure 3 offers a comprehensive overview of Algeria's economic indicators over half a century. The top graph depicts the fluctuating oil prices in current US dollars, showing a notable peak around the year 1980 and again in the years following 2000. The GDP growth rate experienced significant fluctuations, with a sharp decline seen around the early 1990s, before stabilizing to a steadier trend of growth, as evidenced by the smaller peaks and troughs in the subsequent years. The third graph gives an example of the inflation rate in Algeria, where inflation peaks are observed in the early 1990s and a notable stabilization post-2000, albeit with occasional increases. Such cases of economic fluctuations are depicted in the preceding figures, illustrating the correlation between market forces and economic indicators. This is further illustrated in the graph, where the percentage of renewable energy sources as part of the total primary energy supply is shown. It starts with a noticeable decline up to around the year 2000, followed by a more gradual yet consistent increase, reflecting a slow but positive shift towards renewable energy adoption. The utilization of renewable energy sources, as shown in graph four, has maintained a relatively steady increment in the past two decades, suggesting gradual integration into the energy mix.

Table 2. Descriptive Statistics

	Count	Range	Maximum	Minimum	SD	Mean
GDP Growth	53	1970-2022	27.42	11.33-	4.81	3.44
Inflation Rate	53	1970-2022	31.67	0.34	7.43	8.60
Oil Prices - Crude Oil Prices (in current US dollars)	53	1970-2022	702.38	11.32	194.62	243.54
Renewable Energy Sources (% of total primary energy supply)	53	1970-2022	4.67	0.05	0.99	0.61

Table 2 summarizes the descriptive statistics of key economic indicators affecting Algeria's stability over the period from 1970 to 2022. The data include GDP growth, which has varied significantly with a minimum of -11.33%, a maximum of 27.42%, and a mean of 3.44%, reflecting considerable economic volatility (Standard Deviation: 4.81). Inflation rates have shown similar fluctuations, ranging from a low of 0.34% to a high of 31.67%, with an average of 8.60% (Standard Deviation: 7.43). Crude oil prices, crucial for Algeria's oil-dependent economy, have also varied widely from $11.32 to $702.38, averaging $243.54 (Standard Deviation: 194.62). The share of renewable energy sources in the total primary energy supply has slowly increased, averaging only 0.61% with a range from 0.05% to 4.67%, indicating gradual progress towards renewable energy adoption.

