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# Estimation of Net Energy Consumption for Turkey Based on Economic Factors

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**Abstract:** Energy, one of the main determinants of the economy, is an important production factor for all countries. As a developing country, Turkey is a country that increases its energy demand day by day. It is crucial to make reliable energy consumption forecasts for the future in today's world, where there is an energy crisis. In this work, the artificial neural networks (ANN) and adaptive-network-based fuzzy inference system (ANFIS) models were used to examine the effects of imports, exports, economic growth (Gross Domestic Product), and population on the net energy consumption of Turkey. The reliability of the ANN and ANFIS models was determined using several statistical indicators. In the ANN model, $R^2$, MAPE, and cov values were 0.997397669, 0.78259322, and 5.3228538, respectively. In the ANFIS model, $R^2$, MAPE, and cov values were found as 0.997845364, 0.70709233, and 4.84339908, respectively. The obtained results from the ANN are compared with the ANFIS, in which the same data sets are used. The ANFIS model is a little better than ANN model. A new formula for determining net energy consumption is proposed using the weights obtained from the trained network. The results obtained show that both models can be successfully used to forecast energy consumption.

**Keywords:** Net energy consumption, socio-economic variables, prediction, ANN, ANFIS.

# Türkiye İçin Ekonomik Faktörlere Bağlı Olarak Net Enerji Tüketimi Tahmini

**Öz:** Ekonominin temel belirleyicilerinden biri olan enerji, tüm ülkeler için önemli bir üretim faktörüdür. Türkiye gelişmekte olan bir ülke olarak enerji talebini her geçen gün artıran bir ülkedir. Enerji krizinin yaşandığı günümüz dünyasında geleceğe yönelik güvenilir enerji tüketim tahminleri yapmak oldukça önemlidir. Bu çalışmada; ithalat, ihracat, ekonomik büyüme (Gayri Safi Yurtiçi Hasıla) ve nüfusun Türkiye'nin net enerji tüketimi üzerindeki etkilerini incelemek için yapay sinir ağları (YSA) ve uyarlamalı ağ tabanlı bulanık çıkarım sistemi (ANFIS) modelleri kullanılmıştır. YSA ve ANFIS modellerinin güvenilirliği, çeşitli istatistiksel göstergeler kullanılarak belirlenmiştir. YSA modelinde; $R^2$, MAPE ve cov değerleri sırasıyla 0.997397669, 0.78259322 ve 5.3228538 olarak bulunmuştur. ANFIS modelinde; $R^2$, MAPE ve cov değerleri sırasıyla 0.997845364, 0.70709233 ve 4.84339908 olarak bulunmuştur. YSA'dan elde edilen sonuçlar, aynı veri setlerinin kullanıldığı ANFIS modelinin sonuçları ile karşılaştırılmıştır. ANFIS modelinin, ANN modelinden biraz daha iyi sonuçlar verdiği görülmüştür. Eğitimli ağdan elde edilen ağırlıklar kullanılarak net enerji tüketimini belirlemek için yeni bir formül önerilmiştir. Elde edilen sonuçlar, her iki modelin de enerji tüketimini tahmin etmede başarılı bir şekilde kullanılabileceğini göstermektedir.

**Anahtar kelimeler**: Net enerji tüketimi, sosyo-ekonomik değişkenler, tahmin, YSA, ANFIS.

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## 1. Introduction

Today, energy is one of the most critical elements of both human life and economies. It is not possible to produce and maintain daily life without energy. Energy is essential in terms the of socio-economic security of countries as well as in economic and everday life. The Covid-19 crisis has reinforced the importance of energy to modern economies [1]. Turkey's total electricity consumption did not decrease between 1998 and 2020, except for 2001, 2009, and 2019, and continued its increasing trend (Fig. 1).

