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Solar Energy Production in Azerbaijan: Forecast Analysis Using ARIMA Model

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ABSTRACT

The urgent need to address global climate change and promote sustainable development highlights the growing demand for renewable energy sources. Solar energy, in particular, holds significant importance due to its widespread availability and environmentally friendly characteristics. For Azerbaijan, a country dedicated to sustainable development and actively contributing to environmental conservation efforts, renewable energy assumes a central role in its strategic agenda. The objective of this study is to evaluate the historical trajectory of solar energy production in Azerbaijan over the past decade and forecast its future trends until 2030. Utilizing the Autoregressive Integrated Moving Average (ARIMA) model, this study utilizes time series analysis to examine the overall development trends within the solar energy sector. By analyzing past data and using forecasting model, this research endeavors to offer valuable insights to guide policy decisions and strategic planning initiatives concerning renewable energy development in Azerbaijan

Keywords: renewable energy, solar energy production, ARIMA model, forecast, green economics, sustainability.

JEL Classification: C22, F64, O44, Q20, Q42, Q56.

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1. INTRODUCTION

In the current worldwide context, solar energy is widely recognized as the most promising and significant form of renewable energy, presenting unmatched opportunities for sustainable power generation. Solar technologies harness the abundant sunlight resource through the utilization of either photovoltaic (PV) panels or mirrors that concentrate solar radiation, thereby facilitating the conversion of solar energy into electricity. This transformative process not only underscores the advancements in renewable energy technologies but also underscores the crucial role that solar energy plays in addressing the urgent challenges of energy sustainability and environmental conservation on a global scale.

Azerbaijan already has many years of experience in the production of electricity from water. Over the past decade, the country has also established fundamental institutions for various other forms of green energy, notably solar and wind energy. Azerbaijan holds significant potential in harnessing these natural energy resources, paving the way for further advancement in renewable energy initiatives. Azerbaijan has potential opportunities to develop the renewable energy sector. As such, the technical capacity for renewable energy sources within our nation is estimated at 135 GW on land and 157 GW offshore. Economically, the potential is assessed at 27 GW, encompassing 3,000 MW from wind energy, 23,000 MW from solar energy, 380 MW from bioenergy, and 520 MW from mountain river resources (AREN, 2023).

The domain holds strategic importance for Azerbaijan, as the nation aligns with global advancements and commits to pivotal obligations toward fostering a greener future world. Prioritizing the transition to renewable energy sources emerges as a cornerstone for ensuring sustainable development, particularly given Azerbaijan's geographical positioning in a sun-rich region, thereby underscoring the imperative to augment solar energy production. In 2023, the electricity output from solar power plants in Azerbaijan reached 79.4 million kWh, signaling a substantial 30% increase compared to previous years (Renewables, 2024). In 2022, excluding hydropower, solar and wind energy collectively contributed to an electricity generation of 144.2 million kWh (ARDSK, 2023). The solar energy production in Azerbaijan is attributed to electricity generated by 10 solar power stations.

Table 1. Solar energy plants and existing energy potentials in Azerbaijan (with MW in 2022).

1	Babak	22
2	Kangarli	5
3	Sharur	5
4	Gobustan	2.9
5	Samux	2.8
6	Sumgayit	2
7	Sahil	1.9
8	Suraxani	1.6
9	Pirallahi	1.1
10	Culfa	1

Source: Area and Hasanov (2023a).

Figure 1 depicts a substantial increase in solar energy production in Azerbaijan over the past decade. Beginning from minimal levels in 2013, production experienced a significant increase, reaching around 80 million kWh by 2023. This upward trend highlights Azerbaijan's growing commitment to integrating renewable energy sources and its efforts to enhance energy source diversity.

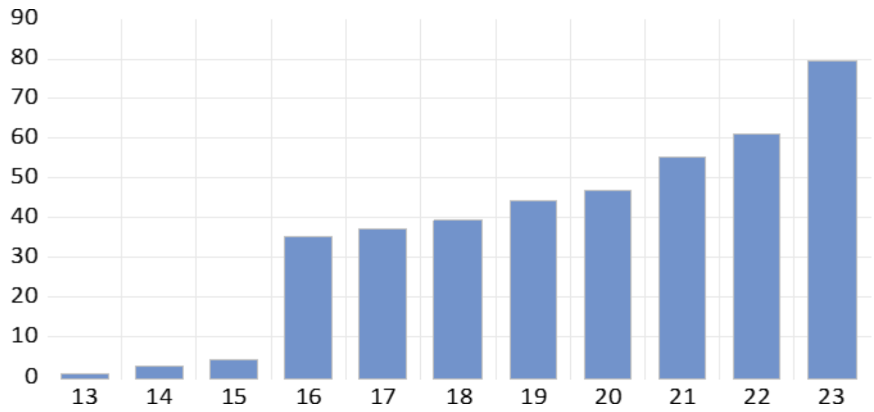

Figure 1. Annual amount of energy received from solar power plants in Azerbaijan (With million kWh, 2013-2023).
Source: ARDSK (The State Statistical Committee of the Republic of Azerbaijan, in Azerbaijani).