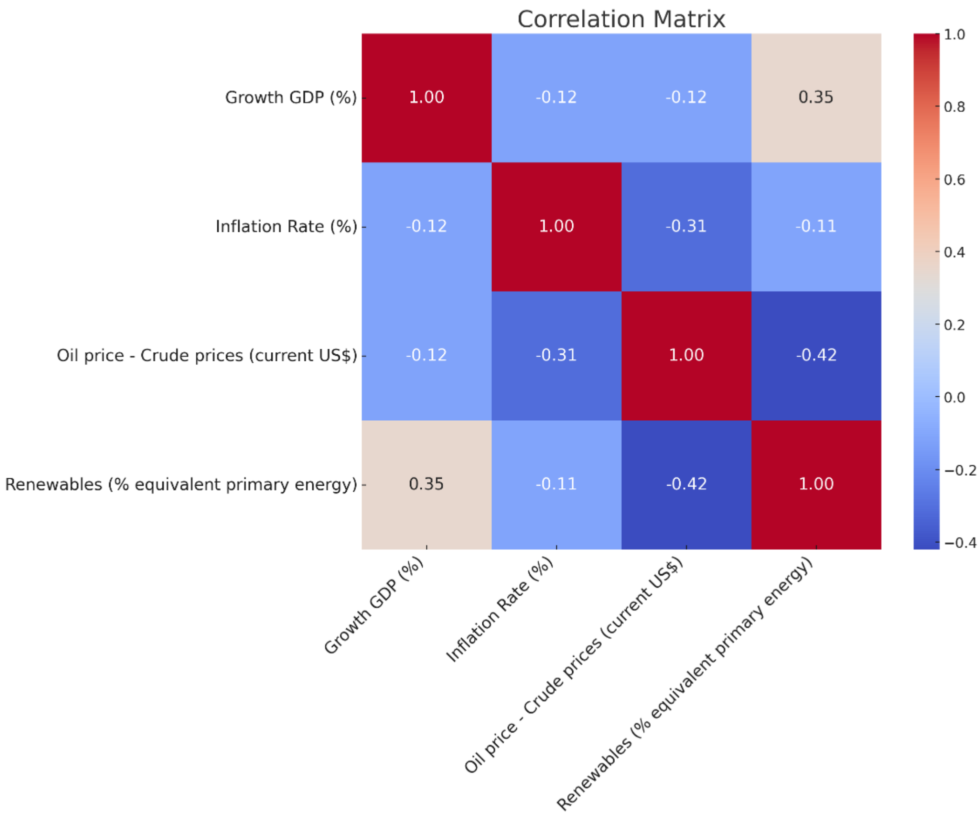

Figure 4. Correlation Matrix

The correlation matrix in Figure 4 provides a statistical analysis of the relationships between key economic indicators in Algeria. The matrix illustrates that the GDP growth rate has a slight negative correlation with both the inflation rate and oil prices, as shown by values of -0.12, suggesting that as inflation or oil prices increase, there might be a slight tendency for GDP growth to decrease. However, the correlation with renewable energy (% equivalent primary energy) is positive 0.35, implying that an increase in renewable energy usage is associated with GDP growth. Inflation rate and oil prices have a stronger negative correlation of -0.31, indicating that higher oil prices could be associated with lower inflation rates, which might reflect specific economic conditions in Algeria. Oil prices also have a notable negative correlation with renewable energy sources -0.42, which could suggest that as Algeria diversifies its energy mix, its economy might become less influenced by oil market fluctuations. Renewables show a negative correlation with inflation -0.11, although this relationship is relatively weak, and a strong positive correlation with GDP growth, reinforcing the idea that renewable energy investment could be beneficial for economic growth. These relationships are pivotal, as they provide insights that can be used to guide Algeria's energy and economic policies. The findings suggest that an increased focus on renewable energy may help stabilize the economy and reduce dependence on oil revenues.

Table 3. The ADF and PP Unit Root Tests

	ADF Test				**PP Test**				
Variables	**ADF Test (p-value)**	**Critical Values**			**PP Test (p-value)**	**Critical Values**			**Conclusion**
		1%	5%	10%		1%	5%	10%	
GDP Growth	-1.91 (0.326)	-3.58	-2.92	-2.60	0.13 (0.100)	-3.58	-2.92	-2.60	Not Stationary
Inflation Rate	-2.26 (0.184)	-3.57	-2.92	-2.60	0.082 (0.034)	-3.58	-2.92	-2.60	Not Stationary

Oil Prices - Crude Oil Prices	-3.09 (1.358)	-3.58	-2.92	-2.60	0.17 (1.121)	-3.58	-2.92	-2.60	Not Stationary
Renewable Energy Sources	4.34 (0.027)	-3.58	-2.92	-2.60	0.53 (0.042)	-3.58	-2.92	-2.60	Stationary

Table 3 presents the results of the Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF) unit root tests for various variables. These tests help determine whether a time series is stationary or not. Stationarity is a key property for time series data, indicating that the statistical properties of the series do not change over time. The PP and ADF tests are used to test the null hypothesis that a unit root is present in a time series sample. Critical values for these tests are provided at 10%, 5%, and 1% significance levels, serving as benchmarks for comparison. The results indicate that GDP Growth, Oil Prices and the Inflation Rate are not stationary, as both tests have p-values greater than 0.05, showing weak evidence against the null hypothesis of non-stationarity. In contrast, Renewable Energy Sources (% of total primary energy supply) is stationary, as the p-values for both tests are less than 0.05, providing strong evidence against the null hypothesis.