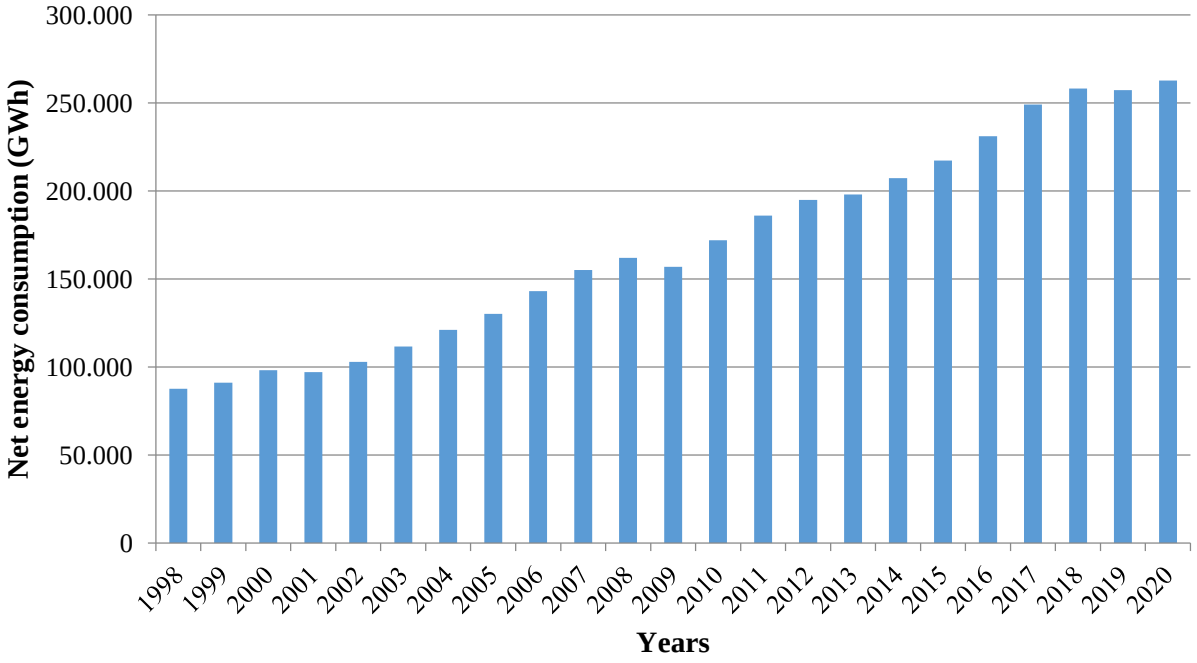


**Figure1.** Turkey's total electricity consumption [2, 3]

In the literature, the determinants of energy consumption generally consist of economic growth, energy prices, population, and demographic effects. Previous studies exploring the impact of demographic variables and socio-economic factors on energy consumption using different approaches are summarized in Table 1.

As seen in Table 1, there are studies on the relationship between socio-economic variables and energy consumption with various methods in the literature. As different from the literature in this study, a comparative analysis of the neuro-fuzzy system and neural network to determine net energy consumption was performed. A new formula to determine net energy consumption is proposed using the weights obtained from the trained network.

## 2. Artificial Neural Networks (ANNs) and Adaptive Neuro-Fuzzy System (ANFIS)

ANN is one of the artificial intelligence methods. ANNs are software-based synthetic structures that mimic biological neurons in the human brain. The basic principles of ANN include learning new information, vital thinking, problem-solving, estimation, etc. features, such as the acquisition of skills. ANN is of interest to researchers because of its features, such as producing solutions by learning the relationship between input and output related to any event, whether linear or not, by associating previously unseen events with previous examples by learning from the samples at hand. Details about ANN can be found in [24-26].

ANFIS model generally uses a hybrid learning algorithm. With the hybrid learning algorithm, ANFIS can create an input-output structure based on predicted input-output data pairs. ANFIS takes advantage of both constructs as it integrates both neural networks and fuzzy logic inference methods. To apply the ANFIS model, a dataset based on input-output is generally needed. The model is created using a learning algorithm based on the selected membership function number and type [27, 28].