The solar energy potential in Azerbaijan offers a forward-looking perspective. Nevertheless, what stands out is the gradual expansion of production capacity from this foundational phase, extending beyond other mega projects slated for implementation. This study delves into the evaluation of Azerbaijan's 10-year solar energy production trajectory and extrapolates future forecasts based on observed growth trends.

2. LITERATURE REVIEW

The ARIMA (AutoRegressive Integrated Moving Average) model was initially formulated by Box & Jenkins (1976). In recent decades, the ARIMA model and its derivatives have been extensively employed, predominantly attributed to their mathematical simplicity and adaptable applicability. Numerous studies in contemporary scientific literature have explored the application of this model. Shumway et al. (2017) undertook comprehensive research on diverse ARIMA models and their suitability in practical applications.

Several scientific studies have explored the econometric analysis of energy issues employing the ARIMA model. Ediger & Akar (2007) argued that time-series models provide more accurate forecasts for Turkey's energy demand, projecting a slowdown and recommending policy adjustments such as inter-fuel substitution. Pasari & Shah (2020) formulated an ARIMA model utilizing a software program to forecast daily and monthly wind speed and temperature in Gujarat, India. Their findings suggest that ARIMA offers more precise wind power forecasts compared to solar power for this particular dataset. Chodakowska et al. (2023) demonstrated that ARIMA models are proficient in forecasting solar radiation across diverse climates, emphasizing the necessity for adaptation to each unique location. In another study example, Atique et al. (2019) applied an ARIMA model to forecast daily solar energy output from a research facility, obtaining satisfactory result s while acknowledging avenues for improvement in future research efforts. In addition to the mentioned studies, several other scholarly works relevant to the topic can be identified (Erdogdu, 2007; Sen, Roy, & Pal, 2016; Alsharif, Younes, & Kim, 2019)

In the Azerbaijani context, where scientific literature on energy evaluation utilizing the ARIMA model is notably scarce, Mammadov (2023) made a significant contribution by employing this model to forecast natural gas production. In general, there has been a plethora of studies focusing on the renewable energy sector in Azerbaijan. Vidadili et al. (2017) conducted an investigation into Azerbaijan's potential transition to renewable energy for sustainable development, driven by global climate concerns, limitations on fossil fuel resources, and the country's dependence on its oil-centric economy. Hasanov (2023b) carried out a comprehensive green economic review of solar, wind, and waste energy, which represent the primary forms of renewable energy that have emerged in Azerbaijan over the past decade. Additionally, a considerable number of significant scientific studies have been conducted in Azerbaijan, examining various aspects of renewable energy types from multiple angles (Mukhtarov, et.al, 2020; Gulaliyev, Mustafayev, & Mehdiyeva, 2020; Mustafayev, Kulawczuk, & Orobello, 2022; Hasanov, Mukhtarov, & Suleymanov, 2023).

3. DATA AND METHODOLOGY

Securing a reliable database is paramount for the execution of the present study. We obtain the data on solar energy production in Azerbaijan spanning from 2013 to 2023. The primary database utilized for the scientific investigation into solar electricity production from renewable energy sources in Azerbaijan was sourced from the official website of the State Statistics Committee of the Republic of Azerbaijan (ARDSK). Additionally, key data centers operated by the Ministry of Energy of the Republic of Azerbaijan (Minenergy) and the State Agency for Renewable Energy Sources (Area) under that Ministry were extensively employed. The variable of interest, solar energy production (Y = SEP), served as the main unit of analysis in this scholarly endeavor. This variable, also referred to as D(SEP) in models and formulas, represents the differenced number.