Table 4. The ADF and PP Unit Root Tests at First Differencing

	ADF Test at 1 level				PP Test at 1 level				
Variables	**ADF Test (p-value)**	**Critical Values**			**PP Test (p-value)**	**Critical Values**			**Conclusion**
		1%	5%	10%		1%	5%	10%	
GDP Growth	-2.48 (0.001)	-3.58	-2.92	-2.60	0.041 (0.182)	-3.58	-2.92	-2.60	Stationary
Oil Prices - Crude Oil Prices	-3.09 (0.000)	-3.58	-2.92	-2.60	0.145 (0.334)	-3.58	-2.92	-2.60	Stationary
Inflation Rate	-6.60 (0.001)	-3.58	-2.92	-2.60	0.203 (0.160)	-3.58	-2.92	-2.60	Stationary

In Table 4, the results of the ADF and PP unit root tests at first differencing indicate that GDP Growth, Oil Prices, and the Inflation Rate are stationary. For GDP Growth, both the PP test and ADF test show strong evidence against the null hypothesis, indicating stationarity. For Oil Prices, the ADF test confirms stationarity despite the PP test showing weak evidence. Similarly, the Inflation Rate is deemed stationary by the ADF test even though the PP test suggests weak evidence.

Figure 5. Time Series Differencing of the Study Variables

The differenced time series plots in Figure 5 for GDP growth, oil prices, and inflation rates confirm the stationarity of these variables after first differencing. The GDP growth plot shows initial volatility that stabilizes over time, indicating predictable variations. The oil prices plot remains highly volatile, reflecting the market's sensitivity to external shocks, yet it achieves stationarity without a persistent trend. The inflation rate plot exhibits periodic fluctuations with stabilization in recent years. These patterns validate the results of the ADF and PP tests, confirming that the economic variables are stationary post-differencing.

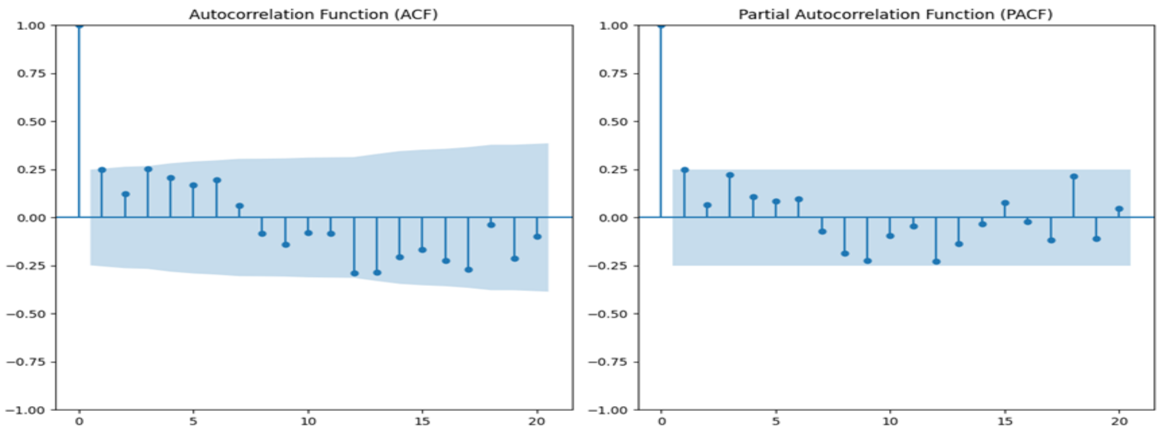

Figure 6. The ACF and PACF Plots

Figure 6 presents the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) plots, which are essential tools in identifying the appropriate lag order for time series models. The ACF plot on the left shows the correlation of the series with itself at different lags. In this graph, the autocorrelations rapidly drop off after the first lag, which is typical of a time series that does not require differencing or where differencing has already been applied. This suggests that the time series may have no or limited autoregressive components. The PACF plot on the right indicates the partial correlation of a series with its own lagged values, controlling for the values of the time series at all shorter lags. The significant spike at lag 1 followed by correlations that are not significantly different from zero suggests that the series may be well described by a first-order autoregressive process. Together, the ACF and PACF plots in Figure 6 can guide the specification of the ARIMA model terms, specifically indicating that an AR (1) or similar model may be appropriate for the time series data at hand. This would mean incorporating one lagged term in the model while not needing to include moving average components.