**Table 1.** Summary of related previous studies

| Authors | Country | Variables | Methodology |
|---|---|---|---|
| Kaytez, F. [4] | Turkey | Future net electricity consumption | Autoregressive integrated moving average and least-square support vector machine |
| Sözen et al. [5] | Turkey | Population, gross generation, installed capacity | Artificial neural network |
| Tartibu and Kabengele [6] | South Africa | Consumption expenditure of households, population, gross domestic product, percentage growth forecasts, | Artificial neural network |
| Hamzaçebi, C. [7] | Turkey | Energy consumption on a sectoral basis | Artificial neural networks |
| Kankal et al. [8] | Turkey | Socio-economic and demographic variables | Artificial neural network |
| Akdi [9] | Turkey | Daily electrical energy consumption | Harmonic regression model and the ARIMA model. |
| Zeng et al. [10] | China | Socio-economic factors | Enhanced back-propagation neural network |
| Perwez and Sohail [11] | Pakistan | Net electricity energy consumption | LEAP model |
| Liu et al. [12] | Chinese | Gross domestic product (GDP), population, imports, and exports | Artificial neural network |
| Deb et al. [13] | Singapore | Building energy consumption | Artificial neural network and adaptive neuro-fuzzy system |
| Pao [14] | Taiwan | Energy consumption | Artificial neural networks |
| Kaboli et al. [15] | Different counties | Future electrical energy consumption | Gene expression programming |
| Es et al. [16] | Turkey | Gross Domestic Product, population, import, export, area of the building, and vehicles number | Artificial neural networks |
| Aydin [17] | Turkey | Population and gross domestic product | Regression analysis |
| Avami and Boroushaki [18] | Iran | Gross domestic product and population | Artificial neural networks |
| Kaytez [19] | Turkey | Solar power capacity | Fuzzy Analytic Network Process |
| Ekinci [20] | Turkey | Electrical energy and population | Artificial neural network and adaptive neuro-fuzzy system |
| Uzlu [21] | Turkey | Gross domestic product, population, import, and export | Grey wolf optimizer- artificial neural network |
| Nebati et al. [22] | Turkey | Population, number of houses, per capita income, number of white goods, and number of workplaces | Regression analysis and time series techniques |
| Es [23] | Turkey | Population, GDP, import, export, building surface area | Grey prediction model |

## 3. Application and Results

In this study, the net energy consumption of Turkey, depending on independent variables such as economic growth, population, imports, and export, is predicted using ANFIS, and ANN approaches. From 1998 to 2020, data were collected for independent and dependent variables obtained from official sources [1-3, 29]. Then models were established for electrical energy consumption estimation with MATLAB software using a neural network and fuzzy logic toolbox.

Different ANN models with other network structures and learning parameters have been set up, and training has been carried out. For the training of the ANN, the feed-forward back-propagation (Feed-Forward BackProp) was chosen as the network type, the Levenberg Marquardt (LM) of the back-propagation algorithm, the hyperbolic tangent sigmoid function (tan-sig) activation function, and the mean square error (MSE) for the evaluation of the network performance function. The optimal number of neurons in the hidden layer was identified using a trial-and-error method. The number of 10 neurons in the hidden layer that gave the most relevant result was used in the data training. Fig. 2 shows the block diagram of the artificial neural network created by the interface nntool.

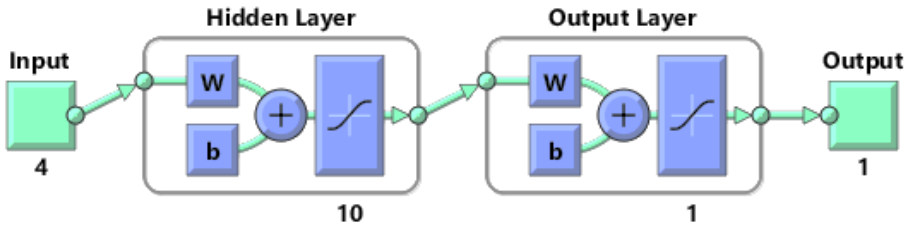


**Figure 2.** Block diagram of the artificial neural network created by the interface nntool

The input and output values should be normalized before the data is trained in the ANN model. The data obtained in this study were normalized between 0 and 1 values. One thousand iterations were used in training. The training process of the network was completed in 12 iterations, and the lowest mean square error (MSE) value was reached in the 6th iteration. In Fig. 3, the performance graph of the model depending on the iteration is seen, and the MSE value was found to be 0.00010942.

