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Forecasting annual gross electricity demand by artificial neural networks using predicted values of socio-economic indicators and climatic conditions: Case of Turkey

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HIGHLIGHTS

- Electricity demand of Turkey increased from 15.6 to 246.4 TW h in 1975–2013 period.
- Population, GDP per capita, inflation and average summer temperature influence demand.
- Future values of descriptor variables can be predicted by time series ANN models.
- ANN model simulated by the predicted values of descriptors can forecast the demand.
- Demand is forecasted to be doubled reaching about 460 TW h in the year 2028.

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ABSTRACT

In this work, the annual gross electricity demand of Turkey was modeled by multiple linear regression and artificial neural networks as a function population, gross domestic product per capita, inflation percentage, unemployment percentage, average summer temperature and average winter temperature. Among these, the unemployment percentage and the average winter temperature were found to be insignificant to determine the demand for the years between 1975 and 2013. Next, the future values of the statistically significant variables were predicted by time series ANN models, and these were simulated in a multilayer perceptron ANN model to forecast the future annual electricity demand. The results were validated with a very high accuracy for the years that the electricity demand was known (2007–2013), and they were also superior to the official predictions (done by Ministry of Energy and Natural Resources of Turkey). The model was then used to forecast the annual gross electricity demand for the future years, and it was found that, the demand will be doubled reaching about 460 TW h in the year 2028. Finally, it was concluded that the approach applied in this work can easily be implemented for other countries to make accurate predictions for the future.

1. Introduction

The world electricity demand has increased extremely in the recent years as the world has become more populated and as the electricity consuming devices and appliances have become more common in the daily lives of people. It is vital for a country to be able to supply the electricity exactly equal to the demand. If the electricity generation capacity of a country is lower than the gross demand, electricity dependent industry is affected negatively and blackouts occur; on the other hand, a higher electricity generation capacity than the demand leads for the power plants to work with idle capacity, which is a waste in economic resources. Hence, accurate prediction of the electricity demand for the future is very important to correctly plan and develop new electricity generation investments for maintaining the electricity demand–supply balance.

In order to forecast the electricity demand with a good precision, one must correctly determine the variables which may influence the electricity demand in that country. Population is one of the key factors that are highly correlated with the electricity demand (more people consume more electricity). However, population alone is not sufficient to explain the changes in the electricity demand through years.

It is also quite common to consider some economic indicators in correlation with the electricity demand (Askarzadeh, 2014); one factor that can be used for this purpose is the gross domestic product (GDP) per capita, which is an indicator of the wealth of the

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people living in a country (Kucukali and Baris, 2010). As the GDP per capita increases the living standards of people get better and their lifestyles become more dependent on energy consuming devices and appliances. In addition to GDP per capita, employment and the inflation rates are two other economic factors that may affect the electricity demand (Zahedi et al., 2013).

Another factor that has a possible effect on electricity consumption is the electricity price (Inglesi, 2010; Kialashaki and Reisel, 2014; Nawaz et al., 2014). If there are available alternatives to electricity consumed in a country, the electricity demand is expected to be price elastic (an increase in price causes significant decline in the demand); otherwise, the demand is expected to be price inelastic (an increase in price causes only minor decline in the demand) (Nawaz et al., 2014).

The consumption of electricity may also depend on climatic conditions such as the average summer and winter temperatures. The hotter it is in the summer, more electricity is consumed for residential cooling, refrigeration and irrigation; on the other hand, the colder it is in the winter more electricity is consumed due to the electricity based heating of the residents (De Felice et al., 2013; Ekonomou, 2010).