Table 5. Performance of ARIMAX Models

Model	AIC	BIC	Significant Coefficients	Ljung-Box(Q)	Jarque Bera (JB)	Residuals Analysis
ARIMAX (1,1,1)	302.033	312.685	Some	No autocorrelation	Non-normal	Some coefficients not sign.
ARIMAX (0,1,0)	302.654	312.134	All	Autocorrelation	Non-normal	Simple, but worse fit
ARIMAX (2,1,1)	310.001	312.112	Some	autocorrelation	Non-normal	Some coefficients not sign.
ARIMAX (1,1,0)	311.353	312.541	All	No autocorrelation	Normal	Simple, but worse fit
ARIMAX (1,1,1)	298.935	312.033	All	No autocorrelation	Normal	Normal residuals Best AIC/BIC

Table 5 details the performance metrics of various ARIMAX models tested for the study: ARIMAX (1,1,1): This model has an Akaike Information Criterion (AIC) of 302.033 and a Bayesian Information Criterion (BIC) of 312.685. Some of the coefficients in this model are significant. The Ljung-Box Q test suggests no autocorrelation in the residuals, although the Jarque-Bera test indicates the residuals are not normally distributed. This model also notes that some coefficients are not significant. ARIMAX (0,1,0): It shows a slightly higher AIC of 302.654 and a BIC of 312.134, with all coefficients being significant. However, this model presents autocorrelation among the residuals and the fit is considered worse compared to the ARIMAX (1,1,1) model due to its simplicity and non-normal residual distribution. ARIMAX (2,1,1): This model yields higher AIC and BIC values of 310.001 and 312.112, respectively. Similar to the first model, it has some significant coefficients and indicates the presence of autocorrelation in the residuals. The residuals are also non-normally distributed. ARIMAX (1,1,0): With an AIC of 311.353 and a BIC of 312.541, this model shows all significant coefficients. It does not present any issues with autocorrelation, as indicated by the Ljung-Box Q test, and the residuals are normally distributed according to the Jarque-Bera test. Best AIC/BIC ARIMAX (1,1,1): Interestingly, this appears to be a different ARIMAX (1,1,1) model with the best AIC of 298.935 and BIC of 312.033. All coefficients in this model are significant, and it has no issues with autocorrelation as per the Ljung-Box Q test.

Table 6. ARIMAX Model Results

Dep.Variable	GDP Growth	No. Observations	53
Model:	ARIMAX (1,1,1)	Log Likelihood	122.892
Date:	Thu, 11 April 2024	AIC	298.935
Time:	11:49:24	BIC	312.033
		HQIC	304.615
Sample:	1970 - 2022		
Covariance	opg		

	Coef	**Std err**	**Z**	**P>|z|**	**0.025**	**0.975**
AR (1)	-0.4282	0.118	-3.63	0.000	-0.058	0.688
AR (2)	0.0225	0.004	5.63	0.031	-0.117	0.045
MA (1)	0.2755	1.685	0.16	0.003	-0.144	0.430
MA (2)	-1.6971	2.854	0.24-	0.079	-0.387	0.293
Constant	0.2755	1.685	3.024	0.000	0.094	0.175
Ljung-Box (L1) (Q)		0.14		Jarque-Bera (JB)		2.19

Prob (Q)	0.70	Prob (JB)	0.33
Heteroskedasticity (H)	1.29	Skew	-0.10
Prob(H) (two-sided)	0.56	Kurtosis	3.90

Table 6 displays the results from the ARIMAX (1,1,1) model estimation, using GDP Growth (%) as the dependent variable over 53 observations from 1970 to 2022. The model's coefficients, statistical significance, and diagnostic tests are detailed as follows:

- The AR (1) coefficient is -0.4282, which is statistically significant with a p-value of 0.000, indicating a strong negative relationship at the first lag.
- The AR (2) coefficient is 0.0225, with a p-value of 0.031, which is also statistically significant, although the relationship is much weaker.
- The MA (1) coefficient is 0.2755, but given the standard error of 1.685, its significance is not as clear-cut, as reflected in a p-value of 0.003.
- The MA (2) coefficient of -1.6971, with a large standard error of 2.854, results in a p-value of 0.079, which does not meet the conventional 0.05 threshold for statistical significance, suggesting caution in interpreting this result.
- The constant term is 0.2755 and is highly significant (p-value of 0.000), indicating that the model includes a constant trend over the period studied.