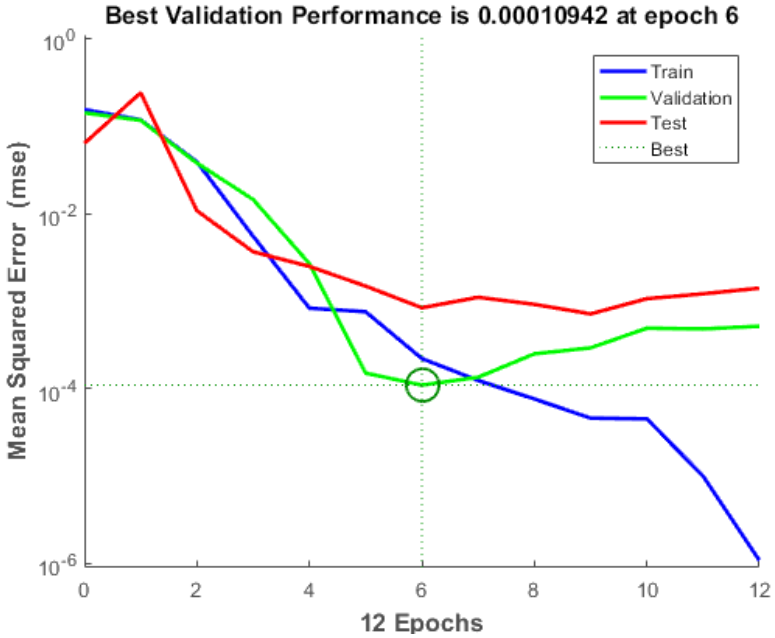


**Figure 3.** Performance variation of training, validation, and test data

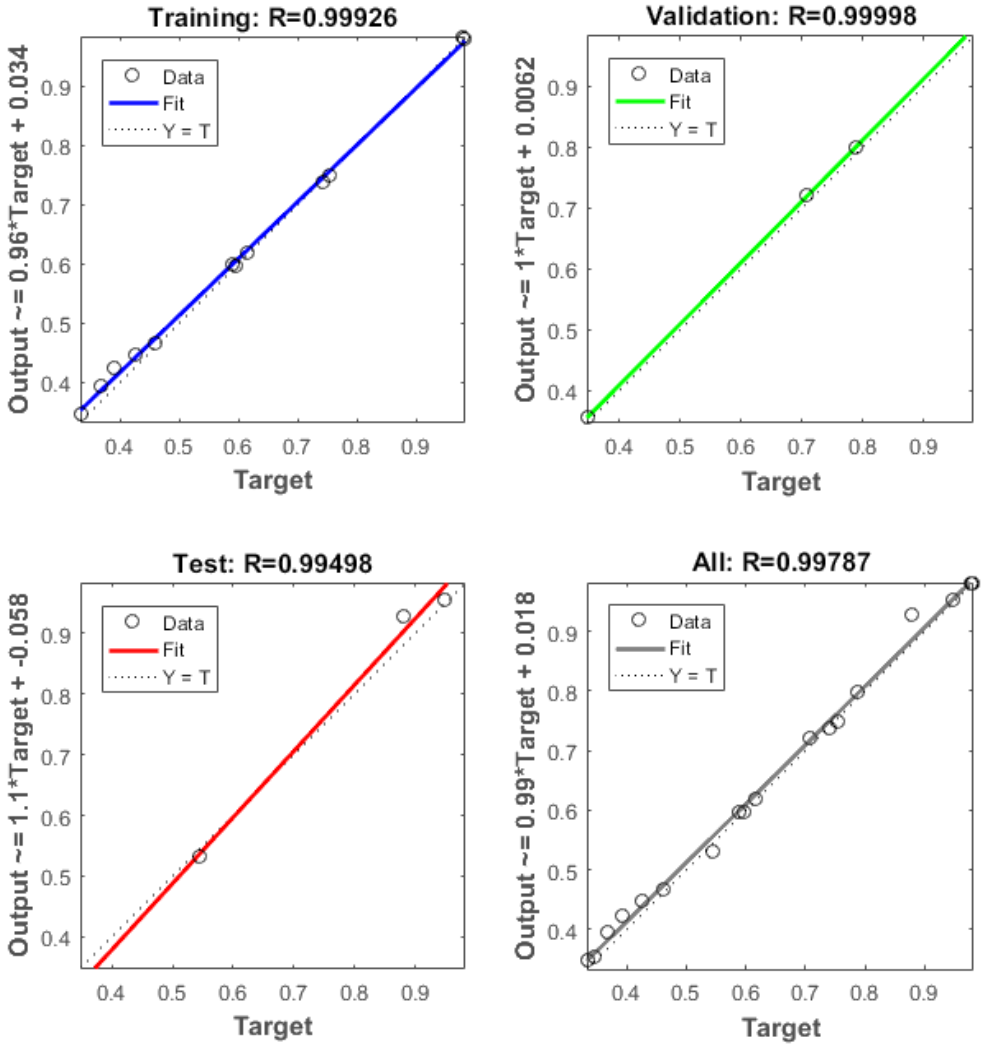


**Figure 4.** Regression graphs of training, validation and test sets

Fig. 4 shows the correlation coefficient (R) graphs showing the model's performance. Considering the correlation coefficient values in Fig. 4, it was found that R = 0.99926 for training data, R=0.99498 for test data, R=0.99998 for validation data, and R=0.99787 for all data. The fact that the values are close to 1 for all data shows a consistency between the data obtained by the ANN method and the actual data. If the correlation coefficient values are relative to 1, the model is successful.

