

**THE REPUBLIC OF AZERBAIJAN**

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**ABSTRACT**

Of the dissertation for the degree of Doctor of Philosophy

**MODELS FOR FORECASTING EXPORT PRICES OF  
LOCALLY PRODUCED ELECTRICITY IN AZERBAIJAN  
FOR THE MEDIUM AND LONG TERM**

Speciality: 5312.01 – “Field economy”

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## GENERAL NATURE OF THE WORK

**Actuality of the research.** Electricity, with its countless benefits transforming every aspect of our lives, stands as one of the greatest discoveries of the modern world. Considered the lifeblood of industrial development, electricity strengthens production processes, accelerates innovation, and ensures the more efficient implementation of processes. The availability and reliability of electricity infrastructure are crucial not only for attracting investments and stimulating economic growth but also for supporting continuous development. Additionally, electricity plays a significant role in meeting the energy demands of household activities, and modern transportation, thus improving overall living standards, enhancing education and healthcare outcomes, and contributing to social welfare and progress.

Future global electricity markets are expected to witness several new trends, including the transition from heavy industry to the service sector, which will lead to a relatively reduced demand for electricity. The use of renewable energy sources in electricity production is forecasted to double globally by 2050. Furthermore, investments in energy storage technologies, microgrids, digital technologies, and energy efficiency emerge as focal points for electricity companies. In recent years, one of the significant transformations observed in electricity markets is the transition from regulated prices to market-determined prices. This restructuring process involves gradually shifting from state-integrated entities to private participants. Internationally, various market structures, including models with full state control over the value chain, models where independent producers collaborate with state energy companies, and models where independent producers and private participants engage in production and sharing, are gradually replacing each other. Therefore, the evolution of electricity markets encompasses increasing demand for sustainable energy sources, the importance of efficient market organization, and the transition to market-determined prices from regulated prices. Considering these developments, it is crucial for Azerbaijan, which has emerged as one of the leading states in energy exports, to consider the transformative changes in global energy

markets in its energy policy.

With abundant natural resources, Azerbaijan increasingly recognizes the strategic importance of electricity in promoting economic development and reducing dependency on hydrocarbon exports. Hence, the development of the energy sector, particularly electricity production, infrastructure development, and increasing exports, has become a catalyst for stimulating the country's trade balance. By investing in electricity production from various sources such as hydro, thermal, and renewable energy, Azerbaijan has increased its potential to export electricity to neighboring countries. This expansion not only strengthens the country's trade balance but also creates extensive opportunities for regional cooperation and diplomatic relations. Currently, electricity export serves as a vital tool for generating revenue, reducing trade deficits, and strengthening Azerbaijan's position in the global energy market.

Electricity trade encompasses wholesale and retail sales, including contracts for the resale of electricity, spot markets, and derivatives markets. Regarding retail sales, direct sales of electricity to end-users are envisaged through contracts with retail sales companies.

Accurately determining export prices in electricity trade holds particular significance as it directly influences market dynamics, competitiveness, and revenue generation. It should be noted that establishing the correct price for electricity export requires comprehensive analysis considering various factors such as production costs, market demand, transmission infrastructure, regulatory frameworks, and geopolitical influences. Accurate price determination will enable Azerbaijan to ensure fair and sustainable economic returns while optimizing the export potential of electricity. Furthermore, precise price determination will contribute to attracting foreign investment, market stability, and fostering long-term partnerships with neighboring countries, thus enhancing Azerbaijan's credibility as an energy exporter and strengthening international cooperation.

Given the foregoing, addressing the impending issue demands consideration of contemporary realities in our country's economy. The relevance of these issues has dictated the selection of the topic and the determination of its purpose and objectives for dissertation research.

**Literature review.** Several scientific works by scholars and experts such as H. Hashimov, N. Hacıyev, Y. Hasanli, N. Yusifbeyli, V. Nesibov, A. Huseynov, G. Mammadova, and others shed light on various problems related to the efficient operation of Azerbaijan's energy system, including research on electricity demand and pricing. In their scientific works, these scholars have illuminated a range of current issues in the energy sector, including electricity pricing research. Forecasting electricity prices in liberal markets is a subject that has been explored in numerous studies and scientific works by researchers such as Z.C. Taysi, C. Özyıldırım, M.F. Beyazit, A. Ozozen, İ. Talaslı, A. Hayfavi, F. Ziel, R. Weron, J. Janczura, B.R. Szkuta, G. Gareta, J.P. Catalao, H.T. Pao, J. Zhang, N. Amjady, M. Hemmati, J. Che, J. Wang, S. Anbazhagan, N. Kumarappan, J. Mei, Adalı, and G. Gao. However, despite the existing research in these scientific directions, new problems arise due to complex international conditions, changing economic structures, and increasing competition at both regional and global levels. It can be said that the development directions of energy policy in Azerbaijan have not been sufficiently explored. Moreover, issues related to forecasting electricity prices have not been adequately addressed. Therefore, Azerbaijan's energy policy in the context of modern economic development trends, particularly the targets and strategies for the republic's electricity exports, must find its own solutions.

