INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS
ISSN(print): 2643-9840, ISSN(online): 2643-9875
Volume 06 Issue 04 April 2023
DOI: 10.47191/ijmra/v6-i4-17, Impact Factor: 7.022
Page No. 1472-1482

Estimation of the Electricity Supply and Demand of Türkiye Employing Deep Learning Networks

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ABSTRACT: Electrical energy, one of the indispensable elements of the economic and social life, is an energy source that has to be provided without interruption in order to ensure the continuity of development. In this work, the monthly electricity supply and demand of Türkiye for the period of 2016-2022 are modelled using advanced machine learning techniques. An autoregressive deep learning network consisting of four hidden layers is developed for the modelling of the electricity supply and demand data having the form of multilayer perceptron artificial neural network. The electricity supply and demand data of Türkiye is gathered from the official sources and then investigated utilizing the seasonality analysis. Then, the deep learning network is developed in Python programming language. The 70% of the available electricity supply and demand data are used as the training data whereas the remaining 30% of the data is the test data. The randomized selection of the train and test data are performed using the classes available in the SciKit-Learn library of the Python programming language. The performance of the developed deep learning network model is evaluated both by plotting the actual and the modelled data on the same axis pair and by using performance metrics of the coefficient of determination, mean absolute error, mean absolute percentage error and the root mean square error. The mean absolute percentage errors of the models have the values of 2.29% and 2.17% for the electricity supply and demand data, respectively, indicating the success of the developed deep learning model for the modelling and the estimation of the electricity supply and demand data. The developed model is considered to be useful for the economic and technical energy planners.

KEYWORDS: Electricity supply, electricity demand, machine learning, deep learning, multilayer perceptron.

I. INTRODUCTION

Electrical energy is a clean energy resource which can be transmitted using electrical networks to distant points without significant loss. In addition, electricity can be transformed to other forms of energy such as the thermal, light and mechanical rotation energies which are used in both household appliances and also in the production industry. The wide usage and the dependency on the electricity leads to its critical status such that even short-term discontinuities of electricity supply and transmission cause social and economic problems. Therefore, the supply and demand chain of electricity should be planned in advance in order not to cause electricity cut-offs or inactive electricity. The high price of the electricity production investments and also the long completion durations of the construction of electricity power plants increase the importance of the planning of the electricity supply and demand.

One of the key components of the electricity supply and demand planning is the short-term and long-term forecasting of the supply and demand. The planning activities are performed according to the electricity supply and demand estimations therefore these estimation studies should be carried out in a realistic manner. On the other hand, Türkiye is a rapidly developing country whose economic growth is well above the World average and the population of Türkiye is also on the rise continuously therefore the electricity consumption of both the industrial facilities and the household are on the rise. This leads to the increased significance of the electricity power supply and demand forecasting for Türkiye. The official electricity supply and demand of Türkiye is performed by the Ministry of Energy and Natural Resources.

There are several methods for the estimation of the electricity supply and demand in the literature. These models utilize linear or nonlinear functions which have their unique performance merits. Linear methods include the simplest least squares approximation to the autoregressive integrated moving average schemes. However, nonlinear methods are also taking great attention recently due to their ability to model seasonal and nonlinear data with high performance. On the other hand, the studies regarding the electricity supply and demand forecasting can also be classified into three groups being the short term, medium term and long term forecasts. The short term forecasts deal with the electricity supply and demand estimation for the next hours, days and weeks while the medium term forecasts try to calculate the electricity supply and demand for on a monthly or tri-monthly basis. The long term forecasts model the electricity supply and demand for the upcoming years. Considering the fact that the electricity energy can not be stored in high quantities, the forecasting of the electricity supply and demand also has impacts on the real time price of the electricity energy market and these types of forecasts require short-term estimation performance. The medium term and the long term estimation quality is needed for the planning of the construction of new electricity power plants and power transmission networks. Therefore, the estimation of the electricity supply and demand has impacts on both the continuity and the price of the electricity energy.

The monthly electricity supply and demand data of Türkiye for the 2016-2022 period are modelled using autoregressive deep learning networks in this work. The past values of the supply and demand data are utilized as inputs of the autoregressive deep learning networks which are developed in Python programming language. The performance metrics of the electricity supply and demand data models are then evaluated which indicate the high accuracy of the developed models.

