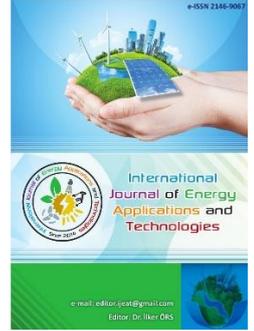




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Original Research Article

### The effect on the wind power performance of different normalization methods by using multilayer feed-forward backpropagation neural network



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#### ABSTRACT

Artificial Neural Networks is the most used machine learning approach today. It is a very successful method in terms of accuracy and reliability. It is widely used in classification and estimation calculations. In order to achieve the desired performance a model created with ANN, a series of processes such as selection of network structure, learning algorithms, input and output values adjustment and transfer functions determination needs to be implemented in a sensitive manner. Multilayer Feedforward Backpropagation Network, which is used most frequently in supervised learning approaches, was considered in this study. The effect on the prediction performance of the developed model was investigated by using different statistical normalization methods on the data to be used in the network. For this purpose, 4-input 1-output artificial neural networks model were operated with wind-based data taken from Osmaniye Korkut Ata University measuring station. Wind speed, Wind Direction, Humidity and Density data are defined as input values while wind power was defined as output value. Input and output data are calculated with different normalization methods and more than one network models are designed with calculated values. As a result, the study showed that artificial neural networks model which is established by sigmoid normalization method has the best performance value.

*Keywords:* Artificial Neural Network, Normalization, Wind Power, Back Propagation

#### 1. Introduction

Machine learning approaches, which are defined as constructs aiming at reaching the end by imitating human intellectual ability, have started to be used in almost every field that can come to mind like medicine, finance, engineering. The main feature of these structures is the processing of input values according to the target output from the given data. There are many types of machine learning approaches that are used on the basis of different learning algorithms. Those most frequently used in these structures, Artificial Neural Networks, Decision Trees, Clustering Algorithms, Support Vector Machines, considered as Genetic Algorithms [1].

Artificial Neural Networks (ANN) is the most utilized machine learning approach using supervised learning algorithms. Artificial Neural Networks (ANN) is the method used in all possible areas and applications. This method, inspired mainly by the nerve cell that constitutes the intellectual structure of human beings, has the ability to model the complex biological structure of the human brain by computer [2]. This method is successful in solving problems that cannot be calculated with nonlinear and classical calculation methods because the structure of neural network is very different from the classical mathematical algorithms used by computers. In addition, the ANN method is widely used in inferring processes from uncertainties such

as future prediction, pattern recognition, time series problems, analysis of data patterns. There is no other artificial intelligence application that performs so well on any data pattern. Thanks to its flexible structure, it can work as a hybrid with different machine learning approaches. However, due to the complexity of its structure, it is known as a difficult technique [3].

The artificial neural network method is a technique based on the outputs targeted according to the characteristics of the inputs, and the smallest unit of the network is the nerve cell with the most basic function that constitutes the structure of the network [4]. Neural networks are defined according to the architectural structure of the connections between input cells and output cells. Basically, there are two different categories as Feed-Forward and Recurrent (Feedback). Within each category, there are Artificial Neural Networks developed for different features and purposes. The main purpose here is to train the network on the targeted problem and ensure learning. In ANN, the learning process can be defined as the process of updating weights on the basis of network architecture in order to perform a task. The weights are updated in every iteration, and the best result is obtained after a certain period of time. The learning algorithm used includes a set of processes in which the learning rules are used to set weights within the network. These algorithms work in three different categories according to the intended purpose, Supervised, Unsupervised and Hybrid [5].