**Purpose and Objectives of the Dissertation Work:** The purpose of the research work is to develop forecast models for export prices of electricity produced in Azerbaijan. To achieve the set goal, the following tasks have been formulated and addressed: Determining the current situation and development trends of global electricity markets. Evaluating the prospects of the restructuring of electricity markets and the transition to liberal market models. Identifying and systematizing the main principles influencing price formation in electricity markets. Clarifying the content and characteristics of existing energy market forms. Studying the models used for forecasting electricity prices. Researching the formation and development of a liberal electricity market in Azerbaijan. Evaluating Azerbaijan's electricity export potential and exploring possible export

strategies. Determining the applicability of ARIMA and LSTM models in forecasting export prices of Azerbaijan's electricity. Assessing Azerbaijan's electricity export potential and developing a possible export strategy.

**Object and Subject of Research:** The object of the research work is Azerbaijan's electro-energy industry. The subject of the research work is the theoretical, methodological, and practical issues of forecasting short and long-term export prices of electricity produced in Azerbaijan.

**Research Methods:** To address identified problems in the dissertation work, various methodologies have been employed, including analysis and synthesis, induction and deduction, statistical and expert methods, scientific abstraction method, grouping method of indicators, analysis of dynamic series and forecasts, tabular and visual presentation of statistical indicators, organizational modeling approaches, among others. Statistical information processing in general involves the utilization of analytical software packages such as "SPSS" and "Python." These programs serve as tools for efficient data processing and analysis.

**The theoretical and methodological basis of the research** is derived from the Decrees of the President of the Republic of Azerbaijan, I. Aliyev, related to the development of the energy system, works of domestic and foreign scholars on issues of electricity price forecasting, legislative and regulatory acts regulating the energy system's activities, and documents of relevant authorities.

**The information base of the research** includes statistical compilations of the State Statistical Committee of Azerbaijan, materials of the International Energy Charter, the database of TEIAS, the electricity transmission operator of the Republic of Turkey, and information from the Ministry of Energy and Azerenerji ASC. Additionally, materials related to the research problem, monographs, and internet resources have been referenced in the writing of the dissertation.

**The main arguments presented for defense are characterized by the following:**

1. It is essential to conceptualize the scientific-theoretical foundations

of electricity price forecasting, including historical data and market trends.

2. Researching methodological approaches to determining the development trends of modern liberal electricity markets is crucial.
3. There is a need for analysis of Azerbaijan's energy system, including the assessment of energy production types and the analysis of the dynamics of the energy transmission system.
4. There is a necessity for a systematic analysis of the impact of forecasting on the economic efficiency of energy production and distribution companies, as well as investment decisions and risk management processes.
5. In addition to statistical methods, the use of machine learning algorithms and artificial intelligence is essential for identifying prospective directions in electricity price forecasting mechanisms.
6. ARIMA and LSTM models offer promising avenues for forecasting Azerbaijan's electricity export prices, surpassing traditional regression models in accuracy.

**Scientific Innovation of the Research:** In the research, for the first time, the problems of forecasting Azerbaijan's electricity export prices were comprehensively studied, and as a result of the models developed to implement price forecasting, scientific ideas were further expanded.

As a result of the research, the following scientific innovations were obtained:

1. During the study, for the first time in the country, the forecasting of electricity prices was carried out based on time series, using input and output variables, analysis of results and model architecture parameters. If in the studies carried out until now, the focus was more on demand forecasting, price forecasting was performed with the application of new models.
2. ARIMA and LSTM models were proposed for forecasting the price of electricity based on historical data in the electricity market in the thesis, and it was found that these models give more accurate results than traditional regression models.
3. Empirical approach used during the research revealed that it is possible to model Azerbaijan's electricity prices in a very promising

way.

4. The results of the research conducted in this work show that the presented model clearly outperforms the standard and even well-performing methods available in the literature in terms of error measures such as MAE and RMSE.
5. Machine learning algorithms prove to be more effective than ARIMA models in identifying non-linear changes in Azerbaijan's electricity prices, indicating the superiority of modern machine learning models.
6. The research suggests the refinement of models for forecasting Azerbaijan's electricity prices and prioritizes the use of hybrid models to achieve more accurate results.

**The practical importance of the research** stems from the fact that the methodological approaches and proposed models in the dissertation can be utilized in the formulation of policies in the electricity sector, as well as in various stages of transforming the country's liberal electricity market and enhancing the efficiency of activities by market operators, generation operators, transmission operators, market operators, independent producers, and traders. The main arguments and results of the research have been considered and positively received in the activities of the Market Operator within Azərenerji ASC and during the teaching process of Financial Instruments at the Niagara Toronto Institute.

**The research findings and individual results** have been published in both domestic and international periodicals, and presented at international and national scientific conferences, symposiums, and seminars, including the "Strategic Priorities of Socio-Economic and Historical Cultural Relations" 1st International Conference on Social Sciences (Baku, 2022), International Conference Of Young Social Science Researchers (Baku, 2022), The XXVIII International Scientific Symposium "Karabakh Is My Native Land" (Amsterdam, 2022), and The XXIX International Scientific Symposium "Turks and The World: Problems of Mutual Relations" (Kars, 2022), and discussed. The research was conducted at the Azerbaijan Scientific Research Project and Energy Institute and the Financial Department of Niagara Toronto Institute.

The main findings of the dissertation have been included in the list of scientific journals approved by the Commission for Attestation under the President of the Republic of Azerbaijan, with 7 articles published, including 5 internationally.

**The name where dissertation work was performed.** Dissertation work was carried out at the Azerbaijan Scientific-Research and Project-Research, Energy Institute and the finance department of Niagara College Toronto.