II. LITERATURE ANALYSIS

There are vast number of studies in the literature regarding the modelling and forecasting the electricity supply and demand. Some of these studies employ traditional linear methods such as least squares approximation while more recent studies utilize nonlinear methods such as machine learning models. Moreover, the results and the performance of linear and nonlinear models are also compared in some of the existing studies. For example, the electricity consumption data of Türkiye for the period of 1970-2002 is modelled in a study using regression and artificial neural networks where it is shown that the artificial neural networks enable the estimation of the electricity demand with high accuracy (Hamzacebi and Kutay, 2004). The optimized Grey model was used in another work for the estimation of the electricity demand of Türkiye employing the electricity consumption data for the 1945-2010 period (Hamzacebi and Es, 2014). A new machine learning method named tree-seed algorithm is used in another study for the modelling of the electricity energy demand data of Türkiye for the period of 1992-2016 and it is concluded that the electricity demand data can be modelled by 3.6% error using the tree-seed algorithm (Kiran and Yunusova, 2022). In another work, the electricity demand of Türkiye on a sectoral basis is investigated for the period of 1970-2004 using artificial neural networks and it is shown that the artificial neural network model provides better performance compared to the linear models (Hamzacebi, 2007). The net electricity generation and demand of Türkiye is modelled in another study for the period of 1979-2006 using the ant colony optimization algorithm where an estimation deviation of 3% to 5% is determined (Toksari, 2009). In another work, the electricity demand of Türkiye is predicted for the 2015-2018 period employing four different artificial neural network models and the seasonal autoregressive integrated moving average (SARIMA) method and it is concluded that the seasonal artificial neural network method has better modelling performance compared to the SARIMA method (Hamzacebi et al., 2019). The electricity load of Türkiye for the period of 1970-2007 is considered in another study using adaptive network based fuzzy inference systems (ANFIS) and autoregressive moving average (ARMA) models where the mean absolute percentage error of the ANFIS model is determined to be 0.474% compared to that of the ARMA model having the value of 5.315% indicating the superiority of the ANFIS model (Demirel et al., 2010). The net energy demand of Türkiye for the period of 1970-2010 is modelled for the estimation of the energy demand of 2011-2025 in another work in which an artificial neural network structure having the input data of gross domestic product (GDP), population, import, export and number of vehicles is used and it is shown that the developed artificial neural network has the mean absolute percentage error between 1.75% to 4.21% demonstrating the effectiveness of the artificial neural networks for the modelling of the energy demand (Es at al., 2014). The energy demand of the industry sector of Türkiye is modelled for the period of 1970-2016 in another study using artificial neural networks and it is concluded that the artificial neural network has the coefficient of determination value of R^2=0.94 proving the effective modelling of the energy demand (Pence et al., 2019). The seasonality Grey model (SGM) is proposed in another work for the modelling of the energy demand forecasting of Türkiye in which the mean absolute percentage error of 5.18% is achieved (Hamzacebi, 2016).

The electricity demand of Türkiye for the 2009-2018 period is considered in another study in which the artificial neural networks and the multivariate regression analysis are used where the population, average household size, GDP, imports, exports and the education level are the inputs (Ulku and Yalpir, 2021). In another work, the hourly electricity demand forecasting of Türkiye is performed employing the long short-term memory (LSTM) and the gated recurrent unit (GRU) models (Biskin and Cifci, 2021). The artificial neural networks is used in another study for the modelling of the electricity consumption of TR81 region (Zonguldak, Karabuk and Bartin provinces of Türkiye) where the population, import, export and the building areas data are taken as inputs and forecasts are performed for the 2016-2020 period (Kocadayi et al., 2017). A hybrid model employing the combination of the multiple linear regression and the artificial neural networks is used in another work for the modelling of the electricity demand of