There are many parameters that affect the performance of the neural network developed to solve a problem. The type of selected network, training and learning algorithms, and transfer functions are examples of these. These are usually functional faults. They can be updated while modelling the network to achieve desired performance. However, the distribution and structure of the data used in the model is also effective on the result performance. The fact that the input data is extremely large or small values is training, thus affecting the performance of the result. If a neural network is modelled in this way, there may be deviations resulting from the emergence. In such a case, it is necessary to maintain the normalization process of the data in order to achieve the desired output result and prevent misdirection. Looking at the literature, it seems that different normalization techniques have been applied. Within these techniques, it is a difficult process to decide which technique is more successful and which data type to apply. Generally, a randomization technique is used or a normalization technique used in the same kind of study is used. However, because different normalization techniques are used in the study, it is not known which technique is more successful [6]. Methaprayoon et al. [7], made an ANN-based study in order to remove the uncertainties in production by incorporating wind power capacity into the plant production plan and

benefited from the data in a wind power plant in Lawton. The data were normalized by sigmoid normalization technique before being processed with ANN. A study was also conducted by Sreelakshmi and Ramakanthkumar [8] to estimate short-term wind power by artificial neural networks. In this study, the largest data in each data set is subject to normalization by dividing it into other data. In this way, the data is normalized between 0 and 1. Bilgili and Sahin [9], in their study, the wind speed potentials of some cities in the Eastern Mediterranean Region were compared using ANN, linear regression and non-linear regression models. The best estimate performance among the models used in this study was calculated and the data were normalized using the Min-Max normalization technique. Peng et al. [10], in their study, presented a short-term wind power prediction approach based on numerical weather forecasting and error correction method. For this purpose, the Back Propagation Neural Network (BPNN) and Support Vector Machine (SVM) based forecasting model and error correction method have been developed. In the developed model, the data was first applied to the Min-Max normalization technique.

In this study, to predict the potential of Osmaniye wind power was utilized the Multilayer Feed-Forward Backpropagation Neural Network using different normalization techniques. Furthermore, the wind potential of the artificial neural network developed as a result of each normalization method used in the study was statistically compared. In this study, the effect of various statistical normalization methods on the result performance of the network is examined by testing the learning performance with least mistake and it is aimed to contribute to the work to be done in this field.

## **2. Artificial Neural Network Features**

Mankind is a creature that thinks and decides and studies on the modelling of human intellectual structure dates back to the 1940s. Modelling has accelerated with the development of computers and electrons. There have been studies on how to transfer the biological structure to these types of systems in order to make the computer-based machines similar to the intellectual structure of human beings in the face of a problem [4, 5].

ANN is an emerging technique inspired by human brain function and working structure of a nerve cell. A biological nerve cell consists of four main sections, Dendrite, Axon, Core and Connections. The task of the dendrites is to transmit signals from the peripheral units to the nucleus of the cell. The core is where the signals are collected by the dendrites and transmitted to the Axon. These signals are being processed by Axon and sent from one nerve cell to another. Learning processes are carried out in these processes. As in the human brain, artificial neural network cells combine to form a neural network. When such a neural network runs, it

can do learning-based operations such as classification, clustering, pattern recognition, making resemblance, prediction, control, and easily transmit what they have learned in the face of other situations. It can produce solutions by using intellectual and observational skills that are comparable to similar problems. No mathematical modelling is needed when performing the learning process. They can produce results about different samples because they learn using examples. Even if the information used is incomplete, a result can be reached. In this way, applications have been developed in many areas that can be conceivable from mathematics to engineering, from medical to economy, from meteorology to electronic-based systems [6, 11-12]. The ANN method, which is widely used in the calculation of the potentials of renewable energy sources, is particularly high in performance compared to conventional methods. Artificial neural networks is successfully used in many areas energy requiring estimation such as solar steam generator modelling, wind potential of a region and solar radiation potential [13].

### 3. The Working Principle of the Artificial Neural Network

The smallest unit of artificial neural networks that have hundreds of models today are neural cells. The structure of a neural cell is shown in Figure 1. In this structure, X is the input. The inputs constitute the data sets entered into the ANN in a problem that needs to be solved. Weights (W) are the most important values that enter the cell and show the effect of each input data on the cell. By multiplying the weights by the input values, the net input value is obtained by adding all the values coming to the nerve cell in the sum function ( $\Sigma$ ). The total function is the activity according to the threshold (B) entered in the system. If the net input value is greater than the threshold value, it means that the nerve cell is active, and if not, it is inactive. The activation function is the function in which an output (y) value is calculated according to the net input value from the total function. This function is important for the behaviour of the nerve cell and should be carefully selected in terms of performance of the results [14].