The ARIMA model is commonly acknowledged for its effectiveness in forecasting financial trends, as substantiated by abundant academic research and econometric investigations concentrated within this specific realm. Nonetheless, this study deviates from convention by conducting a thorough analysis of energy production dynamics, thereby expanding the applicability of ARIMA beyond its theoretical-empirical foundations. ARIMA model is widely recognized as a prominent statistical methodology utilized for forecasting time series data. Employed for analyzing and forecasting future values, this model synthesizes historical data to provide insights into future trends within a time series framework (Fattah, et. al, 2018). In an ARIMA model, labeled as ARIMA (p, d, q), p signifies the autoregressive terms, d represents the differences, and q denotes the moving averages (Gosh, 2020). The 'p' parameter within ARIMA delineates the sequence of autoregressive elements, establishing the quantity of prior observations incorporated for forecasting through regression against historical data. Meanwhile, 'd' delineates the integration order, indicating the frequency of differencing required to attain stationarity in the time series data, thereby upholding enduring statistical coherence across temporal spans. Autoregressive models forecast future values based on a linear combination of their past occurrences. In this study, we explore this approach to forecast sales, represented by equation:

$$Y_t = \alpha_1 Y_t^1 + \varepsilon_t \quad (1)$$

where:

- Y_t is the production in period t.
- Y_t^1 is the production in the previous period.
- ε_t is the error term, assuming white noise (independent and identically distributed with zero mean).

Building upon this foundation, it is proposed a more intricate model expressed in equation:

$$Y_t = \delta + \alpha_1 Y_t^1 \theta_1 t_1 + \varepsilon_t \quad (2)$$

where:

- δ is a constant term.

- α_1 is the coefficient of the autoregressive process, indicating the influence of the previous period's production (Y_t^1) on the current period's sales (Y_t).
- θ_1 is the coefficient of the moving average process, incorporating the impact of the previous period's error term (ε_t^1) on the current production.
- t_1 is a white noise term.

The construction process of the ARIMA Model is methodical and necessitates comprehension of stationarity, differencing, and the ARIMA model notation (p, d, q). To determine the suitable ARIMA model, a series of steps are undertaken. Initially, stationarity testing, such as the Dickey-Fuller test (1979), is conducted alongside differencing. Subsequent to this, autocorrelation and partial autocorrelation analysis are performed, involving the visualization of ACF and PACF plots to identify potential AR and MA terms. Following this, the model is chosen based on ACF/PACF plots and information criteria (AIC, BIC), thereby selecting the optimal ARIMA model. Subsequently, parameter estimation is carried out by estimating the parameters of the chosen model using maximum likelihood estimation. Finally, out-of-sample forecasting is conducted by applying the model to a hold-out period and comparing the forecasts with actual data using the Eviews program. The estimated ARIMA model is then utilized for forecasting solar energy production (SEP) in 2024-2030.

4. EMPIRICAL RESULTS AND DISCUSSION

Table 2 illustrates the descriptive statistics concerning solar electricity production in Azerbaijan, providing a summarized depiction of its distribution. The mean, representing the typical value, indicates that Azerbaijan generated an average of 36.982 million kWh of solar electricity per annum over the specified timeframe. The median, delineating the midpoint of the dataset, signifies that in half of the observed years, solar electricity production surpassed 39.300 million kWh, while in the remaining half, it remained below this figure. In Azerbaijan, the maximum annual solar electricity production is 79.400 million kWh, with the minimum recorded at 0.800 million kWh per year. The standard deviation of 25.265 million kWh indicates significant variability in yearly solar electricity generation, while a Skewness value of 0.153 suggests a distribution close to symmetry. Moreover, with a Kurtosis of 2.119, the distribution of solar electricity production tends towards a more peaked shape.

Table 2. Descriptive statistical view.

Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
36.981	39.300	79.400	0.800	25.265	0.152	2.119

Table 3 presents the findings of an Augmented Dickey-Fuller (ADF) unit root test conducted on a time series dataset representing solar energy production (SEP) in Azerbaijan. This test aims to ascertain whether the data exhibits a unit root, indicating a propensity for random fluctuations without returning to a consistent mean over time. The table provides the test statistic, p-value, and lag length for the null hypothesis positing the presence of a unit root in the data. According to the results, we fail to reject the null hypothesis of a unit root in the data at the 5% significance level, except for the 2nd difference.

Table 3. Unit Root Test Result.

Augmented Dickey-Fuller		Level	1st Difference	2nd Difference
Trend and Intercept	t-statistic	-2.294	-3.049	-8.916
	p-value	0.401	0.175	0.001

Phillips-Perron		Level	1st Difference	2nd Difference
Trend and Intercept	t-statistic	-2.140	-3.310	-6.290
	p-value	0.466	0.129	0.006

In the majority of econometric analyses, the AR(I)MA model is preferred over ARMA due to the non-stationarity of the data. In this study, non-stationarity was detected during the initial data analysis, prompting the adoption of the AR(I)MA (p,d,q) model for experimentation. During the identification phase, a correlogram is crafted to determine the values of p (AR component) and q (MA component).

Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) functions are utilized during this process to discern the most appropriate model. Autocorrelation (AC) refers to the assessment of the likeness between a variable's current value and its historical values. In the context of solar energy, AC would evaluate how today's solar energy production aligns with past production levels. A positive AC signifies that above-average solar energy levels today tend to be followed by similarly high levels in subsequent days, whereas a negative AC indicates an inverse association, where higher levels today are followed by lower levels in the following days. Partial Autocorrelation (PAC) assesses the level of correlation between a variable and its previous values, considering the impact of intervening observations. In solar energy analysis, PAC serves to examine the attributes of a single variable. Positive PAC values indicate a direct correlation, whereas negative values imply an inverse relationship. Figure 2 offers a detailed portrayal of the correlogram specifically concerning solar energy production (SEP).

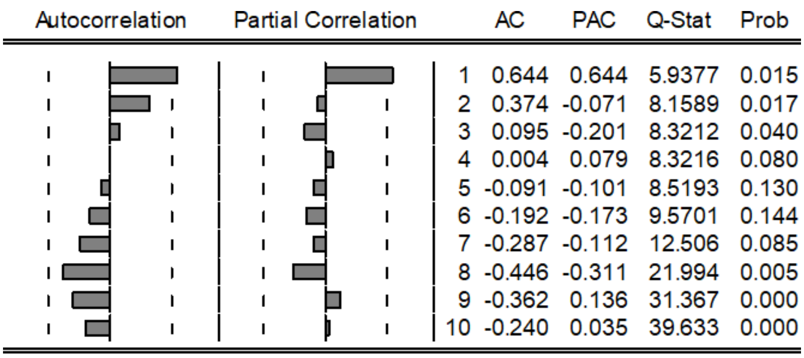

Figure 2. Correlogram of SEP.

The trends observed in the AC and PAC graphs within the correlogram are examined to determine the primary directions of the model. We perform estimation for the following equation to identify a potential candidate model for forecasting, ultimately leading to the forecast:

$$D(SEP) = C(1) + AR(1) * C(2) + MA(1) * C(3) + UNCOND \quad (3)$$

D(SEP) denotes the differenced solar energy production, while C(1), C(2), and C(3) represent the coefficients corresponding to the constant, autoregressive (AR), and moving average (MA) components, respectively. The unconditional component UNCOND (3) represents any additional factors not explicitly accounted for by the autoregressive or moving average terms, providing a residual term to the model.

For a univariate process to be regarded as stable, it is crucial that the residuals of the model exhibit characteristics consistent with White Noise. This criterion is examined through the

Ljung-Box Q statistic, which assesses the null hypothesis. In this context, if the estimated ARMA model displays covariance or stationarity, it is expected that the Autoregressive (AR) roots are situated within the unit circle. Conversely, to ensure invertibility of the ARMA process, all Moving Average (MA) roots must be contained within the unit circle. In time series analysis, data is frequently modeled using AutoRegressive (AR) and Moving Average (MA) models. The inverse roots of these polynomials are pivotal in defining the properties of the model. In Figure 3, the blue point situated within the unit circle, characterized by a radius of 1 and centered at the origin, signifies the stationary and invertible attributes of the ARMA model. The placement of the red dot precisely on the circumference of the unit circle signifies marginal stability within the model.

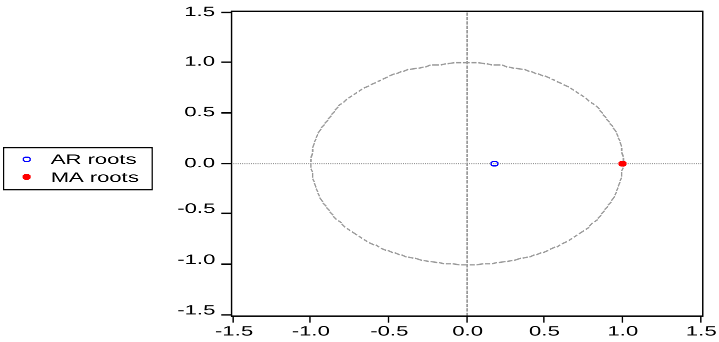

Figure 3. D(SEP): Inverse Roots of AR(1)MA(1) Polynomial(s).

The provided graph in Figure 4 displays the forecasted outcomes of an AR(1)MA(1) model applied to solar energy production (SEPF) in Azerbaijan. It reveals a consistent upward trajectory over time, indicating an anticipated growth in solar energy generation within the country in the years ahead. The dotted orange lines represent the confidence interval (+2 S.E.), outlining the range in which actual values are expected to fall. The widening of this interval over time suggests increasing uncertainty in the forecasts as we extend further into the future.