Türkiye and it is shown that the hybrid model achieves 2.25% forecast error (Aydogdu and Yildiz, 2017). The market clearing price regarding the electricity demand of Türkiye is performed in another study where artificial neural networks is used to predict the hourly electricity demand and the mean percentage error of 0.10 is reached (Ertaylan et al., 2021). The gross electricity demand of Türkiye is modelled in another work using three methods namely the trend analysis, fuzzy logic and the linear regression and the modelling error of these methods are found to be 2.75%, 4.81% and 7.64%, respectively (Yavuzdemir, 2014). The monthly electricity supply from conventional and renewable resources is modelled in another study using a seasonal autoregressive integrated moving average (SARIMA) model for the 2001-2020 period and it is shown that the SARIMA model successfully models the electricity supply data (Kurt et al., 2022). In another work, the regional electricity demand of Türkiye is investigated in the period of 1986-2013 using autoregressive integrated moving average model and it is shown that the utilized model has the root mean square error of 0.11 (Akarsu, 2017). Grey forecasting methods with rolling mechanism is utilized in another study for the modelling of the electrical energy demand forecasting of Türkiye for the 2015-2030 period where it is shown that nonhomogeneous Grey model with rolling mechanism increases the forecasting accuracy (Kusakci and Ayvaz, 2015). In another work, the electricity demand of Türkiye is modelled employing regression and adaptive-network based fuzzy inference systems (ANFIS) and it is shown that both models can be used successfully for the electricity demand estimation (Zengin et al., 2022).

The electricity consumption in Mus Alparslan University campus in Türkiye for the 2014-2019 period is modelled in another study employing classical and deep learning methods and it is shown that the error of the deep learning methods is smaller (Unluk and Pala, 2019). Similarly in another work, the electricity supply of Türkiye for the 2010-2019 is modelled using artificial neural networks and bidirectional long-short term memory where it is shown that both methods can be utilized for forecasting the electricity supply from traditional and renewable resources (Aylak et al., 2021). The peak electricity demand in Kutahya, Türkiye is modelled in another study for the 2000-2004 period using artificial neural networks and it is demonstrated that artificial neural networks can be utilized for the modelling of the electricity demand (Aslan et al., 2006). The relationship between the electricity demand and the development status is investigated in another work for Eskisehir, Türkiye for the period of 1999-2009 and it is shown that the multiple regression analysis can be used to model the demand (Senel et al., 2012). In another work, the electricity load estimation is performed for the Kutahya province of Türkiye in the period of 2000-2004 using linear, quadratic and exponential methods and it is concluded that the exponential model gives the best results (Nalbant et al., 2005). Another machine learning method, the particle swarm optimization algorithm, is utilized in another study for the modelling of the electricity demand of Türkiye for the period of 1970-2015 and it is concluded that the electricity demand can be modelled using both linear and nonlinear equations (Bogar and Bogar, 2017). A regressive model is utilized in another work for the estimation of the electricity demand of the Antalya, Isparta and Burdur provinces of Türkiye for the 1992-2017 period and it is demonstrated that the regressive model can successfully model the electricity demand (Baltas and Akbay, 2021). An elastic net regression model is used in another study for the electricity demand forecast for Türkiye and it is shown that nonlinear autoregressive-based neural network model can be used for the electricity demand forecasting with high accuracy (Tutun et al., 2016). The energy consumption of Türkiye is modelled utilizing autoregressive integrated moving average and regression analysis for the period of 1999-2014 in another work where it is concluded that the autoregressive integrated moving average model provides better accuracy (Ervural et al., 2015). The monthly electricity demand of Türkiye for the 2000-2019 period is modelled in another study where artificial neural networks is utilized and it is shown that the artificial neural network provides high performance modelling reaching 99% accuracy (Yumusak et al., 2019).