It is aimed to reach a solution from existing information with Artificial Neural Networks. Widely used in solving events such as classification and prediction. A different type of Artificial Neural Network model is developed to solve various types of problems, but the most fundamental and oldest is the one-layer perceptron network in Figure 1. Since this structure is insufficient in solving complex problems, it was overcome of the existing problem by using neural networks which are composed of multiple layers and can perform parallel processing [1, 4, 15].

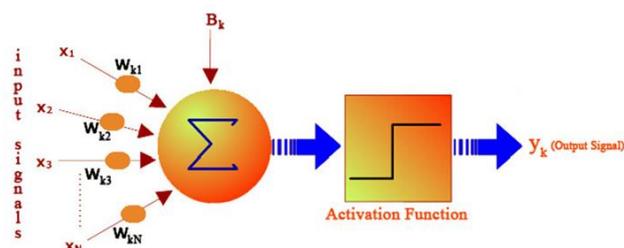


Figure 1. Structure of perceptron artificial neural network

### 4. Feed-Forward Backpropagation Neural Network

The neural network models used in solving complex problems are defined as multi-fold sensors. In addition to the input and output layers in designing these structures, at least one hidden layer must be found. These models, which are evaluated under two parts as forward and feedback networks, have the ability to perform highly parallel processing. In Feed-Forward networks there is movement in one direction from the input data to the output data. At least one cell in the Backpropagation networks is the one that move backwards from the next cell itself. Another important point in developing network models is the learning algorithms used during network training [4, 5].

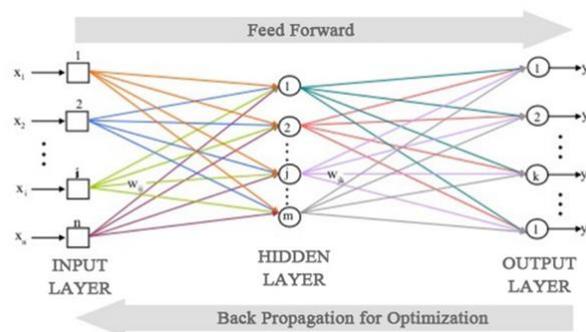


Figure 2. Simple multilayered feed-forward backpropagation artificial neural network

The neural network model, which has been used in recent years for solving prediction problems, is Multilayered Feed-Forward Backpropagation Network (MFFBN) given in Figure 2. While the design of this network is based on Feed-Forward Multilayer Neural Network structure, Backpropagation learning algorithm is also utilized. The backpropagation algorithm is a network in which there is a complete connection between each neural layer in design. In terms of design and work logic, it is a special network compared to other artificial neural networks. The Backpropagation learning algorithm tries to more reduce the non-linear relationship between the inputs and the target output by regulating the weight values of each cell in the layers. It is aimed to achieve the result in two basic structures

such as propagation and adaptation when network is created. Weights must be rearranged at each connection point to reduce faults from output to input. In its design, there are nerve nodes in each layer of the network that are processed nonlinearly and in parallel. Feedforward Backpropagation network exhibits non-static behaviour. For this reason, many field applications can be developed [14, 15].

## 5. Methodology of Study

### 5.1. Wind-Based data set

The data utilized in the study was obtained from the meteorological station established in Osmaniye Korkut Ata University. The measuring device is 20 meters above the ground and 120 meters above sea level. The location of the station is in the northern hemisphere at 37.05 north latitude and 36.14 east longitude and the distance to the sea is 20 km [16]. In order to predict wind power, the wind speed, wind direction, humidity and air temperature data were taken from the measurement station from July to December 2012. Hourly averages of the measured data are calculated every five minutes. The power formula given in Equation 1 was used to estimate wind power.

$$\text{Power} = \frac{1}{2} \rho A v^3 \quad (1)$$

In a wind turbine, when the wind power is calculated, the wind speed fluctuation intervals are observed throughout the year. In the formula given in Equation 1, the wind speed ( $v$ ) is directly proportional to the wind power. However, the air density ( $\rho$ ) and the wing areas ( $A$ ) are variables that affect the wind power. Wing areas can be neglected because of the use of same type wing in wind turbines [17].