**Structure and volume of the dissertation.** The dissertation consists of an introduction (8 pages - 15,367 characters), three main chapters of research (Chapter I (41 pages - 73,406 characters), Chapter II (20 pages - 31,747 characters), Chapter III (53 pages - 74,031 characters)), a conclusion reflecting the main findings of the research (3 pages - 5,848 characters), a bibliography (12 pages), and a summary list (1 page), totaling 140 pages. The dissertation includes 10 tables, 14 figures, and 6 graphs to ensure the directionality of the research topic. The total character count of the dissertation (excluding the bibliography, tables, figures, and graphs) is 200,399 characters.

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## MAIN SCIENTIFIC POINTS DEFENDED IN THE THESIS

The first chapter, titled "Theoretical and Methodological Foundations of Price Formation in Global Energy Markets," explores the nature and economic importance of energy, the characteristics of global electricity markets, changes in the structure of international electricity markets, the transition of global electricity markets to the liberal market model, and the determination of electricity prices based on sequential models.

**Clause 1. For the first time, the forecasting of electricity prices has been carried out based on the time horizon, input and output variables used, analysis of results, and model architecture parameters. Unlike previous studies, which focused more on demand forecasting, price forecasting has been achieved through the application of new methods.**

Using data covering the period from 2012 to 2022, the prices for Azerbaijan's electricity exports in global markets have been modeled and future price forecasts have been made based on statistical methods. The research compared the application of the ARIMA model, a traditional statistical method, with modern artificial neural network (ANN) techniques and found that the latter yielded superior results.

During the research, data from 2012 to 2022 on the average daily selling prices of Azerbaijan's electricity were used. Information on energy prices was obtained from the database of TEİAŞ. It should be noted that except for the crisis year of 2015, Azerbaijan's electricity exports have been continuously increasing in terms of both quantity and export revenues from 2012 to 2022, thereby significantly impacting the country's economy.

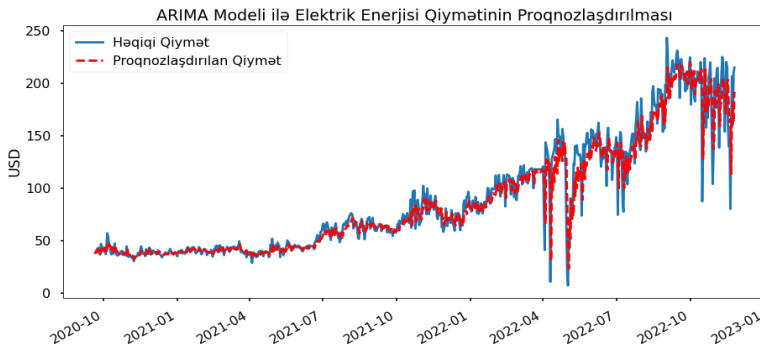
While many different variables, different periods, and different information sources and forecasting methods have been used in research on forecasting electricity prices in global markets, it has been observed that artificial neural networks (ANNs) outperform conventional forecasting methods. Especially during non-linear periods, the superiority of ANNs over traditional forecasting methods lies in their ability to conduct analyses regardless of the stationarity of the series. In this context, it has been decided that the use of ANNs will

be appropriate for calculating Azerbaijan's electricity.

Traditional time series analysis methods such as the ARIMA model have also been used as forecasting methods. The ARIMA (autoregressive integrated moving average) model is considered one of the general methods that serves to model using past values of stationary time series and error values. In the study, ANN analyses were conducted using the Python programming language and the Keras library, while Time Series analyses were conducted using the EViews software package.

Before moving on to forecasting, it is required to check for autocorrelation and variance of variables in the ARIMA model estimation. It should be noted that the presence of autocorrelation and variance problems in the error terms as a result of ARIMA analysis will directly affect the accuracy of forecasting. For this purpose, the results of the Ljung-Box test, which is widely used for autocorrelation testing, have been reviewed.

The results of the Ljung-Box autocorrelation test indicate that there is no autocorrelation problem among the error terms up to the third order. Furthermore, autocorrelation and partial autocorrelation coefficients and graphs show that there is no autocorrelation problem with respect to errors up to the seventh lag.



**Figure 1. Forecasting Electricity Prices with the Final ARIMA Model**

After checking for autocorrelation and variance in the evaluation, an attempt was made to forecast the electricity sales price in

Azerbaijan from November 2020, the last month of the original series, as shown in Figure 1 in comparison with real prices. As evident from the forecast results, while the selected model may not accurately predict sharp changes in electricity prices, it can be considered successful in forecasting average prices. It should be noted, however, that as previously noted in other studies, the results obtained in this study suggest that ARIMA models are not suitable for accurate price forecasting but may yield more effective results in providing general forecasts.

**Clause 2. Based on historical price data in the electricity market, ARIMA and LSTM models have been proposed for the advance prediction of electricity prices, with these models found to provide more accurate results than traditional regression models.**

During the research, using data covering the years 2012-2022 for Azerbaijan's electricity sales prices in international markets, comparisons were made between the ARIMA model, a statistical method widely used in modern research, and artificial neural networks (ANNs). Based on this comparison, the model with higher forecasting power was determined.

The study utilized data from 2012 to 2022 regarding the average daily sales prices of Azerbaijan's electricity, obtained from the TEİAŞ database. It should be noted that except for the crisis year of 2015, Azerbaijan's electricity exports witnessed continuous growth in both quantity and export revenues from 2012 to 2022, thereby significantly impacting the country's economy.