The installed power supply capacity of Türkiye is modelled in another study for the 1960-2014 period using machine learning algorithms and it is shown that the machine learning algorithm provides over 95% accuracy (Demir and Aydin, 2017). In another work, an exponential mathematical model is used for the modelling of the electricity demand of Türkiye until 2037 with the Mittag-Leffler functions (Calik and Sirin, 2017). The daily electricity demand of Türkiye for the period of 2003-2010 is also modelled utilizing regression analysis and least squares method in another study (Balci et al., 2012). The energy deficit estimation of Türkiye for the period of 2012-2020 is modelled employing artificial neural networks in another work where it is estimated that domestic electricity production would increase in the mentioned period (Esen, 2013). The modelling methods for the electricity supply and demand of Türkiye are summarized in another study in which it is shown that feedforward neural networks, recursive models, swarm intelligence, fuzzy logic, autoregressive models, regression models and Grey prediction models are used for the modelling and forecasting the electricity supply and demand of Türkiye (Ozkurt et al., 2021). In another work, the recursive multilayer perceptron model is utilized to model the hourly electricity demand of Türkiye in which the average error of 10.65% is achieved (Topalli and Erkmen, 2003). Multilayer perceptron based artificial neural networks is used also in another study for the modelling and estimation of the electricity demand of Türkiye for the period of 1991-2005 where daily and monthly demand are modelled and the error values of 3.12% and 2.21% are reached for daily and monthly estimations (Yalcinoz and Eminoglu, 2005). The model analysis for energy demand, multilayer perceptron and radial based artificial neural network models are employed in another work for the modelling of the electricity demand of Türkiye for the period of 1981-2007 and it is observed that radial based neural networks provide the best accuracy (Cunkas and Altun, 2010). The electricity demand of Türkiye for the 1970-2014 period is modelled dependent on the GDP using fuzzy logic and regression methods in another study where it is shown that the fuzzy logic provides better accuracy (Kucukali and Baris, 2010). The hourly electricity demand of Türkiye for the 2001-2002 period is modelled in another work using radial based neural network and autoregressive moving average models in which the load and the temperature are taken as the inputs of the models and it is shown that the radial based neural network has better results compared to the autoregressive moving average model (Topalli et al., 2006).

The electricity demand of Türkiye for the period of 1975-2010 is modelled using artificial neural networks taking economic indicators as inputs in another work and it is observed that the relative root mean square error of 1.15% is reached (Kavaklioglu et al., 2009). Similarly in another study, the monthly electricity demand is modelled using seasonal autoregressive integrated moving average and nonlinear autoregressive artificial neural networks and it is concluded that the mean absolute percentage error of the artificial neural network is below 2% (Tutun et al., 2015). The electricity demand of Türkiye for the period of 1976-2006 is modelled in another work employing ant colony optimization and artificial bee colony algorithm where it is shown that the artificial bee colony algorithm models the electricity demand more accurately (Kiran et al., 2012). In another study, the electricity demand of Türkiye for the period of 2009-2010 is modelled utilizing autoregressive integrated moving average and multilayer perceptron neural networks and it is concluded that the multilayer perceptron neural network performs better than the autoregressive integrated moving average method (Kolmek and Navruz, 2015). The least squares support vector machines model and the multilayer perceptron artificial neural network are used for the modelling of the electricity demand of Türkiye for the 1970-2009 period in another work and it is shown that least squares support vector machines has better accuracy (Kaytez et al., 2015). The multilayer perceptron artificial neural network approach is used also in another study where the electricity demand of Türkiye is modelled for the period of 1975-2013 and it is shown that the root mean square error of less than 5% is achieved (Gunay, 2016). Ant colony optimization algorithm is utilized in linear and quadratic equations in another work for the modelling of the electricity demand of Türkiye for the 1990-2013 period and it is demonstrated that the mean absolute percentage error lower than 5% is achieved (Toksari, 2016). Similarly in another study, the artificial bee colony algorithm is utilized for the linear, quadratic and exponential equations for the modelling of the electricity demand of Türkiye for the 1970-2013 period where it is shown that the linear model has the best accuracy (Sonmez et al., 2017). In another work, the electricity demand of Türkiye for the 2013-2014 period is modelled employing the seasonal ARIMA and multilayer perceptron neural network model and it is shown that the multilayer perceptron neural network has the mean absolute percentage error of less than 1% (Bozkurt et al., 2017). The hourly electricity demand of Türkiye for the 2005-2016 period is forecasted in another study using artificial neural networks when the input data of historical load and economic factors are taken into account and it is concluded that the developed model reaches the mean absolute percentage error of 1% (Basoglu and Bulut, 2017).