### 5.2. Network structure and factors affecting ANN performance

When developing any model using historical data the most important problem for researchers is how to create the network. First, it is necessary to choose the network algorithm appropriate to the type of data available. When an appropriate algorithm is selected the accuracy of the developed model and the estimation power will be high. Then the architecture of the network should be established. In this phase, the input layer, the hidden layer and the output layer must be arranged and relations between each other should be determined. The design of the network must be completed by selecting the latest appropriate training and learning algorithm [18].

In this study, MATLAB R14a software was used to design the ANN model. To date, Feed-Forward Backpropagation supervised neural network model which is the most used and successful neural network model is preferred in the developed structure. Figure 3 as seen, 4-Input 1-Output and

1-Hidden layer network architecture were created. Different types of learning algorithms exist in neural network models. Learning algorithms are the most important elements that determine the performance of a neural network. In general, it is possible to divide them into two different categories, adaptation and education [19]. In the developed network, LEARNGDM and LEARNGD are used as learning based algorithms and TRAINLM learning algorithms are also used as education-based algorithms.

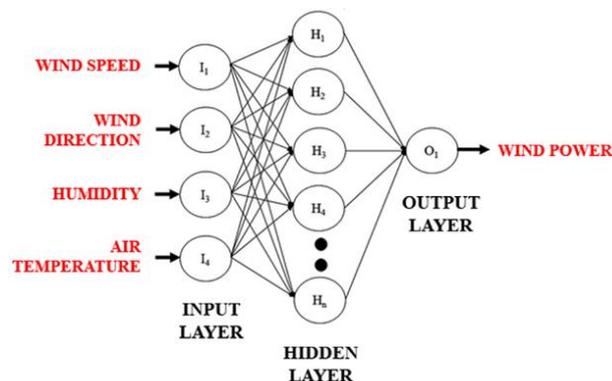


Figure 3. Architecture of modeled artificial neural network

Once the ANN model has been designed, it will greatly contribute to the solution of the problem. However, in some cases the developed model may not provide the desired results. It is possible to examine the factors affecting ANN's performance in three sections. These are the complexity of the network, the complexity of the problem and lack of learning. Problems with the network usually arise from shortcomings in the architectural phase. In general, a neural network consists of input and output layers. However, since such a structure is insufficient for many complex problems, multi-layer structures are used. The number of hidden layers in multi-layered structures and the neuron cells to be used in these layers are highly influential on network performance. The correct selection of neuron cells to be used in the entry layer and the effect of these data on the neuron cell on the output layer must be carefully adjusted. Problems with learning usually occur in the architectural phase of the network. The wrong network type, transfer function, learning and training function is functionally occurring. Another issue on performance is the complexity of the problem. This structure usually manifests itself in the educational phase. It occurs either as a result of incomplete or irregular data or as a result of functional errors in the course of training. If functional errors are ignored, most of the data values come out as irregularities. In order to solve this problem, the data must be subjected to normalization process. Normalization process has a very important role on the result of training and testing processes in a neural network [20-22].

**5.3. Frequently used data normalization techniques**

Meteorological data are generally known as irregular data, but they are also constantly changing depending on time and season. For example, the wind speed is such an irregular source of data. It can be very low or too high for instant. It can be considered that wind speed naturally affects ANN performance negatively. Due to reasons similar to this, before performing an operation on raw data with ANN, the data must be subjected to an appropriate statistical normalization process in order to improve the performance of the resultant and accelerate the training. In this way, irregular data will be regularized, and network training will be more efficient. Numerical values in datasets are widely used for ANN applications that over-peak outside of the desired limits [2, 3].