Traditional time series methods, such as the ARIMA model, were employed as forecasting methods. The ARIMA (autoregressive integrated moving average) model is considered one of the general methods that serve to model using past values of stationary time series and error values. In the study, ANN analyses were conducted using the Python programming language and the Keras library, while Time Series analyses were conducted using the EViews software package.

The forecasting stages carried out using the ARIMA model are listed below, followed by an explanation of each stage:

- Initial Description and Visualization of the Data Set: Initial

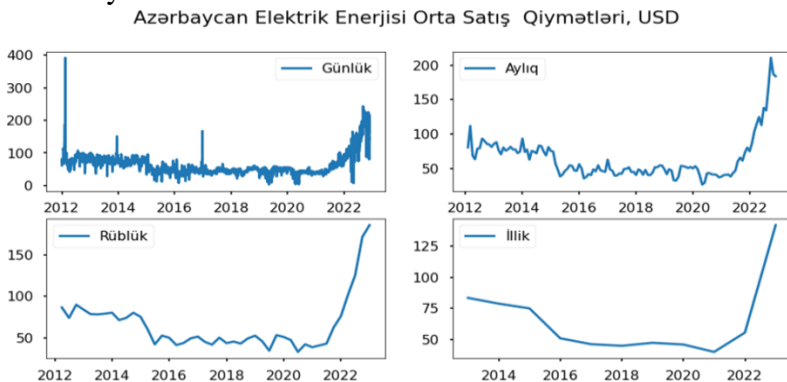
descriptive analysis of the time series data was performed to understand trends and seasonality. An attempt was made to determine whether the ARIMA model is suitable.

- **Standardization of the Data Set and Testing for Stationarity:** The data set was transformed to a range of 0-1 to reduce outliers, and then stationarity was tested. Stationarity is a requirement for ARIMA models. If the data is not stationary, taking the difference of the data is required to achieve stationarity. (Phillips-Perron and ADF stationarity tests conducted using the Eviews program revealed that the electricity price variable was not stationary.)
- **Taking the Difference of the Variable (d value in ARIMA):** If the data is not stationary, an attempt was made to achieve stationarity by taking the difference of the variable with its value from one period ago. Differencing removes the previous observation from the current one. The calculation resulted in the first difference making the series stationary.
- **Analysis of Autocorrelation and Partial Autocorrelation (determination of p and q values):** Autocorrelation and partial autocorrelation graphs were analyzed using the Eviews program to determine the appropriate order of autoregressive (p) and moving average (q) terms for the ARIMA model. The autocorrelation graph helped determine the q value, while the partial autocorrelation graph helped determine the p value.
- **Identification of the ARIMA Model:** Based on the results of the previous steps, appropriate values for p, d, and q were determined to identify the ARIMA model. Accordingly, based on the results of the autocorrelation test, the p value (autocorrelation value) was determined to be 2, the d value (difference) was determined to be 1, and the q value (moving average) was determined to be 2.
- **Evaluation of the ARIMA Model:** Using the respective values of p, q, and d, the parameters of the ARIMA model were estimated using the Maximum Likelihood Estimation method. It is worth noting that seasonal observations were observed during the initial analysis; therefore, the SARIMA form of the

ARIMA model was used, which includes both the non-seasonal and seasonal components.

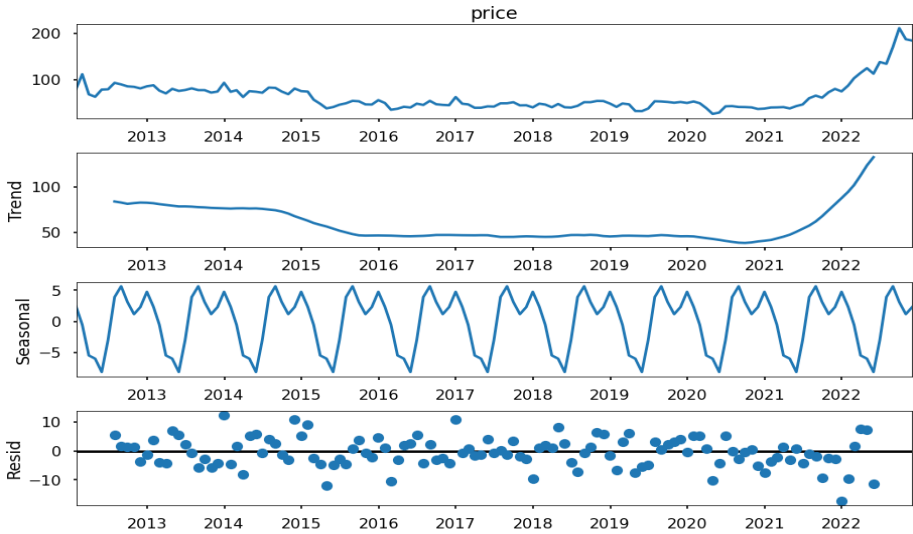
- Diagnostic Checking of the Model: Evaluation was conducted to ensure that the residuals of the ARIMA model follow a normal distribution with zero mean and constant variance. The Ljung-Box test was used to check for autocorrelation in the residuals.
- Forecasting with the Model: The results of the ARIMA model estimated were utilized to forecast the outcomes for the years 2020-2022 to provide forecasts for future periods.
- Evaluation of the Model: To properly evaluate the ARIMA model, the forecasted values were compared with the actual values, and appropriate evaluation measures such as Mean Squared Error (MSE) or Mean Absolute Error (MAE) were used.