Particle swarm optimization based modelling is performed in another study for the electricity demand of Türkiye for the period of 1979-2013 in which economic indicators are used as inputs and it is shown that a coefficient of determination value of 0.99 is achieved (Gulcu and Kodaz, 2017). Historical electricity consumption, socio-economic factors and the weather are taken as inputs in another work for the modelling of the electricity demand of Türkiye for the period of 2012-2016 using multilayer perceptron neural networks and it is concluded that the mean absolute percentage error of less than 2% is reached (Aydin and Toros, 2018). Similarly, past values of the demand are used as inputs in another study for the estimation of the hourly electricity demand of Türkiye for the period of 2018-2019 utilizing multilayer perceptron based neural networks where it is shown that high accuracy is achieved (Arslan et al., 2018). Historical temperature and consumption are used as inputs in another work for the multilayer perceptron and nonlinear artificial neural network based modelling of the electricity demand of an industrial region of Türkiye for the period of 2014-2016 where it is concluded that the multilayer perceptron based neural network performs better (Ozden and Ozturk, 2018). Similarly, the lagged electricity price, temperature and the economic factors are used to model the hourly electricity demand of Türkiye in another study for the 2013-2015 period using multilayer perceptron, long short-term memory and the gated recurrent unit based models and it is shown that the gated recurrent unit based model gives accurate results (Ugurlu et al., 2018a). Long short-term memory is also used in another work for the estimation of the hourly price of the electricity demand of Türkiye for the period of 2017-2018 and the mean absolute percentage error of 0.24 is achieved (Ugurlu et al., 2018b). Similarly, modelling the hourly electricity demand of Türkiye for the 2012-2014 period is investigated in another study using multilayer perceptron, gradient-descent momentum, Levenberg–Marquardt algorithm and Broyden–Fletcher–Goldfarb–Shanno algorithm and it is concluded that the Broyden–Fletcher–Goldfarb–Shanno algorithm provides accurate results (Gokgoz and Filiz, 2020). The long-short term memory method is utilized in another work for the estimation of the hourly electricity demand of Türkiye for the 2016-2020 period and it is observed that mean absolute percentage error lower than 5% is reached (Ozkurt et al., 2020). In another study, artificial neural network with improved genetic algorithm is used for the modelling of the hourly electricity demand (Srinivasan, 1998). Similarly, the radial based neural networks, dynamic neural networks and autoregressive models are used for the hourly electricity demand estimation in another work (Kodogiannis and Anagnostakis, 1999).

In this study, the monthly electricity supply and demand of Türkiye for the 2016-2022 period are modelled using autoregressive deep learning networks consisting of four hidden layers. The electricity supply and demand data of Türkiye is taken from the official sources and then the seasonality analysis is performed on the data. The deep learning network is developed in Python programming language where 70% of the available data are used as the training data and 30% of the data is utilized as the test data. The performance of the developed deep learning network models are investigated by plotting the data and also by using figure of merits such as the coefficient of determination, mean absolute error, mean absolute percentage error and the root mean square error. The developed model is considered to be useful for the electricity supply and demand planners.

III. MATERIAL AND METHODS

The electricity supply and demand data of Türkiye have been taken from the official sources (EDDS, 2023). As it can be observed from Figure 1, the electricity supply and demand data move very close which is needed for two reasons: i) to prevent electricity interruptions and, ii) to eliminate excessive supply which causes power waste. The electricity supply and demand data is highly nonlinear and seasonal as expected however in order to investigate the seasonality of these data, the seasonal-trend decomposition with Loess method (Cleveland et al., 1990) is utilized in Eviews where the seasonal and trend components of the electricity supply and demand data are observed. The seasonal decomposition of the electricity supply and demand data are given in Figure 2 and Figure 3, respectively.

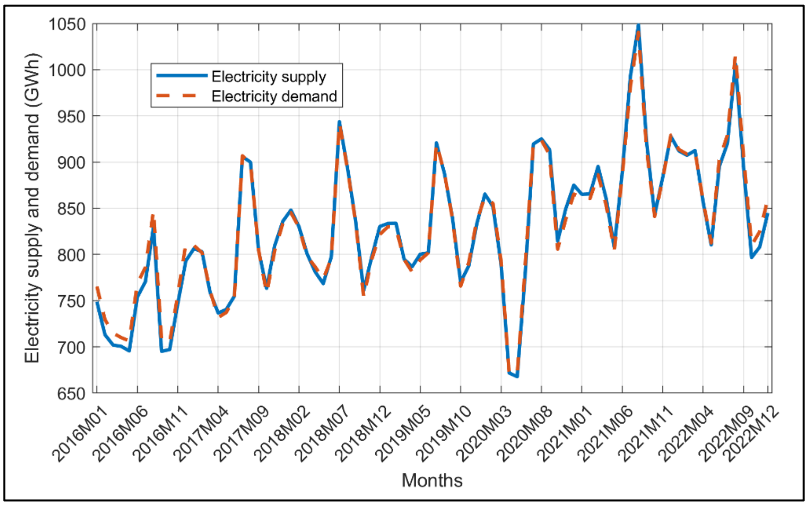

Figure 1. Monthly electricity supply and demand data of Türkiye for the period of 2016-2022 (EDDS, 2023)