More than one normalization technique is utilized in scientific studies. In this study, the most commonly used normalization techniques are examined in different areas.

**5.3.1. Frequently used data normalization techniques**

It is a widely used normalization technique. This technique calculates the average ( $\mu_i$ ) and standard deviation ( $\sigma_i$ ) of the data set where the normalization process is the value to be performed. The Z-Score technique is used in fixed situations where the values of a data set do not change [23].

$$N_i = \frac{(x_i - \mu_i)}{\sigma_i} \tag{2}$$

$N_i$  and  $X_i$  represent the normalized data and raw input value respectively in Equation 2.

**5.3.2. Min-Max normalization technique**

Another common used normalization is the Min-Max normalization technique. This method finds the minimum and maximum values of the raw data set and normalizes each input value linearly in the interval 0 and 1 according to the formula given in Equation 3. The main problem with the Min-Max normalization method is that the minimum and maximum values of the non-sample data set used in the calculation are unknown [3, 6].

$$N_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{3}$$

In this case  $x_{min}$  and  $x_{max}$  represent the minimum and maximum values in the raw data set, respectively.

**5.3.3. Median normalization technique**

In this normalization technique, the median value of the raw data is found, and the values are normalized by dividing the values in the data set by this number. In the formula given in Equation 4, Median (x) is the calculation of the median value of the numbers in the raw data set. The most advantageous aspect of other normalization methods of the median normalization technique is that it is not significantly affected by excessive deviations [3].

$$N_i = \frac{x_i}{Median_x} \tag{4}$$

**5.3.4. Sigmoid normalization technique**

A system modelled with ANN is known as a technique that is unaffected by the distribution of data sets that the system has not previously seen during training. For this reason, it is one of the most used techniques. The result is usually 0 to 1 or -1 to 1. There are several sigmoid techniques that produce non-linear results [2]. The formula given in Equation 5 is used in this article. In the formula given in Equation 5, the  $e^{xi}$  value computes the natural logarithm of the corresponding number.

$$N_i = \frac{e^{xi} - e^{-xi}}{e^{xi} + e^{-xi}} \tag{5}$$

**6. Results and Discussion**

Four different ANN models were designed using the normalization methods in the study. Also, another model without normalization was designed to compare the designed models in terms of performance. WIND SPEED, WIND DIRECTION, HUMIDITY and TEMPERATURE data measured between July-December of 2012 were used in designing models. A total of 3553 piece of hourly data was used. Wind Power values corresponding to each wind speed were calculated according to Equation 1. The density value was taken as 1.225 kg/m<sup>3</sup>. 2938 piece of data (between July and November) were used as training data. The rest (615 pieces) was used as training data. It is expected from the system to uncover the best model which predicts the Wind Power of potential of November.

Since ANN models were designed by using raw data and normalized data, it was attempted to establish certain standards in each network structure. Thus, there will be no design advantage between the models and the performances will be evaluated transparently. The parameters of the designed models using ANN are given in Table 1.

**Table 1.** Standard parameters used in developed ANN models.

Network Type	Multilayer Feed-Forward Backpropagation(MFFBN)
Training Function	TRAINLM
Learning Function	LEARNGDM, LEARNGD
Performance Function	MSE
Number of Layers	1 - 10
Number of Hidden Neurons	1 - 100
Activation Function Used	TANSIG - LOGSIG

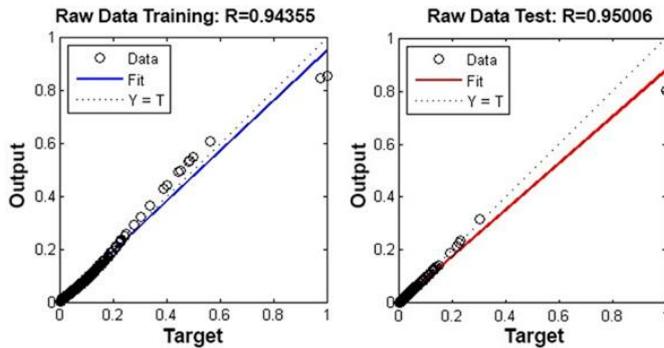
The network type of ANN as shown in Table 1 was selected, after trying different network structures, as Feed-Forward Backpropagation because of its superior performance over other networks. In each model, the activation functions of