For many years, many different forecasting tools based on data mining were applied to predict the future electricity or energy demand. Multiple linear regression (MLR) (Bianco et al., 2009, 2013; Ekonomou, 2010; Geem and Roper, 2009; Kialashaki and Reisel, 2014), methodologies based on fuzzy logic (Azadeh et al., 2010; Kucukali and Baris, 2010; Zahedi et al., 2013), autoregressive forecasting methods (García-Ascanio and Maté, 2010; Kheirkhah et al., 2013; Nawaz et al., 2014), support vector regression models (Ekonomou, 2010; Kavaklioglu, 2011) and artificial neural network (ANN) based models (Ekonomou, 2010; Geem and Roper, 2009; Kankal et al., 2011; Kavaklioglu et al., 2009; Kheirkhah et al., 2013; Kialashaki and Reisel, 2014; Pao, 2009; Zahedi et al., 2013) have been widely applied for this purpose. Various papers published in the last five years to forecast the electricity or energy demand for different countries with a variety of methods, together with the input variables considered and the forecasting time period are reviewed and summarized in the Supplementary Material. In some of these studies the demand was modeled as a function of the past data of the demand (time series approach) to forecast the possible demand in the future (Azadeh et al., 2010; Bianco et al., 2013, 2010; García-Ascanio and Maté, 2010; Hamzacebi and Es, 2014; Kheirkhah et al., 2013; Pao, 2009). Although, accurate results can be achieved when this method is employed, the factors leading to an increase or decrease in the demand cannot be analyzed this way. One other type of approach commonly implemented is to adopt the demand as a function of some descriptor variables (Askarzadeh, 2014; Behrang et al., 2011; Ekonomou, 2010; Geem and Roper, 2009; Ghanbari et al., 2013; Inglesi, 2010; Kavaklioglu, 2011; Kavaklioglu et al., 2009; Kialashaki and Reisel, 2014; Kıran et al., 2012; Kucukali and Baris, 2010; Nawaz et al., 2014; Zahedi et al., 2013). However, the problem with this approach is that the future values of the descriptor variables are uncertain (i.e. the population in the future is unknown); therefore, the demand is usually forecasted using the predicted values of the descriptor variables based on different scenarios that are in some cases too arbitrary.

In this study, both approaches are combined in a way that, the future values of the descriptor variables (i.e. population) were predicted using the past values of these variables by time series ANN models, and the future values of the electricity demand were forecasted using the predicted values of the descriptor variables by multilayer perceptron ANN models. Inspired from the biological nervous systems, ANNs mimic the learning that happens in humans; they have a great ability to approximate any nonlinear relationship that exists between a set of input variables and an output variable (Günay and Yildirim, 2011; Kialashaki and Reisel, 2014). Moreover, they are available as a toolbox in many of the programming environments (i.e. MATLAB, Weka, etc.); and thus, they are easy to implement for any purpose. They are also proven to be very successful for time series modeling in which the future values of a variable is determined using its past values (Kheirkhah et al., 2013).

In order to test the success of the approach, Turkey was chosen a case study since the rise in the energy demand of Turkey through years is even sharper than most of the other countries; such that, the annual gross electricity demand of Turkey increased from 15.6 TW h in the year 1975 to 246.4 TW h in the year 2013 (multiplied by a factor of 15.7 in this time interval) (TEIAS, 2013). Fossil fuel (petroleum, coal and natural gas) based electricity generation has been the primary way to meet this enormous increase of electricity demand. However, due to the fact that the fossil fuel resources are too limited in Turkey, they are mostly imported from other countries; consequently, most of the electricity demand of Turkey is supplied by foreign sources, which makes the accurate prediction of the future electricity demand even more crucial.

In this work, a database (covering the years between 1975 and 2013) was constructed including population, GDP per capita, inflation percentage, unemployment percentage, average summer temperature and average winter temperature to forecast the annual gross electricity demand of Turkey. First, the future values of the statistically significant descriptor variables were predicted from their historical values using time series ANN models, and possible future trends of these variables were analyzed. Then, the results were validated for the years that the electricity demand was known (2007–2013). Finally, the future electricity demand for Turkey for the years between 2014 and 2028 were forecasted by multilayer perceptron ANN models using the predicted values of the descriptor variables, and the results were also compared with the official predictions (done by Ministry of Energy and Natural Resources of Turkey).

2. Computational details

2.1. Data

Historical data for population, GDP per capita, inflation percentage, unemployment percentage, average summer temperature and average winter temperature (input variables), and the electricity demand (output variable) were collected from different sources for the years between 1975 and 2013. The gross electricity demand data (including the losses related to electricity transmission and distribution) was taken from the 2013 dated report of Turkish Electricity Transmission Company (TEIAS, 2013) while the past population data was extracted from Turkish Statistical Institute (TurkStat, 2013). Among the economic indicators, GDP per capita (based on purchasing power parity in international dollars) was calculated from the statistical data supplied by Organization for Economic Cooperation and Development (OECD, 2015), historical inflation percentage (based upon the consumer price index) was taken from World Wide Inflation Database (WWID, 2014), and the unemployment percentage was taken from International Monetary Fund World Economic Outlook Database (IMF, 2013). Finally, the average summer (June, July and August) and winter (December, January and February) temperatures were mined out from the report of Turkish State Meteorological Service based on the measurements made on 130 meteorological stations all over the country (MGM, 2014). The missing data points in the database were determined by linear interpolation or extrapolation using the closest values.

It should be noted that, the price of electricity was not used as a descriptor input variable in this work since the electricity demand