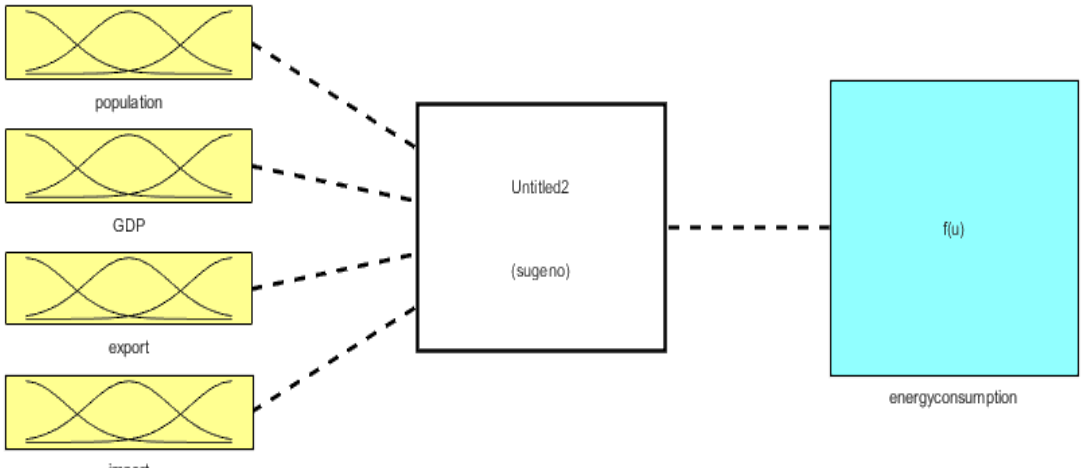


**Figure 5.** The ANFIS model

In addition, the neuro-fuzzy (ANFIS) model was used to forecast energy consumption. Different ANFIS structures were tried, and a suitable model structure was defined. The model is trained using the hybrid learning rule with 1000 iterations. Gaussian membership functions are used in the ANFIS model (Fig. 5). Info for the ANFIS model being used in the study has been shown in Table 2.

**Table 2.** Some specifications of optimal ANFIS model

| Characteristics | |
|---|---|
| Number of nodes | 47 |
| Number of linear parameters | 20 |
| Number of nonlinear parameters | 32 |
| Total number of parameters | 52 |
| Number of training data pairs | 18 |
| Number of fuzzy rules: 4 | 4 |
| Membership function type | Gaussian |
| Training algorithm | Hybrid |
| Fuzzy structure | Sugeno |
| Epochs | 1000 |

For the test data set, the actual energy consumption and the estimated energy consumption values with the ANN model are compared in Fig. 6. The correlation coefficient value for the actual and estimated energy consumption values was found to be 0.9818. This value can be considered satisfactory. In Fig. 7, the correlation coefficient found with the ANFIS model for the same data set was 0.9917. This value is very acceptable.