Tansig and Logsig were set to give the best performance in the hidden and output layers. Mean Square Error (MSE) statistical error scale was used to observe the performance of the network. Number of cells in the hidden layer and the number of layers for each model were determined differently for each model until the best performance was observed. Because the hidden layer and its cell count in each layer do

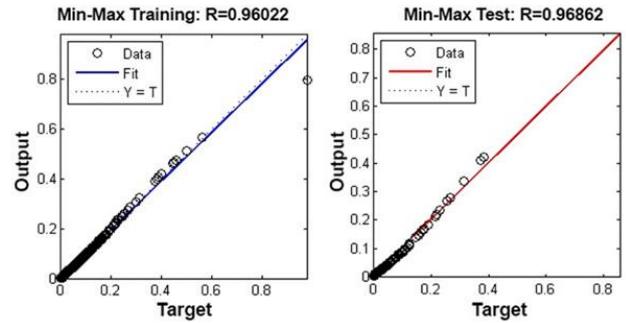
not show the same effect in another model. If the number of layers is low, it creates problems in complex systems, while if it is too many, it can lead to network instability. There is no mathematical rule that determines the number of hidden layers and how many cells will be in each of these layers in an ANN model. It is entirely decided by trial and error [24].

**Table 2.** Meteorological values used in the study

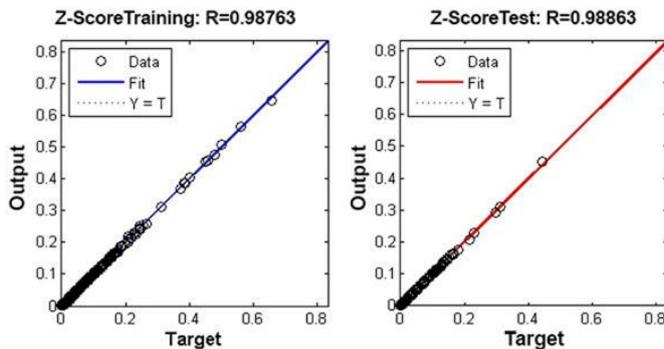
Measured Raw Input Values						Calculated Raw Output
Date	Hour	Speed	Humidity	Temp	Direction	Wind Power
1.07.2012	00:00-01:00	0.9083333	49.5	25.966667	168.75	0.459031
1.07.2012	01:00-02:00	0.25	53.5	24.633333	156.5625	0.009570
1.07.2012	02:00-03:00	0.2333333	57.9166667	23.966667	138.75	0.007781
1.07.2012	03:00-04:00	0.8916667	60.6666667	22.475	88.125	0.434224
1.07.2012	04:00-05:00	0.425	57.5	21.741667	123.75	0.047019
1.07.2012	05:00-06:00	0.175	55.1666667	22.675	92.8125	0.003283
1.07.2012	06:00-07:00	0.2666667	45.4166667	24.433333	104.0625	0.011615
1.07.2012	08:00-09:00	1.0166667	29	29.116667	258.41667	0.643638
*****	*****	*****	*****	*****	*****	*****
*****	*****	*****	*****	*****	*****	*****
31.12.2012	21:00-22:00	0.3583333	60.75	10.108333	135	0.028182
31.12.2012	22:00-23:00	0.4666667	60.0833333	9.1833333	135	0.062248
31.12.2012	23:00-00:00	0.2833333	56.25	9.5	135	0.013932