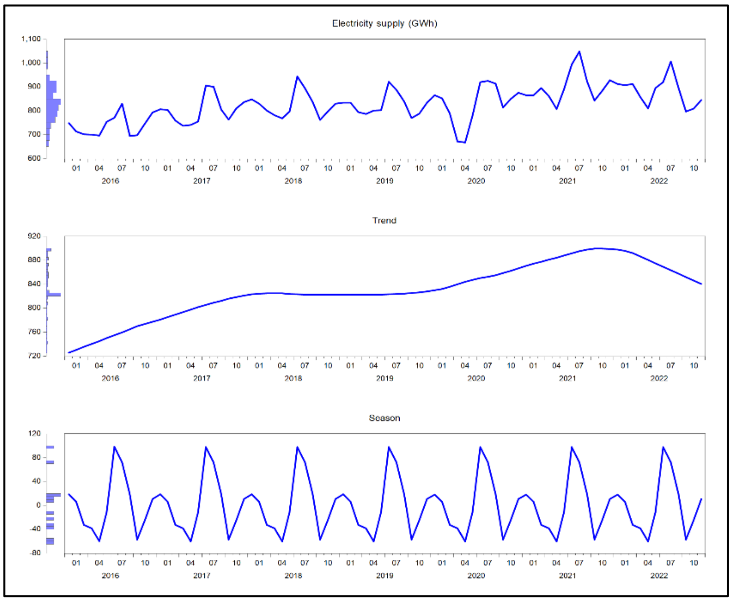

Figure 2. Seasonal and trend decomposition of the electricity supply data of Türkiye for the period of 2016-2022

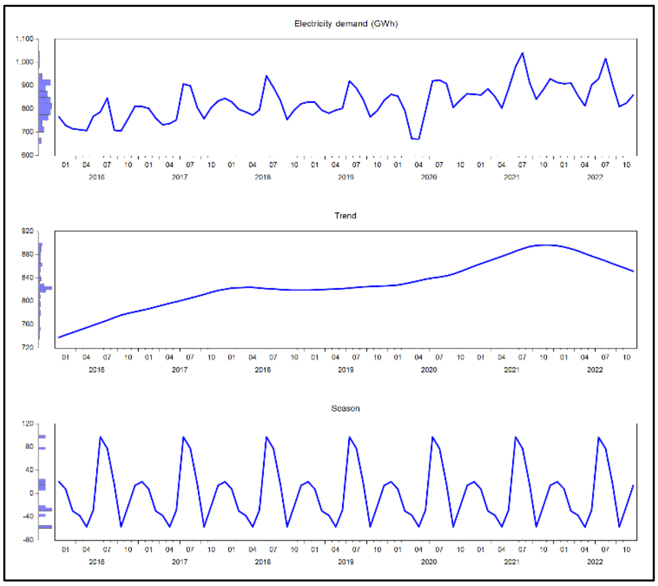

Figure 3. Seasonal and trend decomposition of the electricity demand data of Türkiye for the period of 2016-2022

The seasonal components observed from Figure 2 and Figure 3 verify that the monthly electricity supply and demand data are highly seasonal therefore their modelling obviously require nonlinear methods such as machine learning. In this study, an autoregressive deep learning network is developed for the modelling of the electricity supply and demand data. The structure of the developed deep learning network is shown in Figure 4.

