Long-Term Forecasting of Annual Electricity Consumption by Artificial Neural Networks: A Case Study in Iran

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Abstract
Forecasting of annual electricity consumption is one of the important bases of management decision making for power generation groups as well as power policy adjustment for governments. The aim of this study is to forecast long-term electricity demand by artificial neural networks. Two conventional methods i.e. regression and exponential smoothing have also been used to forecast the demand. A comparison is done between the methods to find the most appropriate. The economic indicators used are gross domestic product (GDP), population, number of customers and electricity average price. Electricity consumption in Iran is considered as the case study (1967-2009).

Keywords
Long-term forecasting, artificial neural networks, regression, exponential smoothing

1. Introduction
The estimation of electrical energy demand based on economic indicators could be done with different kinds of mathematical models. Kermanshahi investigated the problem of long-term load forecasting of total amount of power demand up to year 2005 for nine Japanese power utilities by artificial neural networks (ANNs) \cite{Ref1}. ANN has also been used for long-term demand forecasting \cite{Ref2}. Kermanshahi proposed a long-term load forecasting method using two different artificial neural networks; a recurrent neural network (RNN) and a multi-layer feed-forward network with back-propagation (BP) learning \cite{Ref3}. Azadeh used an integrated genetic algorithm (GA) and ANN to estimate and predict electricity demand in Iran's agriculture sector \cite{Ref4}. They all reported satisfactory results. The estimation of Iran’s annual electricity consumption in high energy consuming industries based on economic indicators using ANNs was reported by Azadeh \cite{Ref5}. In this research, ANN, regression model, exponential smoothing are used. Then, the case study and variables for estimation of the consumption values are introduced. The ANN model is then compared with a regression model, exponential smoothing and actual data.

2. Forecasting Methods

2.1 Artificial Neural Networks
ANNs belong to that type of information-processing systems which allow approximation to the nonlinear behavior that is characteristic in geophysical processes. The basis of an artificial neural network is the concept of neurons as is the case with biological neural networks. Artificial neurons are extremely simple abstractions of biological neurons. A simplified mathematical model of such a neuron is seen in Figure 1. The unit takes an argument (v) which is formed as the sum of a weighted input (w·x) and produces an output (a) by means of a transfer or activation function, f\textsubscript{a}, which is typically a step function or a sigmoid function. The neuron equation is simply \cite{Ref6}:

\begin{equation}
    a = f_a(v) = f_a(w \cdot x)
\end{equation}
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Figure 1: An artificial neuron with a single scalar input and a bias.

\[
a = f_t(v) = f_t(WX + b)
\]  

(1)

Where

- \(X\) Input to the neuron
- \(W\) Synaptic weight
- \(b\) Bias
- \(a\) Output of the neuron
- \(f_t\) Transfer function

Some common transfer functions are shown in Figure 2.

![Transfer Functions](image)

Figure 2: Three different types of transfer functions.

In this work one of the most common neural network modeling i.e. multilayer perceptron (MLP) which is the most famous feed forward network has been used.

2.2 Regression Model

Regression analysis is a technique used for the modeling and analysis of numerical data consisting of values of a dependent variable (response variable) and of independent variables (explanatory variables). Regression can be used for prediction (including forecasting of time-series data), inference, hypothesis testing, and modeling of causal relationships. In this study linear multiple regression model with the following formula has been used:

\[
Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + \cdots + b_n X_n
\]  

(2)

Where

- \(Y\) Dependent or response variable
- \(X_i\) Independent or explanatory variables
- \(a\) and \(b_i\) \((i = 1, \ldots, n)\) Model parameters

2.3 Exponential Smoothing

Time series models are quite well known to predict a variable behavior in the future by knowing its behavior in the past. One of the time series models is double exponential smoothing. This method is used when the forecasted time series exhibits a linear trend [7]. The following data-generating model is assumed to underlie the process [8]:

\[
Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + \cdots + b_n X_n
\]  

(2)
\[ A_t = \alpha D_t + (1 - \alpha)(A_{t-1} + T_{t-1}) \]  
\[ T_t = \beta (A_t - A_{t-1}) + (1 - \beta)T_{t-1} \]  
\[ F_{t+1} = A_t + T_t \]

Where  
\( \alpha \) is a smoothing coefficient specified between 0 and 1.  
\( \beta \) is a trend smoothing coefficient specified between 0 and 1.  
\( D_t \) is demand in time period \( t \).  
\( A_t \) is unadjusted forecast (before trend).  
\( T_t \) is estimated trend.  
\( F_{t+1} \) is trend-adjusted forecast.

3. Data  
The actual data is composed of 43 years of annual electricity consumption in Iran. Moreover, 35 years of the actual data is used for training the ANN and regression models and the remaining 8 years are to be used for testing and comparing the three models with actual 8 years of data. Figure 1 shows the annual electricity consumption in Iran (1967-2009).

![Figure 1: Annual electricity consumption in Iran (1967-2009)](image)

4. Efficiency Index  
If \( X_t \) is the actual observation of period \( t \) (\( t = 1, \ldots, n \)) and \( X'_t \) is the forecast for that period, the mean absolute percentage error (MAPE) is defined as:

\[ \text{MAPE} = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{X_t - X'_t}{X_t} \right| \]
5. Modeling and Analysis

5.1 Using Artificial Neural Networks (ANNs)
The input variables were chosen according to international standards and studies which states the indicators (independent variables) are as follows: (1) Gross Domestic Production, (2) Population, (3) The number of customers, (4) Electricity average price [4, 5, 9]. The unique output was annual electricity consumption. Several feed-forward back-propagation network architectures with 1 hidden layer were tested. Finally, the feed-forward back-propagation MLP networks of size 4×4×1 proved to have the least MAPE. Annual electricity consumption forecasts for 2002 to 2009 using ANNs are shown in the Figure 4 with plus (+) sign.

5.2 Regression Model
Linear multiple regression model was used in this section. The model used is follows:

\[ Y = 43510.34 + 0.045462X_1 + 11.05326X_2 - 2121.31X_3 - 47.9904X_4 \]  

where
- \( Y \): Annual electricity consumption forecasts
- \( X_1 \): Gross Domestic Production
- \( X_2 \): Population
- \( X_3 \): The number of customers
- \( X_4 \): Electricity average price

Annual electricity consumption forecasts for 2002 to 2009 using linear multiple regression model are shown in the Figure 4 with triangle (\(\Delta\)) sign.

5.3 Exponential Smoothing
The SPSS Clementine software was used to forecast the annual electricity consumption forecasts for 2002 to 2009 using exponential smoothing. The forecasts for 2002 to 2009 using double exponential smoothing are shown in the Figure 4 with plus (+) sign.

6. Discussion and Conclusions
Now the 8 observed annual data for 2002 to 2009 is used to validate the obtained models. The validation is performed by calculating the MAPE between the observed and forecasted values in the period of 2002–2009. The results obtained are reported in Table 1, for three models. Figure 4 shows the actual data versus predicted values of electricity consumption using the models for 2002 to 2009.

<table>
<thead>
<tr>
<th>Model</th>
<th>MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANN MLP(4×4×1)</td>
<td>0.02</td>
</tr>
<tr>
<td>Regression</td>
<td>0.03</td>
</tr>
<tr>
<td>Double Exponential Smoothing</td>
<td>0.04</td>
</tr>
</tbody>
</table>
The utilized ANNs, regression and exponential smoothing for long-term forecasting, such as annual forecasting show good results. However the ANN approach proved to be most efficient which has the least MAPE comparing with those of regression and exponential smoothing.

References