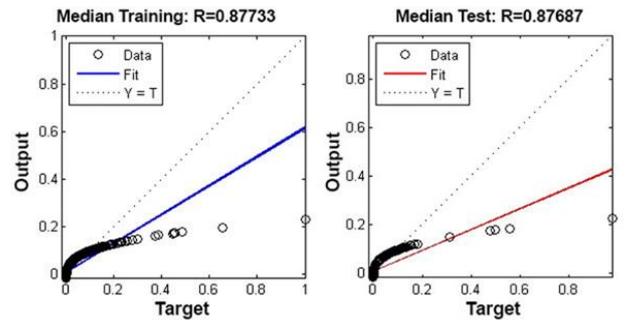
**Figure 4.** ANN regression performance graphic of Raw Data



**Figure 5.** ANN regression performance graph after Min-Max normalization



**Figure 6.** ANN regression performance graph after Z-Score Normalization



**Figure 7.** ANN regression performance graph after Median Normalization

When we look at the regression training and test graphs taken from the MATLAB program, there are no significant differences in terms of results. However, it is expected that the results obtained by using Sigmoid normalization

technique will be very close to the real values. The MSE performance graph in Figure 9 confirms this expectation greatly.

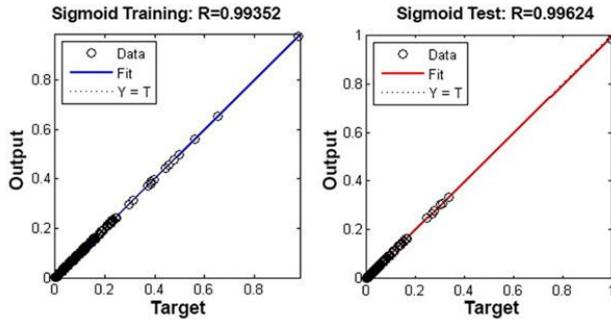


Figure 8. ANN regression performance graph after Sigmoid

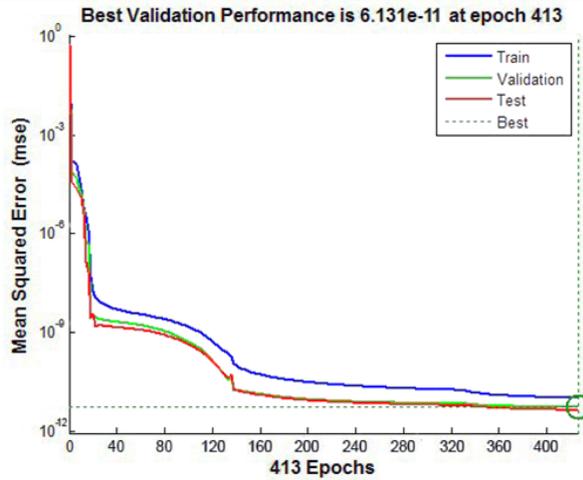


Figure 9. Sigmoid MSE performance graph

Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) statistical error methods are used for performance evaluation of the models. Formulas for the methods are given in Equation 6 and Equation 7. Among these methods, MAPE is used as an effective method to compare performance of more than one model. In addition, Simple Regression Analysis ( $R^2$ ) of each model was made and compared using Equation 8. Regression results should be between 0 and 1. As the result approaches to 1, it can be concluded that the convergence between the actual values and the predicted values are achieved substantially [25].

$$MAPE = \frac{1}{n} \sum_{i=1}^n \left| \frac{P_i - O_i}{P_i} \right| * 100 \quad (6)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}} \quad (7)$$

$P_i$  and  $O_i$  denotes predicted and real values respectively in Equation 7-8.

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - y'_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (8)$$

$y_i$ ,  $y'_i$  and  $\bar{y}$  values are real, predicted and mean values respectively in Equation 8.