Before commencing the application of the ARIMA methodology, it was imperative to initially observe the fluctuations in electricity sales prices over time to formulate an initial understanding of stationarity. For this purpose, a graphical analysis was conducted to depict the daily, monthly, quarterly, and yearly trends of Azerbaijan's electricity sales prices, as presented in Figure 1, thus forming an initial perception of stationarity.



**Figure 2. Presentation of Azerbaijan's electricity sales prices over different periods**

As evident from the figure, considering the variability in price changes over time, its stochastic, trend, and seasonal components were presented in Figure 3.



**Figure 3. Deterministic (trend and seasonality) and stochastic components of Azerbaijan's electricity prices from 2012 to 2022**

During the forecasting of time series with ARIMA, it is crucial to consider that variables possess a unit root (stationarity) property, indicating that the effect of any shock to the variable will not be long-lasting. Therefore, before forecasting, efforts were made to determine the stationarity properties of the series through ADF and PP tests. Additionally, considering volatility in time series, it was deemed appropriate to transform the price variable to ensure normal distribution properties and mitigate the issue of changing variance. Within the research framework, standardization of the data set was required for price forecasting purposes. For this purpose, the minimum-maximum scaling method was employed for data set standardization, transforming the data set to fit within the range of 0-1.

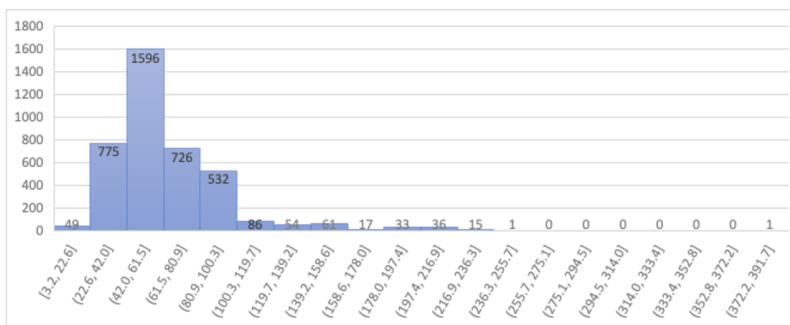
**Table 1. Initial Description of the Data Set: Statistical Analysis**

Statistical Measure	Value
Mean	63.92
Median	55.56
Standard Deviation	32.67
Kurtosis	8.86
Skewness	2.43

Source: Compiled by the author.

The table demonstrates that the mean price of electricity in Azerbaijan from 2012 to 2022 was \$63.92, with a median of \$55. Additionally, during the same period, the standard deviation was 32.67, indicating significant volatility in prices, suggesting a high level of risk. It is noteworthy that over the past decade, the maximum price of Azerbaijani electricity in international markets was recorded at \$391 on February 13, 2012, while the minimum price was \$3 on May 5, 2019. Skewness and kurtosis indicators, recorded as 2.43 and 8.86 respectively, suggest a distribution of data similar to standard values as noted by Hari et al. (2010).

Based on the histogram depicted in Figure 1, prices during the period were primarily between \$42 and \$61, with a range spanning from \$22 to \$81. However, it was observed that due to sharp price increases, other groups also had sufficient distribution within this range.



**Graph 1. Distribution histogram of Azerbaijan electricity sales prices in 2012-2022**

Source: Prepared by the author.

Considering the above, standardization was conducted before modeling the data using the Minimum-Maximum normalization method. With this approach, the newly formed data were standardized to a range of 0-1. Subsequently, the data set was divided into training and testing data sets. For the prediction of time series, a Long Short-Term Memory (LSTM) model, a type of Recurrent Neural Network (RNN), was constructed using the Keras library in Python. LSTM networks are distinct for their ability to retain memory. To achieve this, new data sets for both the training and testing sets were sequenced to allow the models to consider previous data as input. The models were then tested with sequence lengths of 10, 20, 30, 50, and 60, and their performances were compared based on Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE) metrics, aiming to identify the LSTM model with the highest predictive power.

During the construction of the LSTM model, the first layer comprised 128 neurons, with parameters configured to utilize all input parameters for the output layer (`return_sequence=True`). The second layer consisted of 64 neurons, using only the output data from the last layer of sequences. The third layer was a Dense layer with 25 neurons responsible for processing the output data from the neurons. The fourth and final layer was a single-output layer without the use of an activation function.

**Clause 3. The empirical approach used initially indicated the potential for modeling Azerbaijani electricity prices effectively.** Until 2015, losses in transmission and distribution were high, resulting from station loading to meet demand. From this year onwards, reforms and renovation works in the national grid reduced technical losses significantly, leading to actual capacity increases despite an increase in subscriber numbers.

The installation of meters and tariff adjustments in 2016 particularly affected household consumption, resulting in a redirection of domestically consumed electricity for export, transforming Azerbaijan from a net importer to a net exporter by 2019. Azerbaijan's main export markets include Turkey and European countries, with occasional transit markets in Georgia, facilitating energy trade based

on demand and supply, resulting in significant differences in monthly and hourly prices. For instance, in Georgia, the balancing market ESCO manages electricity trading, while exchanges such as EPIAŞ in Turkey, IBEX in Bulgaria, and OPCOM in Romania operate in their respective countries.

These observations led to the following conclusions:

1. Azerbaijan aims to facilitate electricity transmission with neighboring countries through three main corridors: the North-South corridor between Russia-Azerbaijan-Iran, the Russia-Azerbaijan-Georgia corridor, and corridors linking Azerbaijan-Georgia-Turkey.