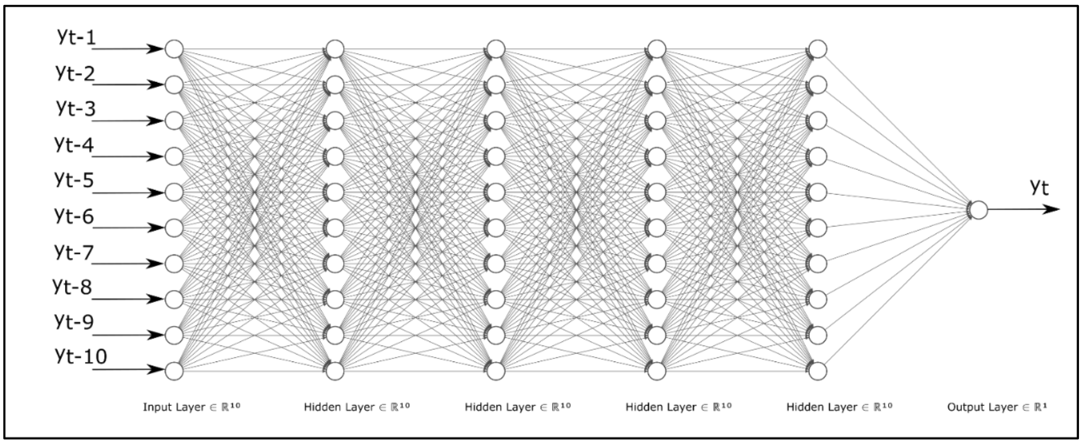

Figure 4. The structure of the implemented deep learning network

The structure of the developed autoregressive deep learning network is shown in Figure 4 and it can be observed from this figure that the previous ten values of the output variable is fed as inputs to the deep learning network hence making it an autoregressive deep learning model. Moreover, there are four hidden layers in the multilayer perceptron structure such that the developed model is a deep learning network. The autoregressive deep learning model shown in Figure 4 is developed in Python programming language using the MLPRegressor class of the SciKit Learn library (Geron, 2022). The 70% of the available data is used as the training data while the remaining 30% of the data is utilized as the test data. The modelling results and their performance assessment are presented in the next section.

IV. RESULTS AND DISCUSSION

The electricity supply and demand data are classified as the training and the test data using the test_train_split class of the SciKit-Learn library and then the developed autoregressive deep learning network is trained for the electricity supply and demand data separately.

In order to provide autoregression, the previous values of the electricity supply and demand data are split and grouped in Python programming language using a custom coded function. In this way, the inputs of the electricity supply and demand data are prepared. The concept of the data splitting and grouping function is shown in Figure 5.

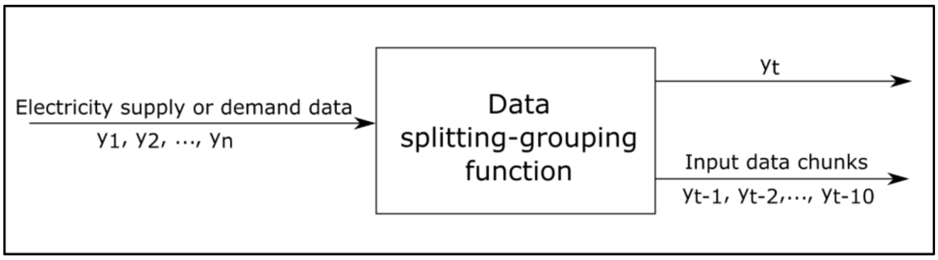

Figure 5. The concept of the implemented data splitting-grouping function

The implemented autoregressive deep learning network is trained using the electricity supply data as the next step after splitting and grouping the data input. The obtained electricity supply data from the trained autoregressive deep learning model and the actual electricity supply data are plotted on the same axis pair in Figure 6.

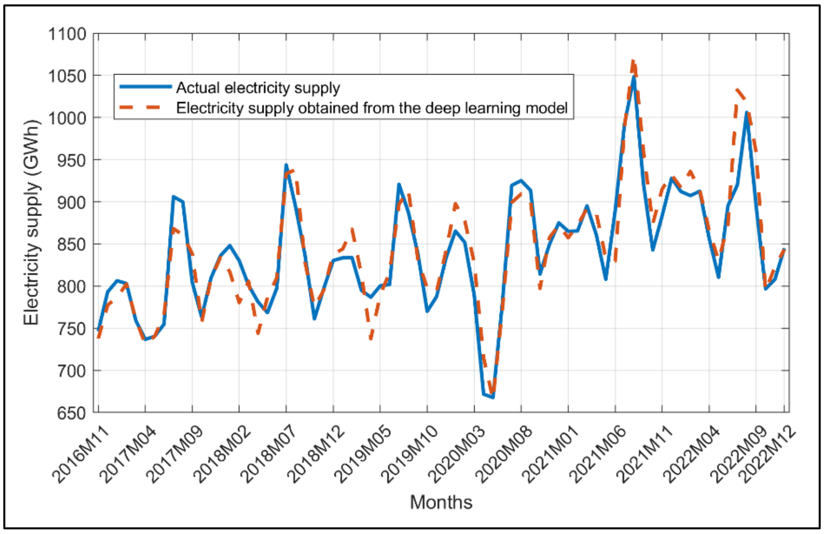

Figure 6. The actual electricity demand data and the data obtained from the developed deep learning model.