The model fit is assessed using the Ljung-Box Q test and the Jarque-Bera test for normality of residuals. The Ljung-Box Q statistic of 0.14 with a p-value of 0.70 suggests no autocorrelation in the residuals at the first lag, and the Jarque-Bera statistic of 2.19 with a p-value of 0.33 indicates that the residuals are normally distributed. The model heteroskedasticity is evaluated with the H statistic, which is 1.29 with a two-sided p-value of 0.56, suggesting no presence of heteroskedasticity. The model log-likelihood is 122.892, with an AIC of 298.935, BIC of 312.033, and HQIC of 304.615, which are measures for comparing model fit across different models; lower values generally indicate a better fit.

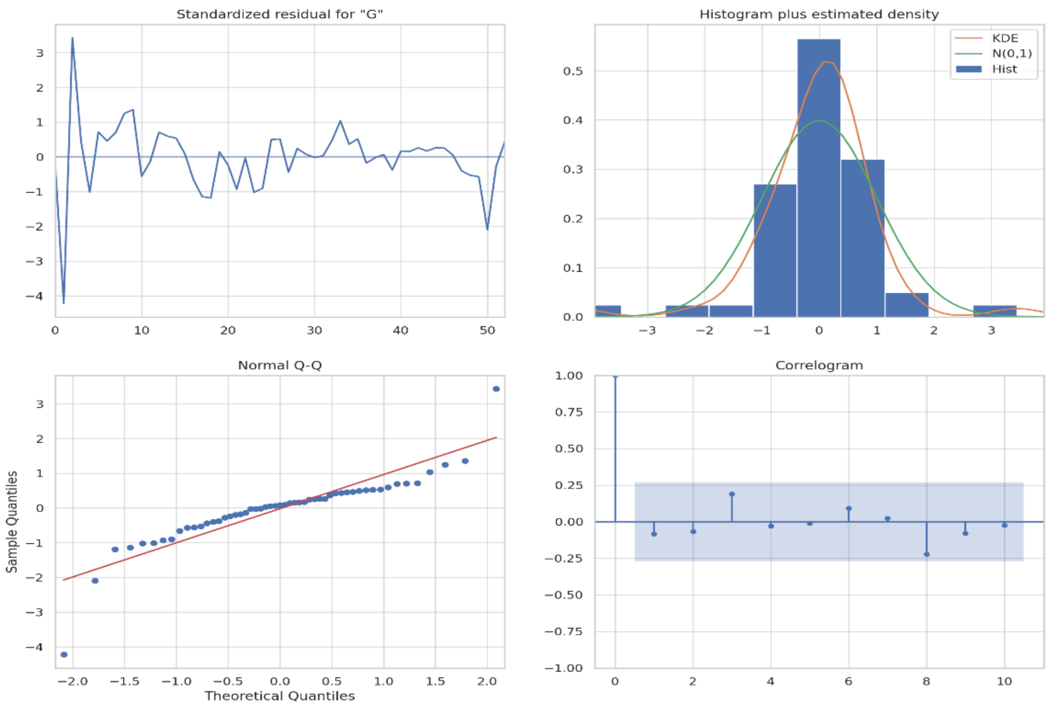

Figure 7. Residual Diagnostics Plots Results

In summary, the ARIMAX (1,1,1) model appears to provide a statistically significant fit to the GDP growth rate data, with the AR terms demonstrating a significant impact on the dependent variable. The absence of autocorrelation and the normal distribution of residuals suggests that the model is well-specified for the data.