2. While efforts are made to explore efficient utilization of these corridors, ongoing works continue to enhance efficiency. For example, the construction of the 230 kV Masalli-Astara power transmission line with Iran is underway, aiming to increase the current 550 MVt transmission capacity to 700 MVt, which would significantly contribute to the integration of the Russia-Azerbaijan-Iran energy systems and facilitate transit power transfers.

3. Furthermore, considering the stabilization of Georgia's energy systems through Azerbaijan and the differing energy frequency regimes between Georgia and Russia, exploring bilateral agreements for the resale of Russian electricity to Georgia could aid in achieving export goals. It is also essential to evaluate the capabilities of cross-border lines and transmission systems to successfully implement regional integration.

**Clause 4. The research results indicate that the presented model overtly outperforms standard and even highly effective methods available in the literature in terms of error measures such as MAE and RMSE.**

Forecasting for day-ahead markets has been attempted in one of the leading electricity exchanges globally, Nord Pool Exchange. Multi-layer Artificial Neural Networks have been shown to have better predictive power in terms of MAPE, MSRE, and RMSE compared to ARIMA models. Time series are categorized based on the intervals at which they are observed, i.e., the frequency of observation. When time series are observed once a year, they are termed as annual; twice a year, semi-annual; four times a year, seasonal (quarterly); monthly for each

month of the year; and daily for each day of the year.

Autoregressive models were first introduced by Yule in 1926, and moving average models were used by Slutsky in 1937. In 1938, Wold combined autoregressive and moving average models to propose the autoregressive moving average (ARMA) method. However, the practical application of these models began only in the 1960s, coinciding with the development of computer technology.

A stochastic process where the current value of a variable is expressed as a function of its past values is referred to as an autoregressive process. In other words, an AR(p) model is a regression model with  $Y_t$  as the dependent variable and  $Y_{(t-1)}, Y_{(t-2)}, \dots, Y_{(t-p)}$  as independent variables, where p represents the number of lags, i.e., the number of past values considered.

$$AR(p) Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \dots + \phi_p Y_{t-p} + \delta + a_t \quad (1)$$

Here,  $Y_{(t-1)}, Y_{(t-2)}, Y_{(t-p)}$  represent the past observed values of the dependent variable, and  $\phi_1, \phi_2, \phi_3$  represent the coefficients of the past values. ARMA models can be expressed as a linear combination of a specified number of past values and error terms. In this regard, ARMA models encompass both autoregressive AR(p) and moving average MA(q) processes, and determining the optimal values of p and q lags is crucial. Given the aforementioned measures, multiple suitable models may exist, and in such cases, selecting the best model becomes imperative. The best model should fit the data well and possess high predictive power. To compare the forecasting abilities of models, various measures can be employed, including the sum of squared residuals (RSS), mean squared error (MSE), root mean squared error (RMSE), mean absolute error (MAE), mean absolute percentage error (MAPE), mean percentage error (MPE), mean squared percentage error (MSPE), and Theil's U-Inequality coefficient. Once the model is constructed and passes the adequacy tests, it can be used for future forecasting.

**Clause 5. The research findings reveal that machine learning algorithms, which allow for identifying non-linear changes in forecasting Azerbaijani electricity prices, are more effective than ARIMA models, indicating that modern machine learning models produce more efficient results.**

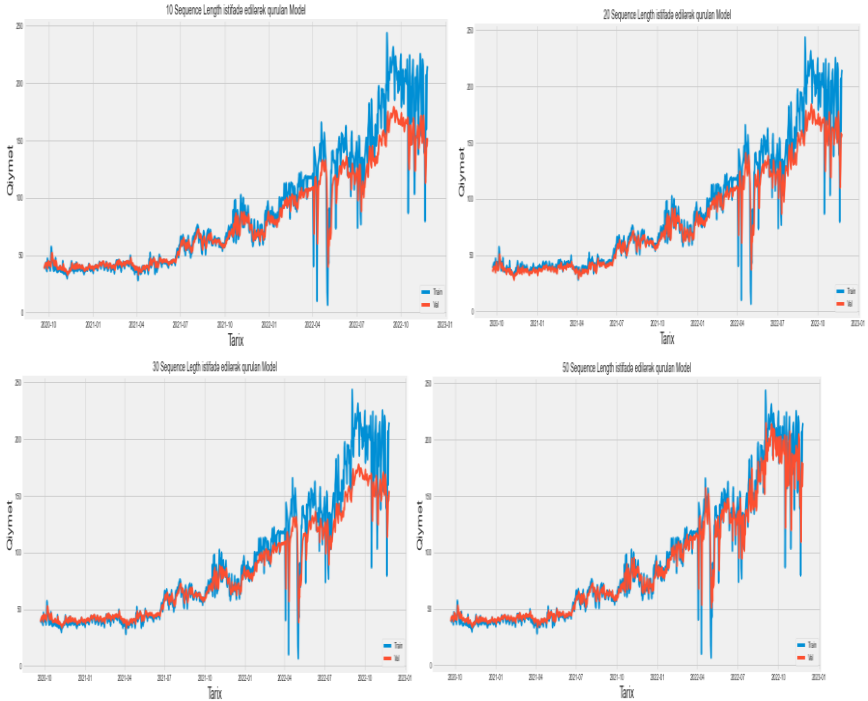
During the analysis of model results, it was observed that the best results were achieved with the application of 100 epochs and the Early Stopping method. Considering the high value of the epoch parameter, the batch size was set to 20 to expedite the training process. Subsequently, the most suitable model was selected, and it was applied to the test dataset reserved for this purpose. The factual and forecasted values of the data from September 20, 2020, to November 25, 2022, were compared across multiple parameters.