After normalization over raw data, each model created using multilayer Feed-Forward Backpropagation based Artificial Neural Network method was trained. The standards in Table

1 were followed to minimize structural differences between models. In order to achieve best performance, each model's hidden layer neuron count, activation and learning functions were changed. Models with 4, 8, 12, 16, 24, 36, 40, 48, 60, 64, 80, 96 neurons in each network's hidden layer were tested with different activation and learning functions over 0-1000 epoch values. When the network achieves best performance, model capability of predicting wind power were tested with data model has not previously seen. Actual values and predicted values were calculated using statistical performance measurement formulas given in Equation 6-8. The best values are shown in Table 3. In the table, the model ANN-5 which was implemented using Sigmoid technique has a quite close value to 1 (0.950000) than any other models. Also,  $RMSE = 0.000002$  value is quite low compared to other normalization techniques. However,  $MAPE = 0.038591$  value was found a bit higher than the model ANN-3's  $MAPE = 0.031865$  which was implemented using Z-Score technique.

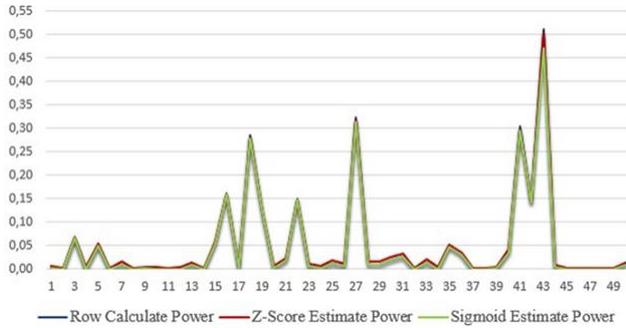
Table 3. Models best performance results

MODELS	$R^2$	RMSE	MAPE(%)
ANN-1 (RAW DATA)	0.929624	0.392410	59.605671
ANN-2 (MIN-MAX)	0.939697	0.000540	47.167730
ANN-3 (Z-SCORE)	0.949992	0.002136	0.031865
ANN-4 (MEDIAN)	0.904016	5.491063	26.876141
ANN-2 (SIGMOID)	0.950000	0.000002	0.038591

In this study, it can be concluded that the model implemented using Sigmoid normalization technique has better performance compared to other models considering the  $R^2$  and RMSE values. However, MAPE is the deciding measurement here. The model with the Z-Score technique has higher MAPE value than any other models.

Generally, in studies that predicts the wind power potential using ANN, the predicted results produced by the model and the normalized real values are compared so that a statistical judgement can be made. Since we use more than one normalization technique, each technique is examined as in Table 1 and the calculated results are shown. Table 1 shows that ANN-3 (Z-Score) and ANN-5 (Median) models dominate performance in five different ANN models including raw data. The other models have not been evaluated because of their low performance values. In Figure 10, the calculated real values and the above-mentioned methods are compared. In order to be used in the chart, 50 sequential data from the 615 pieces of hourly data from December 2012 were randomly selected. Z-Score normalization values were denormalized to raw data because of its compliance to the calculated real values. Since Sigmoid normalization results have the 0-1 structure of the real values, no conversation process is done. Figure 10 shows that Z-

Score and Sigmoid techniques prediction results are highly in compliance with the calculated real values. In the graphic, the sigmoid technique prediction results show a better performance than the Z-Score, even if the estimation results are small.



**Figure 10.** Comparison of actual calculated power values with Z-Score and Sigmoid ANN models

## 7. Conclusion

In this study, the most commonly used normalization techniques have been determined in the field of predicting wind power using ANN and the effects of wind power on the wind-based data patterns have been investigated. For this purpose, it was aimed to predict wind power by using the wind-based data taken from the meteorological station which was established at Osmaniye Korkut Ata University. More than one model were implemented using Multilayer Feed-Forward Backpropagation network method and these models were compared statistically. The goal of the study is to find the best model performance. In the study, normalization-based models were investigated with both the statistical results and the graphical comparison method. Also, the performance loss of the model without normalization can be clearly seen in the study. When the results obtained from the techniques applied to wind-based data are evaluated, the highest predictive accuracy is given by the Sigmoid and Z-Score normalization techniques. When both techniques are compared, the prediction results of the Sigmoid technique are very close to the real values. In this study, wind potential is successfully predicted by using Artificial Neural Networks method. It is also thought that the study will give light to new studies in this area.

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