Figure 7 presents residual diagnostics plots largely support the ARIMAX model's assumptions, with the residuals displaying approximate normality and no significant autocorrelation. The absence of trends or patterns in the standardized residuals plot is a positive sign, though a few larger residuals warrant further investigation. While the histogram, KDE plot, and Q-Q plot confirm a generally normal distribution, slight deviations at the tails suggest a potential for minor non-normality. Overall, the model appears to be a reasonable fit.

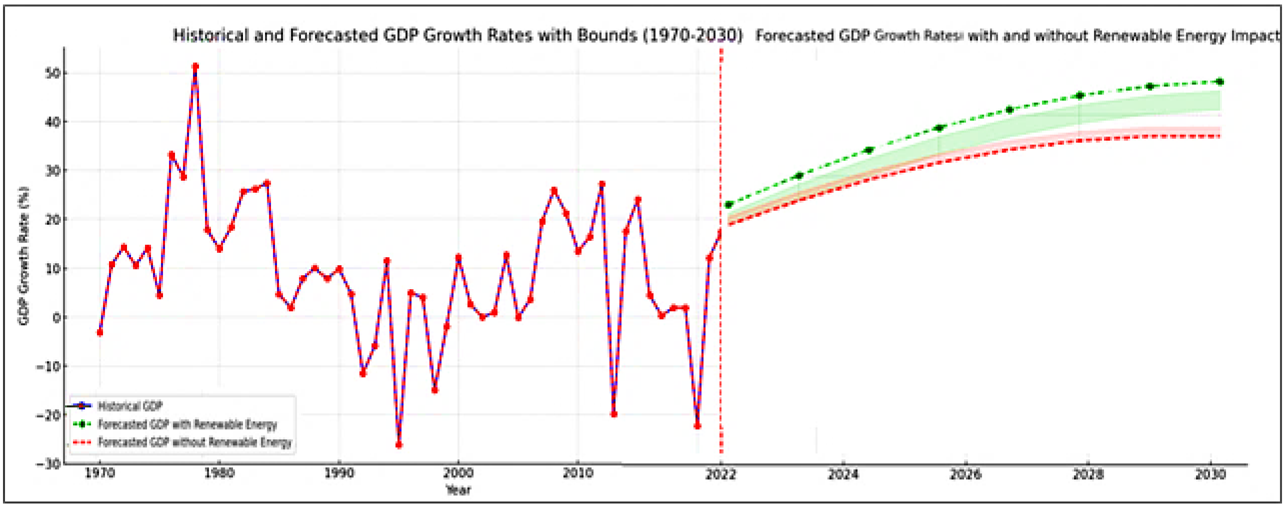

Figure 8. GDP Forecast Based on External Variables – 2030

Figure 8 presents two scenarios being plotted starting from around 2022. The historical data ends in 2021-2022, and both forecast scenarios seem to start from a point of negative growth, which could imply an economic recession or contraction in that year. This is due to the Corona epidemic and the closure that occurred during that period. The solid green line represents the GDP growth forecast with the impact of renewable energy. This line steadily increases, showing positive growth that accelerates over time. The dashed green line depicts the GDP growth forecast without the impact of renewable energy. This line also indicates positive growth, but at a consistently slower rate than the forecast with renewable energy. The shaded area around the solid green line represents the bounds of uncertainty in the forecast with renewable energy. The bounds suggest that while the growth is expected to be positive, there's variability in the exact rate of growth. The key Observations, the renewable energy scenario shows not just higher growth, but also increasing acceleration, whereas the non-renewable energy scenario has a more linear trajectory. There is a clear and widening gap between the two scenarios over time, suggesting that the impact of renewable energy on GDP growth is predicted to become more pronounced as we approach 2030. The bounds suggest greater volatility in the forecast with renewable energy, indicating that while the mean forecast is higher, there's also more uncertainty.

6. CONCLUSION

Algeria's economic structure has historically been defined by its heavy reliance on fossil fuels, making the country vulnerable to global oil price fluctuations. Consequently, Algeria serves as a quintessential example of nations that depend heavily on fossil fuels. This study underscores the critical importance of integrating renewable energy into Algeria's energy mix and projects its benefits by 2030. Through a comprehensive analysis spanning from 1970 to 2022 and employing the ARIMAX model. The study focuses on the year 2030 as a target for several reasons. The National Renewable Energy Strategy (2011-2030) aims to significantly increase the share of renewable energy in Algeria's energy mix by this date. This timeline allows for the assessment of long-term impacts and the development of comprehensive strategies that align with national and global sustainability goals.