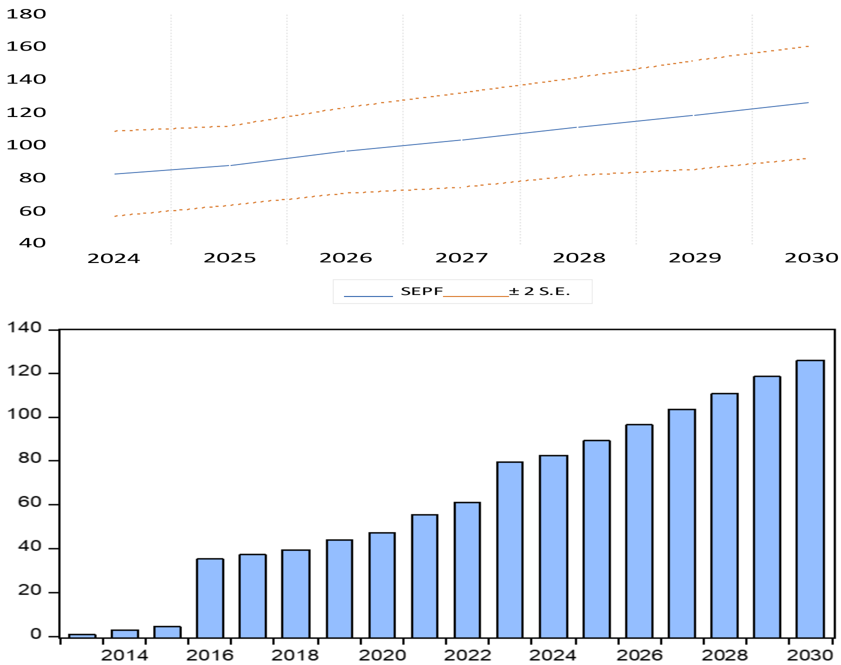

Figure 4. Solar energy production forecast (SEPF) results (in million kWh).

The forecast analysis spans from 2024 to 2030, encompassing the period when predictions are made. Simultaneously, the graphical representation extends from 2013, marking the inception of solar energy production, to 2030, the endpoint of the forecast, offering a comprehensive view of the entire timeline, including historical data and projected trends.

It is crucial to acknowledge that while forecast analysis provides valuable insights, it is not infallible due to the multifaceted nature of economic dynamics. The ARIMA model, while offering useful forecasts, relies on the assumption that future trends will mirror past patterns. However, the complexities of real-world factors can lead to deviations between forecasted and actual values. Hence, continuous updating of the model with new data and consideration of additional influencing factors are also essential for robust forecasting practices.

The study indicates a positive trajectory in Azerbaijan's solar energy production, potentially influenced by advancements in solar technology, increased investment in renewable energy, and governmental policies promoting solar energy adoption. Several factors, including governmental policies such as feed-in tariffs, tax incentives, and financial support aimed at encouraging solar power plant development, as well as heightened awareness of climate change emphasizing the significance of clean and sustainable energy sources like solar power, might have contributed to the increase in solar energy production.

In 2022, the total energy output from the 10 stations amounted to 45 MW. There are plans to elevate this figure to 1,500 MW in the future, leveraging the opportunities presented by the existing potential. A significant factor that is anticipated to have a substantial impact on future renewable energy production in Azerbaijan is the execution of state mega projects. As these projects unfold and undergo careful analysis of their actual potential and performance metrics over time, they are expected to shape the course of renewable energy generation in the country. The 230 MW Garadagh Solar Power Plant (President.az, 2023) and the 240 MW Shafaq Solar Power Plant (BP, 2022) exemplify major investment undertakings in renewable energy production in Azerbaijan. These projects are expected to significantly enhance the country's solar energy generation capacity in the coming years.

5. CONCLUSION

This research has provided a comprehensive overview of solar electricity production in Azerbaijan, detailing the country's potential and existing infrastructure. Through empirical analysis utilizing key econometric methods, the study applied the ARIMA model to forecast solar energy production trends over the subsequent six years. The mathematical modeling revealed that, should the current trajectory persist, Azerbaijan's solar energy production is projected to surpass 120 million kilowatt hours by 2030. These findings underscore the importance of continued investment and strategic planning in renewable energy initiatives to meet growing energy demands while advancing towards sustainability goals. In the context of a discussion panel, it can be elucidated that the metric analysis is limited to a decade-long trend, thus additional factors such as upcoming mega projects have the potential to significantly augment solar electricity production.

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Conflicts of Interest:

The author declares that they have no competing interests.

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