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Development and validation of artificial neural network models of the energy demand in the industrial sector of the United States

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ABSTRACT

In the United States, the industrial sector is the driving engine of economic development, and energy consumption in this sector may be considered as the fuel for this engine. In order to keep this sector sustainable (diverse and productive over the time), energy planning should be carried out comprehensively and precisely. This paper describes the development of two types of numerical energy models which are able to predict the United States' future industrial energy-demand. One model uses an ANN (artificial neural network) technique, and the other model uses a MLR (multiple linear regression) technique. Various independent variables (GDP, price of energy carriers) are tested. The future industrial energy demand can then be forecasted based on a defined scenario.

The ANN model anticipates a 16% increase in energy demand from 2012 by 2030. In this forecast, the model assumes that the effective independent parameters remain constant during this period and only GDP grows with a second-order polynomial trend. The forecast result, which shows consistency with published predictions, may be considered as an indication of the need for development of new and low-cost energy sources.

This study suggests that the ANN technique is a reliable and powerful technique which can effectively perform input/output mapping. In order to validate the performance of the models, the results of the ANN model is compared to the projections from the Energy Information Administration of the U.S. Department of Energy.

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1. Introduction

Mathematical modeling makes it possible to predict the behavior of a broad range of energy systems in response to fluctuations in affecting parameters. In other words, energy models which explain the properties of the system mathematically are powerful tools for studying energy production and demand problems. As a practical matter, the only means for constructing a comprehensive model is through careful integration of separate mathematical descriptions of the systems' components.

Because of the power of the mathematical models in the analysis of the past conditions and for forecasting the future, mathematical models are widely used in energy demand modeling. Mathematical energy models integrate scientific and technical knowledge with the purpose of predicting system behavior. Such knowledge is incorporated into the computational codes that the computers execute in model utilization. From this perspective, the significance of mathematical and computational modeling of energy systems is clear; it is one of the most applied methods for predicting the behavior of systems efficiently and effectively [1]. In this study, mathematical models based on numerical simulation permit the study of a complex energy system that otherwise would be too complicated, too costly, or even impossible to thoroughly investigate. The ANN (artificial neural network) technique is one that can overcome the limitations of traditional approaches by solving a complex modeling problem which is difficult to analytically describe.

Based on the ability of mathematical energy models, and since the availability and use of energy is one of the most essential elements of development in industrial countries, many studies have been performed to develop mathematical energy models for use in evaluating the future availability of energy and to help policy makers to plan accordingly. People's well-being, industrial

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competitiveness and the overall functioning of society are dependent on safe, secure, sustainable and affordable energy. As industrial activities in a country expand throughout the years, the need for accurate development plans for energy production becomes more important.

Clarifying the relationship between energy demand and economic growth by means of mathematical energy models has been a crucial issue for countries around the world during last two decades [2–5]. The ability to forecast energy demand due to economic growth based on mathematical models may be helpful in estimating the potential scale of energy production and supply infrastructure. If we could thoroughly understand how economic growth and pricing policies lead to changes in energy demand, we might be able to manage the high dependency of industry on energy and the resulting increased energy burdens at a lower economic and environmental cost. Climate change caused by energy consumption in industrial activities is currently one of the most important environmental problems, and it must be dealt with adequately [6]. Successful planning for future energy needs based on current and potential resources can assist policy makers and investing companies in this endeavor.

Among energy demands of economic sectors of a country, industrial energy consumption is one of the hardest end-uses to analyze, model, and forecast. The structure of energy demand for an entire industrial sector is unclear. For example, the energy demand of the industrial sector might not be strongly correlated with population size because industrial products may be sold in domestic markets or exported to global markets. To describe how the dependent variable (energy demand in industrial sector) and independent variables (such as prices of energy carriers) interact with each other, we need to measure the relationship between the variables using covariance and correlation methods.

In this study, United States' energy demand in industrial sector is forecast. ANN is chosen as the forecasting tool. The reasons behind this choice are the ability of ANN to forecast the future values of many variables simultaneously and to model the nonlinear relation in the data structure. To show these reasons, a comparison between the performance of ANN models and multiple linear regression (MLR) models is done. The organization of the rest of the paper is as follows. The second part includes a brief review of the background of this problem. Third part reviews the previous studies which contributed to this topic. In part four, background information of ANN and MLR modeling is briefly summarized. In part five, data are analyzed, models are compared, and results are discussed. The final section reviews the conclusions of this paper.