**Table 2. LSTM Analysis Results Based on Epochs and Error Values**

Sequence Length	MAE $\sum_{t=1}^n \left  \frac{y_t - \hat{y}_t}{n} \right $	RMSE $\sqrt{\frac{1}{n} \sum_{t=1}^n (y_t - \hat{y}_t)^2}$	MAPE $\sum_{t=1}^n \left  \frac{y_t - \hat{y}_t}{y_t} \right  \frac{100}{n}$
30	12.171	20.026	0.120
20	11.682	19.157	0.121
10	12.116	20.031	0.119
50	8.418	14.484	0.088

Source: Compiled by the author.

As evident from Table 2 and Figure 4, the LSTM model with 50 lag values, established with 20% test dataset, exhibited more successful results with 0.08 MAPE, 14.48 RMSE, and 8.48 MAE indicators for forecasting Azerbaijani electricity sales prices compared to other LSTM models. The results also demonstrated that the LSTM model, considered as one of the machine learning models, was sufficiently more accurate compared to the statistical method ARIMA model.



**Figure 4. Determining the Forecasting Power of the LSTM Model Using 100 Epochs and Early Stopping Method**

*Source: Compiled by the author.*

**Table 3. LSTM Analysis Results Based on Epochs and Error Values**

<b>Year</b>	<b>Mid price (\$/mVt)</b>
<b>2023</b>	146.14
<b>2024</b>	153.21
<b>2025</b>	158.22
<b>2026</b>	162.33
<b>2027</b>	165.65
<b>2028</b>	169.41
<b>2029</b>	172.51
<b>2030</b>	175.81

*Source: Compiled by the author.*

As a result, using a constructed LSTM model, export prices of electricity for Azerbaijan for the years 2023-2030 have been calculated, and the results are presented in Table 3. According to the forecast, the average annual growth rate of Azerbaijan's electricity price over the next 8 years will be 3 percent, reaching \$176 USD in 2030.

Overall, the analysis of time series encompasses both traditional statistical models like ARIMA through the Box-Cenkins method, as well as machine learning approaches such as artificial neural networks. These methods allow for the modeling and forecasting of time-dependent data, providing insights and forecasts in various fields. To this end, several studies have attempted to analyze the forecasting capabilities of various models for predicting electricity prices in specific markets by combining them with neural network models. For instance, Taysi et al. found similar performance between SARIMA and neural network approaches in modeling time series statistics in the Turkish electricity market. Ozyildirim and Beyazit (2014) introduced the radial basis function artificial neural network method, which outperformed linear regression models in modeling electricity prices. Ozozen et al., on the other hand, achieved more successful forecasts by combining seasonal ARIMA and artificial neural network models for predicting hourly electricity prices in Turkey.

In general, by presenting a range of models used in forecasting electricity prices, their strengths, and suitability for specific market conditions are highlighted. The comparative analysis of these models aids in determining the most effective approaches for accurate and reliable forecasting of electricity prices. While both the ARIMA and LSTM models demonstrate suitability for accurately forecasting the export prices of electricity produced in Azerbaijan, the machine learning model LSTM appears to be more effective compared to ARIMA.

**Clause 6. It has been proposed to enhance the relevant models for forecasting Azerbaijan's electricity prices and prioritize the use of hybrid models to achieve more accurate results in the electricity markets.**

In the final phase of the research work, a comparison of the models used for forecasting electricity prices has been conducted, and research has been carried out on which model is more effective for the medium and long term for the Azerbaijani energy system. Considering the unique characteristics of the electricity industry, the operation of sophisticated systems is crucial for the efficient operation of the national grid. The wholesale trade of electricity is conducted through various mechanisms, including short-term sophisticated markets (day-ahead, intra-day, and balancing markets), and long-term bilateral contracts. Daily markets operate after the closure of the day-ahead market, facilitating real-time balance of electricity production and consumption. On the other hand, bilateral contracts play a significant role in reducing risks associated with fluctuations in energy prices. Producers and consumers hedge against sharp price fluctuations in spot markets by entering into non-standard physical contracts. Futures contracts, forward contracts, energy option contracts, and energy swap contracts, including derivative financial products, play an important role in reducing risks in energy markets. These market mechanisms provide participants in the energy trading markets with stability and financial security by effectively managing risks associated with changes in energy prices. For example, energy futures contracts are standardized contracts traded on sophisticated futures exchanges, while forward contracts are customized contracts for specific terms. Energy swap contracts stabilize energy prices over a specified period, providing income for producers and price stability for consumers.

Similar to other time series models, factors affecting electricity prices on a daily, weekly, or yearly basis, in other words, seasonality, play a key role in price modeling approaches. When it comes to selecting variables for price forecasting, in addition to previous electricity prices, fundamental factors such as system loads, temperature indicators, fuel costs, and reserve limits are essential. Various modeling approaches are used for price forecasting. Multi-agent models simulate mutual interactions among various agents, such as companies, to build the price process. These models focus more on quality indicators and have limitations in accurately forecasting electricity prices. Fundamental models aim to determine physical and

economic relationships in electricity production and trade. Reduced form models focus on characterizing the statistical properties of electricity prices, while time series models analyze chronological data to forecast future values based on lagged variables, errors, or both.