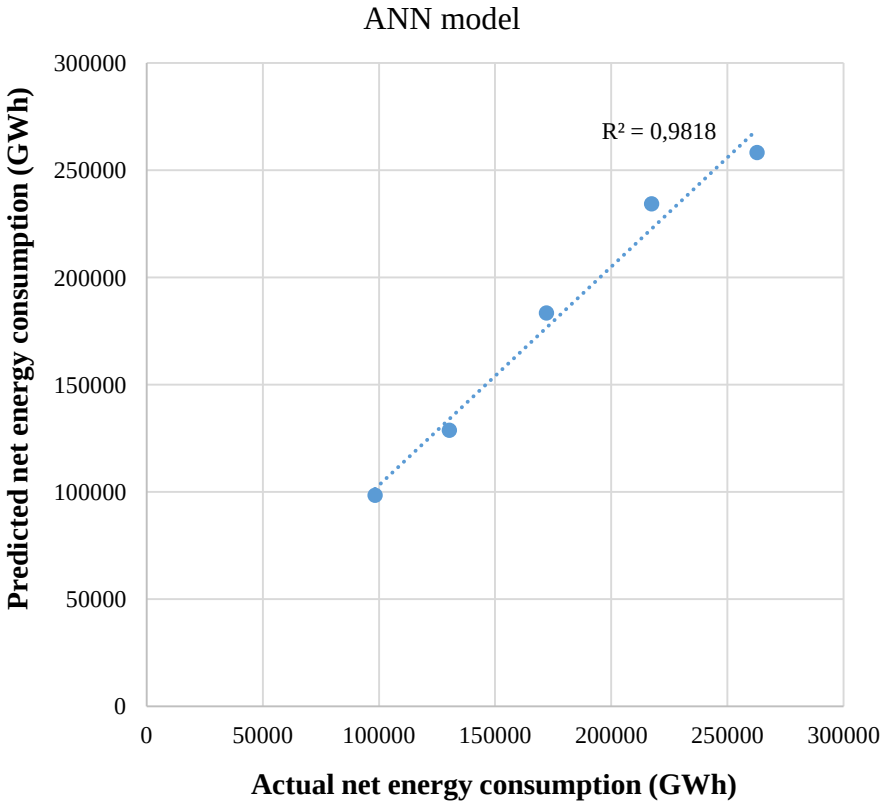


**Figure 6.** Comparison of actual and ANN predicted net energy consumption values

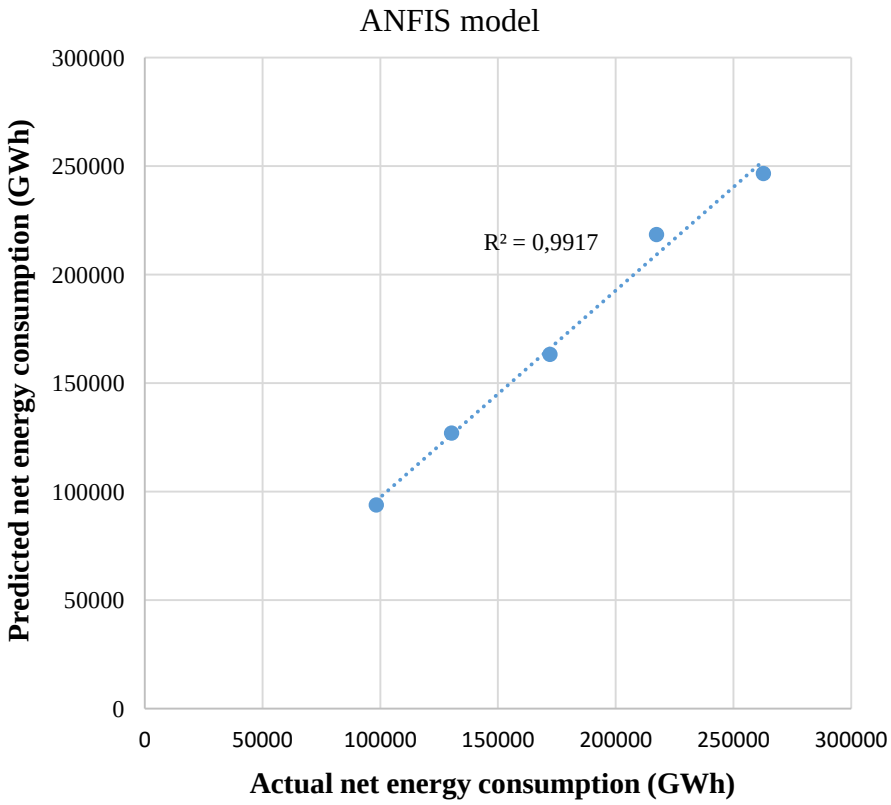


**Figure 7.** Comparison of actual and ANFIS predicted net energy consumption values

To understand whether the ANN and ANFIS models work well, some statistical indicators such as coefficient of multiple determination ($R^2$), mean absolute percentage error (MAPE), and coefficient of variation (cov) are looked at. These statistical indicators can be calculated with the following equations [30].