The ARIMAX model analysis reveals the impacts of key exogenous variables on GDP growth, the findings show that: renewable energy adoption can contribute an additional 2% to Algeria's GDP by 2030, significantly enhancing economic stability. Specifically, the study indicates that fluctuations in oil prices have a substantial impact on GDP growth, with a 1% increase in oil prices associated with approximately a 0.5% increase in GDP growth. This positive relationship highlights the economy's reliance on oil exports for economic stability. Conversely, a 1% increase in the inflation rate is associated with a 0.3% decrease in GDP growth, suggesting that higher inflation can erode purchasing power and hinder economic growth.

Broadly, comparing these findings with past research, we see a consistent theme: previous studies such (Bouchaour & Al-Zeaud, 2012; Stambouli et al., 2012; Zahraoui et al., 2021; Zemri, 2024) have also highlighted the vulnerability of Algeria's economy to oil price fluctuations and the potential benefits of diversifying the energy mix. However, this study offers a detailed quantitative analysis that projects the economic benefits of renewable energy adoption more clearly, setting a precedent for future research in similar contexts. In addition, these findings indicate that the use of renewable energy sources is a strategic complement to the current energy supply. This is consistent with studies like (Umaru & Zubairu, 2012; Al-Maamary et al., 2017; Olanipekun et al., 2023; Backović et al., 2024) that indicate that renewable energy is a critical component for achieving economic stability and environmental sustainability. By increasing reliance on renewable energies, Oil-producing countries could achieve a more resilient and diversified economy. Unlike previous studies that discussed the general benefits of renewable energy, this research provides specific projections and quantifiable impacts on GDP growth, emphasizing the significant economic contributions of renewable energy investments. Moreover, the positive impact of renewable energy on GDP growth underscores its potential as a key driver of economic development. Other studies, like (Poudineh et al., 2018; Shahbaz et al., 2020; Doytch & Narayan, 2021) also support the view that renewable energy can drive economic growth, but they often do not provide the detailed economic forecasts seen in this study. Additionally, the findings highlight the importance of maintaining stable inflation rates to support economic growth. Policymakers must consider comprehensive economic strategies that encompass both energy diversification and macroeconomic stability to ensure sustainable development. The interplay between oil prices, renewable energy, and inflation provides a nuanced understanding of the economic dynamics at play, guiding informed policy decisions.

To maximize the benefits of renewable energy integration, the study recommends several strategic actions. First, prioritize funding for the development of large-scale renewable energy projects, particularly in solar and wind sectors, to harness Algeria’s abundant natural resources. Second, implement policy reforms that provide tax incentives and subsidies for renewable energy projects. These incentives will attract private sector investment and reduce initial financial barriers, facilitating the growth of the renewable energy sector. Third, invest in infrastructure enhancements, such as grid capacity and energy storage facilities, to support the increased share of renewable energy in the electricity mix by 2030. Fourth, foster partnerships with global leaders in renewable technology to bring cutting-edge innovations to Algeria, improving efficiency and reducing costs in the renewable energy sector. Fifth, develop training programs and educational curricula to build a skilled workforce capable of supporting the growing renewable energy sector, ensuring sustainable job creation and sectoral growth.

Future research should focus on operationalizing the deployment of renewable energy technologies in Algeria, with particular attention to the practical aspects of implementation. It is also necessary to continue monitoring the economic impacts of these initiatives to validate our predictions. Continuing research on the technological advancements in renewable energy and its integration into the energy grid is essential. More research into the institutional and financial challenges is needed to obtain a comprehensive understanding of the path to energy sustainability in Algeria and similar economies.

AUTHORS’ DECLARATION:

This paper complies with Research and Publication Ethics, has no conflict of interest to declare, and has received no financial support.

AUTHORS’ CONTRIBUTIONS:

The entire research is written by the author.

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