Similar to other time series, the Box-Jenkins method, suitable for both stationary and non-stationary processes, is widely applied in price modeling approaches. The respective methodology covers several steps, including model identification, estimation, adequacy testing, and future forecasting. For this purpose, the series should first be brought to a stationary state by eliminating trends and seasonal effects. Then, model identification is carried out based on the graphs of autocorrelation and partial autocorrelation functions of stationary series. The autocorrelation function (ACF) helps determine the moving average (MA) term ( $q$ ) during the construction of ARIMA models, while the partial autocorrelation function (PACF) helps determine the autoregressive (AR) term ( $p$ ).

Moreover, in recent years, machine learning methods, especially artificial neural networks (ANNs), are widely used in time series analysis. When it comes to the advantages of artificial neural networks (ANNs), they outperform conventional methods in many forecasting tasks, including solving complex problems, handling incomplete data, and parallel processing. However, although some neurons may fail during data processing, the ability of ANNs to process information, suitability for solving non-linear problems, and the ability to make logical and real decisions based on learned events lead to higher results.

In conclusion, a range of models used in forecasting electricity prices have been presented in the literature, highlighting the strengths of each and their suitability for specific market conditions. The comparative analysis of these models helps determine the most effective approaches for accurate and reliable forecasting of electricity prices.

While both the ARIMA and LSTM models demonstrate suitability for accurately forecasting the export prices of electricity produced in Azerbaijan, the machine learning model LSTM appears to be more effective compared to ARIMA.

## **Results:**

As a result of the research, the following were concluded:

1. Considering the important role of electricity export in achieving Azerbaijan's long-term strategic goals, international strategies for export were considered.
2. During the research, by using statistical model ARIMA and LSTM, artificial neural network model, application of the hybrid model was achieved, which shows results more accurately than the price estimation models conducted in previous periods.
3. The research revealed that one of the most important changes characterizing electricity markets in recent years is the replacement of regulated electricity prices with prices determined by the market and the gradual transition of the field controlled by vertically integrated state-owned companies to liberal market models in which independent market participants are active.
4. SWOT analysis has been developed.
5. All models of the analyzes conducted during the research were comparatively evaluated and presented in the form of tables.
6. While comparing the accuracy of forecasts based on MAE and RMSE in the dissertation, it was found that the ARIMA model gives satisfactory results in short-term forecasting, but LSTM is more successful than machine learning models based on the neural network system in accurately determining price volatility.
7. Besides, the research results show that the presented model clearly surpasses the standard and even very good methods available in the literature in terms of error measures such as MAE and RMSE.
8. Based on the obtained results, it is desirable to continue work towards the improvement of relevant models for forecasting the price of electricity in the next studies and the study of the possible use of hybrid models in electricity markets to obtain more accurate results.

**The main provisions of the dissertation work, the obtained results and proposals are reflected in the following published scientific works:**

1. Ali Abbasov. Electricity market establishment and its current

- situation in Europe. Aqrosvit, Kiyev 2020, səh: 48-53.
2. Ali Abbasov. Electricity price forecasting models. *İnvestici-i-Praktika*. Kiyev 2020, N:886, səh: 75-79
  3. Nazim Hajiyev, Klaudia Smolag, Ali Abbasov, Valeriy Prasolov. Energy war strategies: The 21th century experience. *Energies*. 2020
  4. Ali Abbasov. “Karakabk is My Native Land!” The XXVIII International Scientific Symposium. Amsterdam, Holland 2022, səh:167-170.
  5. Ali Abbasov. “Turks and the World: Problems of Mutual Relations”, The XXIX International Scientific Symposium, Kars, Turkey, 2022, səh:164-168.
  6. Əli Abbasov. Azərbaycan Əmək və Sosial Münasibətlər Akademiyası, I Beynəlxalq Sosial Elmlər Konfransı, Sosial-İqtisadi və Tarixi-Mədəni Əlaqələrin Strateji Prioritetləri. Bakı 2022, səh:424-427.
  7. Ali Abbasov. Enhanced ARIMA approach of electricity price forecasting. *European Chemical Bulletin*. Budapest, Hungary 2023, səh:3405-3426.
  8. Ali Abbasov. Forecasting hourly electricity prices in European Nations: Utilizing machine learning and deep learning techniques for sustainable energy decision-making. *Journal of Harbin Engineering University*, Harbin, China 2023, səh: 2383-2392.
  9. Əli Abbasov. Elektrik enerjisi bazarlarında qiymət formalaşma mexanizmi və ticarətin strukturu. *İqtisadi İstlahatlar Jurnalı*. Azərbaycan Respublikası İqtisadi İslahatların Təhlili və Kommunikasiya Mərkəzi. Bakı 2023, səh:92-96.
  10. Ali Abbasov. Common Indicators of Electricity Markets and Trade Structures. *International Convergence of Young Social Science Researchers ICYSSR 2023*, UNEC, Bakı 2023, səh:7.
  11. Əli Abbasov. Box-Jenkins Metodologiyası əsasında qısamüddətli dövr üçün elektrik enerjisinin qiymətlərinin proqnozlaşdırılması xüsusiyyətləri. *İpək Yolu Jurnalı*, Bakı 2023, səh: 5-10.







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The dissertation can be found in the library of the Institute of Economics of the Ministry of Science and Education of the Republic of Azerbaijan.

Electronic versions of the dissertation and its abstract are available on the official website of of the Institute of Economics of the Ministry of Science and Education of the Republic of Azerbaijan ([economics.org.az](http://economics.org.az))

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