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_{e,i} - t_{a,i})^2}{\sum_{i=1}^{n}(t_{a,m} - \bar{t}_{a,m})^2} \quad (1)$$

$$MAPE = \frac{1}{n}\left[\frac{\sum_{i=1}^{n}\left|y_{ei} - t_{a,i}\right|}{\sum_{i=1}^{n} t_{a,i}} x100\right] \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_{e,i} - t_{a,i})^2}{n}} \quad (3)$$

$$cov = \frac{RMSE}{|\bar{t}_{a,m}|} \times 100 \quad (4)$$

It is specified in the equations, $y_{e.i}$ refers to the estimated value, $t_{a.i}$ to the actual value, $\bar{t}_{a.m}$ to the mean of the actual value, and n to the number of data.

## 4. Results and Discussion

In this study, net energy consumption was estimated for Turkey by using imports, exports, economic growth, and population variables with ANN and ANFIS models. The performances of the

ANFIS and ANN models developed in this work were evaluated using several statistical performance evaluation criteria. Mean absolute percentage error (MAPE), coefficient of variation (cov), and coefficient of multiple determination ($R^2$) indicators were used to evaluate the performance of the developed ANN and ANFIS models. Smaller values of MAPE and cov indicate higher accuracy of estimates; larger $R^2$ values indicate a higher linear relationship between predicted and actual values. A list of the statistical measures of net energy consumption is presented in Table 3. In the ANN model, $R^2$, MAPE, and cov values were 0.997397669, 0.78259322, and 5.3228538, respectively. In the ANFIS model, $R^2$, MAPE, and cov values were found as 0.997845364, 0.70709233, and 4.84339908, respectively. As can be seen in Fig. 6, Fig. 7, and Table 3, the results of the ANFIS model are slightly better than ANN.

**Table 3.** Comparison between ANN and ANFIS models for net energy consumption.

| **Model** | **MAPE** | **cov** | **$R^2$** |
|---|---|---|---|
| ANN | 0.78259322 | 5.3228538 | 0.997397669 |
| ANFIS | 0.70709233 | 4.84339908 | 0.997845364 |

The net energy consumption with the ANN model can be formulated with the help of weights and activation functions depending on imports, exports, economic growth, and population. The mathematical formulations obtained from the ANN model are given below. In these formulas, $E_{i,}$ the first two values are the multiplication of the input parameters ($I_n$) with their weights at location n, and the last constant value ($b_n$) symbolizes the bias term. The subscript i illustrates the number of the hidden neuron. There are ten neurons in a single hidden layer. $F_i$ is the activation function in every neuron of the hidden layer. The activation function was chosen as tan-sigmoid as seen from the $F_i$ function. Accordingly, the following formulas are derived from calculating the net energy consumption values:

$$E_i = \sum_{n=1}^{10} I_n w_{ni} + b_n \tag{5}$$

$$F_i = \frac{2}{1+e^{-2E_i}} - 1 \tag{6}$$

The input parameters are: $I_1$ = Population (P), $I_2$ = Gross domestic product (GDP), $I_3$ = Exports (E) $I_4$ = Imports (I)

The coefficients of Eq. (5) are given in Table 4.

**Table 4.** Bias values and weight coefficients of the ANN used for the net energy consumption

| **Neuron position ($w_{ni}$)** | **$I_1$(P)** | **$I_2$(GDP)** | **$I_3$(E)** | **$I_4$(I)** | **$b_n$** |
|---|---|---|---|---|---|
| 1 | 1.93 | -1.6743 | 1.1126 | 1.0502 | -2.1215 |
| 2 | 0.72792 | 1.2021 | -1.544 | -1.519 | -1.7662 |
| 3 | -1.7121 | 1.085 | 0.63925 | -1.2809 | 1.4267 |
| 4 | 1.7046 | -1.1087 | 1.5028 | -1.6918 | -1.3563 |
| 5 | -0.24127 | 1.6248 | 0.4154 | -2.0936 | -1.3069 |
| 6 | -1.5629 | -1.2834 | 1.089 | 1.3169 | -0.43868 |
| 7 | -1.2583 | -0.25863 | 1.8634 | 1.5477 | -0.23522 |
| 8 | -0.051418 | 1.9864 | -0.92453 | -1.2292 | 1.2665 |
| 9 | 1.2909 | 0.39011 | -0.027587 | 0.88469 | 2.4448 |
| 10 | 1.4054 | 1.3287 | -0.90721 | -1.3134 | 2.4129 |