Similarly, the developed deep learning network is trained for the electricity demand data and then the obtained model data and the actual electricity supply data are plotted in Figure 7.

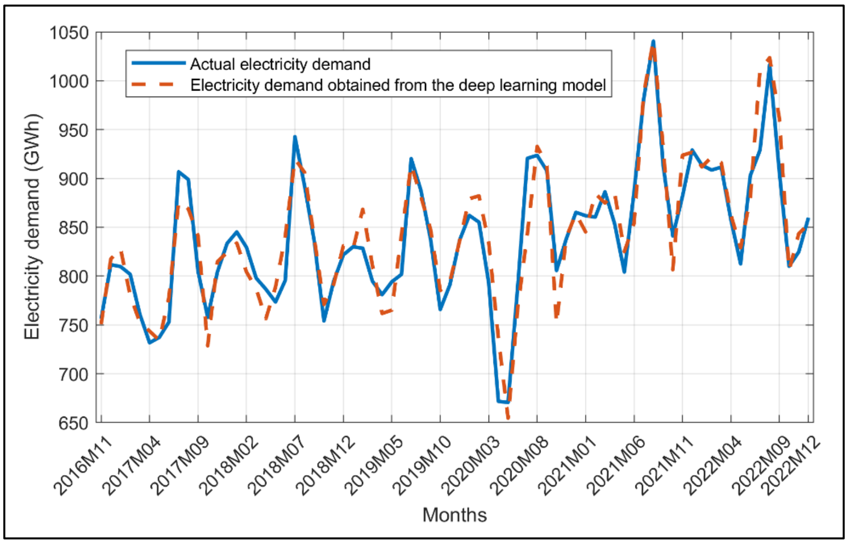

Figure 7. The actual electricity demand data and the data obtained from the developed deep learning model.

As it can be observed from Figure 6 and Figure 7, the developed autoregressive deep learning network successfully models both the electricity supply and the demand data for Türkiye in the 2016-2022 period. The performance merits namely the coefficient of determination (R^2), mean absolute error (MAE), root mean square error (RMSE) and the mean absolute percentage error (MAPE) of the autoregressive deep learning model are also calculated in Python programming language for the electricity supply and the demand data and these performance metrics are given in Table 1.

Table 1. Performance metrics of the developed electricity supply and demand models

Model	R^2	MAE	RMSE	MAPE
Electricity supply model	0.850	19546.543	26935.801	2.294%
Electricity demand model	0.855	19745.846	26266.918	2.179%

The performance metric values shown in Table 1 also verify the accuracy of the developed autoregressive deep learning model considering that the models that have MAPE values lower than 10% are considered to be highly accurate (Cuhadar, 2013).

V. CONCLUSIONS

The electricity supply and demand of Türkiye for the period of 2016-2022 are modelled in this work. The monthly electricity supply and demand data are taken from official sources and then the seasonality and nonlinearity of these data are investigated in Eviews software. The seasonal-trend decomposition using Loess method is used for separating the trend and seasonal components of the data. Then, it is observed that the electricity supply and demand data have strong seasonal components indicating that the modelling of these data has to be performed using nonlinear methods. For this aim, an autoregressive deep learning model is developed in Python programming language where the inputs of the deep learning model are the past values of the output. In order to use the developed model, the electricity supply and demand data are split and grouped utilizing a custom function written in Python. Then, the developed autoregressive deep learning model is trained using electricity supply and demand data separately. The actual electricity supply and demand data and the results of the developed deep learning model are plotted in order to visually inspect the model performance. The plots indicate that the developed model can be used for the estimation of both the electricity supply and demand data. Furthermore, the performance metrics of the electricity supply and demand models such as the coefficient of determination, mean absolute error, root mean square error and the mean absolute percentage error are calculated. The MAPE values less than 3% also verify the accuracy of the developed autoregressive deep learning model for the representation of the electricity supply and demand data. It can be argued that the developed autoregressive deep learning model can be used to model and forecast electricity supply and demand data of other countries and regions.

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