2. Previous studies on the modeling of energy demand in the industrial sector

Planners, policy-makers, and the private sector rely on energy forecasts to make policy and investment decisions. Hence, there are many studies related to energy demand modeling in the literature for countries around the world using a variety of mathematical techniques. Recently, researchers have applied AI (artificial intelligence) techniques in their studies as a forecasting method. For Turkey, which had the highest average population growth rate among the IEA (International Energy Agency) member countries, Hamzacebi [7] explored net electrical energy consumption on a sector basis through 2020 and the results are compared with official forecasts of the Turkey. The results of this study showed a good agreement between predicted values of energy consumption between the ANN and the official forecasts. In 2007, Akay and Atak used the GPRM (Grey prediction with rolling mechanism) method to forecast electricity demand of Turkey. GPRM showed high prediction accuracy with little computational effort required [8]. Duran used the ACO (ant colony optimization) method to estimate energy demand of Turkey. The model used population gross domestic product, imports, and exports to predict the energy demand of the Turkey until 2025 based on three proposed scenarios [9]. Ünler proposed a model using PSO (particle swarm optimization) method to forecast the energy demand of Turkey. Population, GDP, imports, and exports were used as independent indicators to forecast energy demand and the results were compared with the results of the ACO model developed for same problem [10]. As another approach for forecasting short-term gross annual electricity demand for Turkey, Kucukali and Baris applied fuzzy logic. The proposed model used GDP as the sole independent parameter and captured the system behavior of the period 1970–2014 [11]. In 2012, Bilgili et al. applied ANN, LR (linear regression), and NLR (nonlinear regression) to estimate the electricity consumption of the residential and industrial sectors in Turkey. Installed capacity, gross electricity production, population and total subscribership were selected as independent variables. Prediction of the electricity consumption is based on two different scenarios and the results of the three methods were compared [12]. The comparisons showed good agreement between the actual data and forecasted results. Also, the performance values of the ANN method were better than performance values of the LR and NLR models.

In 2008, Adams and Shachmurove built an econometric model of Chinese energy economy. This model is based on energy balance and used to forecast Chinese energy consumption and imports to 2020 [13]. For Iran as a case study, Azadeh et al. presented an integrated algorithm for forecasting monthly electricity consumption based on a supervised multi-level perceptron ANN, computer simulation and design of experiments. Iran's electricity consumption data for 131 months from 1994 to 2005 were analyzed and applied to the proposed algorithm to show the applicability of ANN and its superiority to conventional time series and simulated-based ANN according to statistical analysis of the results [14]. Regarding the industrial sector of Iran, Azadeh et al. developed an ANN to forecast annual electricity consumption. In addition, the ANN forecast is compared with actual data and conventional regression model to show the superiority of ANN models [15]. In 2010, Azadeh et al. applied a fuzzy regression algorithm to estimate the energy consumption of Iran. They showed that the proposed algorithm is capable of managing imprecision, ambiguity, and lack of data due to fuzzy regression mechanism [16].

The application of the mathematical models in energy modeling and forecast has been applied to other countries as well. For example, Geem and Roper, estimated energy demand of South Korea with an ANN model. This model has four independent variables including GDP, population, import, and export amounts [17]. In 2013, Kialashaki and Reisel developed energy demand models which are able to forecast energy demand of residential sector of the United States. In this study the ANN model is chosen based on the model evaluation parameter [18]. As can befrom this review of past studies, there is a clear trend towards applying AI (artificial intelligence) techniques in this field.

In the United States, the EIA (Energy Information Administration) has published energy forecasts since 1982. These energy forecasts, which are presented in the Annual Energy Outlook, are the main sources of policy decisions in the United States. To make projections, EIA used the IFFS (Intermediate Future Forecasting System) between 1982 and 1993, and used the NEMS (National Energy Modeling Systems) since 1994. IFFS and NEMS apply balanced supply demand approach; however, NEMS uses this approach in more detail [19]. Auffhammer evaluated the rationality of published forecasts of EIA under symmetric and asymmetric loss and found evidence of asymmetric loss in areas including oil, coal and electricity prices and natural gas consumption [20].

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