In addition, the actual input data of the diverse parameters required to be normalized in the range (0-1). For this aim, the actual values of each parameter are divided with the coefficients given in Table 5. At last, the net energy consumption depending on the population (P), Gross domestic product (GDP), Exports (E) and Imports (I) for Turkey can be computed from:

$$E_{11} = 0.29392\,F_{11} - 0.30798\,F_2 - 0.12903\,F_3 + 1.9704\,F_4 - 1.0225\,F_5 - 0.87659\,F_6 + 0.44717\,F_7 - 0.34554\,F_8 + 0.83089\,F_9 + 0.42317\,F_{10} - 0.17616 \quad (7)$$

$$F_{11} = \left( \frac{2}{1+e^{-2E_i}} - 1 \right) * 263000 \quad (8)$$

The constant coefficient seen in Eq. (8) is the normalization coefficient used to turn the normalized output data into actual energy consumption.

**Table 5.** Normalization coefficients of input data

| Input data | Coefficient |
|---|---|
| Population (P) | 84000 |
| Gross domestic product (GDP) | 13000 |
| Export (E) | 181000000 |
| Import (I) | 261000000 |

The comparison of the actual energy consumption values and the energy consumption estimated by the ANN method depending on the economic growth, population, import, and export values for Turkey in Table 6, error and percentage error values are given. It is seen that these error values are at an acceptable level. As seen in Table 6, the ANN model's most significant percentage error value was found to be 7.81 %, and the most significant percentage error value in the ANFIS model was found to be 6.09 %.

**Table 6.** Comparison of estimated net energy consumption with ANN and ANFIS models with actual net energy consumption

| Year | Population | GDP | Export | Import | Actual | ANN predicted | Error | ANFIS predicted | Error |
|---|---|---|---|---|---|---|---|---|---|
| | (Thousand) | ($) | (Thousand US $) | | Energy consumption (GWh) | | (%) | Energy consumption | (%) |
| **2000** | 64269 | 4249.101 | 27774906 | 54502821 | 98296 | 98375.52 | 0.08 | 93891 | 4.48 |
| **2005** | 68435 | 7375.667 | 73476408 | 1.17E+08 | 130263 | 128694.26 | 1.20 | 127029 | 2.48 |
| **2010** | 73142 | 10629.47 | 1.14E+08 | 1.86E+08 | 172051 | 183393.58 | 6.59 | 163323 | 5.07 |
| **2015** | 78218 | 11085.32 | 1.51E+08 | 2.14E+08 | 217312 | 234286.37 | 7.81 | 218553 | 0.57 |
| **2020** | 83385 | 8599.26 | 1.7E+08 | 2.2E+08 | 262702.1 | 258208.82 | 1.71 | 246694 | 6.09 |

## 5. Conclusion

Energy consumption estimates should be made for the correct use and management of our country's natural and economic resources. Accordingly, determining the power plants to be established and their capacities is essential for the direction of the energy market.

In this work, ANFIS and ANN models were used comparatively to determine Turkey's net energy consumption using economic growth, population, export, and import indicators, which are the most emphasized in the literature. The results obtained with the ANFIS method are slightly better than those obtained with the ANN model. Using the weights obtained from the trained network, a new

formulation is presented to determine the net energy consumption. The estimated values with the ANN and ANFIS models were compared with the actual values. As a result of the statistical analysis, $R^2$, MAPE, and cov values in the ANN model were found as 0.997397669, 0.78259322, and 5.3228538, respectively. In the ANFIS model, $R^2$, MAPE, and cov values were found as 0.997845364, 0.70709233, and 4.84339908, respectively. These values were found to be at an acceptable level. In addition, the most significant percentage error value in the ANN model was found to be 7.81 %, and the most significant percentage error value in the ANFIS model was found to be 6.09 %. It is seen that these error values are at an acceptable level.

The results obtained from this study will help scientists working on energy, determining Turkey's energy policies, and determining future investments in energy.

## Author(s) Contributions

DŞ determined the subject and scope of the research and what data would be used in the study. AŞŞ implemented the program. AŞŞ performed the calculations, and DŞ checked. DŞ and AŞŞ co-authored the article. Both authors read and approved the final version of the article.

## Conflict of Interest

The authors declare that there is no conflict of interest.

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