Influence of the price of electricity for the industry on the consumption in the economic sector in Bulgaria

Kostadin Yotov 1, Emil Hadzhikolev 1, Stanka Hadzhikoleva 1

1 University of Plovdiv “Paisii Hilendarski”, Department of Mathematics and Informatics, 236, Bulgaria Blvd. Plovdiv, Bulgaria

e-mail: kostadin_yotov@abv.bg, hadjikolev@uni-plovdiv.bg, stankah@uni-plovdiv.bg

Abstract. Forecasting electricity consumption is extremely important for the planning and management of a country’s electricity system. It is an important factor for the effective planning of the production facilities operation, the future exports or imports, the behavior and direction of energy flows both in the country and in the connected international networks. Electricity consumption depends on many macroeconomic and demographic indicators, social parameters, climate conditions, etc. Their study and prediction with standard mathematical methods is a complex task. The article presents a study conducted using one of the most popular artificial intelligence techniques, namely – neural networks. Two models of neural networks have been created. One models the changes in the price of electricity, and the second – the dynamics of electricity consumption depending on its price.

1. Introduction

The efficient functioning of the National Electric Energy System (NEES) of a country is extremely important for the industry, agriculture and everyday life, and hence for the prosperity of its citizens. That is why monitoring and optimizing it is an important task for any government.

The national electricity system in the most general terms can be considered as a set of capacities for production of electricity, transmission network providing its transportation in accordance with established quality standards, distribution system, and the final users – consumers. In fact, the NEES has a complex structure. Production facilities, for example, can be different types – nuclear power plants (NPPs), hydro and thermal power plants (HPPs, PSHPs, TPPs). We can add to them the producers of electricity from renewable sources – wind power plants, photovoltaic and geothermal systems, etc. Energy transmission networks, in turn, are structured by systems of power lines and substations forming complex rings for voltages of 400 kV, 220 kV, 110 kV, 20 kV. Other needs specific to individual economic entities are the power lines of 10 kV, 6 kV, 1 kV, 0,4 kV. Distribution networks can be implemented under different schemes (air, cable, mixed) and for different voltages, and end users are generally of two types – household and commercial (industry, transport, services, agriculture and fisheries).

Many factors are important for the proper functioning of NEES, the more important of which are: condition and management of the individual components of NEES; accurate forecasting of losses in the NEES units; precise calculation of the electric energy balance; forecasting electricity consumption, etc. Electricity consumption forecasting is extremely important and influences greatly the management decisions for the planning and management of NEES. Accurate forecasting of probable electrical loads is a prerequisite for effective planning of the operation of production facilities, proper maintenance of the electricity transmission and distribution network, planning of future exports and imports, the
behavior and direction of energy flows both in the country and in related international networks. This task is so important and it is set in the Rules for power system management [1] and the Rules for management of the electricity distribution networks [2] issued by the Energy and Water Regulation Commission (EWRC). The successful solution of this task is directly related to the correct assessment of the factors influencing consumption. This includes various macroeconomic and demographic indicators, social parameters, climate conditions etc. The gross domestic product (GDP), energy intensity (EI), population size, population income, expected temperatures for the period, energy efficiency, electricity price and several other factors are of great importance. The article describes models for forecasting the price of electricity for industry and electricity consumption of the economic sector in Bulgaria.

2. Influence of the price of electricity on consumption
According to the National Statistical Institute [3] and Infostat [4], electricity prices for households and industry in the 2007-2018 period change in an upward trend, according to the graph on fig. 1.

![Figure 1. Price of electricity (BGN / thousand tonnes of oil equivalent) for households and industry in the 2007-2018 period.](image)

The subject of this study is the following issue: Will the electricity consumption in industry decrease when its price increases? Of course, when discussing the impact of electricity price on its consumption, we must pay attention to the fact that ultimately, the total electricity consumption is affected not only by changes in electricity prices, but also by changes in the prices of individual energy sources, such as natural gas, for example. Electricity consumption may also be affected by national policies for energy production from forest biomass [5] or environmental influence on renewable sources productivity [6]. Research shows that there is a strong correlation between electricity consumption and coal prices [7]. On the other hand, more and more companies are developing and implementing programs for optimizing electricity consumption. The task set in the present study is the construction of artificial neural networks showing the dynamics of energy consumption and electricity prices in Bulgaria.

3. Approaches to forecasting energy consumption
Whether it is long-term, medium-term or short-term forecasts, forecasting electricity consumption plays a key role in investment planning, introducing new capacities or putting out unnecessary ones, and assessing the behavior of the entire economic system. Effective modeling of electricity consumption is becoming a vital task aimed at avoiding costly mistakes with unreasonable investments, shutting down important facilities, improperly scheduled repairs or short-sightedness in exports or imports. Numerous studies have been described in the scientific literature using various approaches to forecasting energy consumption.
Traditional methods such as correlation and regression analysis have been used in the researches conducted by [7] and [8]. [7] have done a basic in-depth analysis of the influence of individual factors that affect electricity consumption. The gross domestic product of the country, the number of the population, income, prices, temperature and other factors are considered. Estimates are made based on three different scenarios. All three options use forecasts for gross domestic product, population, gross value added by economic sectors, and number of employees. The Risk Management Lab team has created mathematical and statistical models for forecasting the electricity balance [8]. They determine many factors influencing electricity consumption and calculate corresponding correlation coefficients. They then determine the Pearson coefficients used in their mathematical models. Unfortunately, one of the limitations of statistical analysis models is related to the fact that the efficiency of their forecasting is highly dependent on the sample size and the set of complex variables [9], [10].

Another possible approach is the use of time series in forecasting consumption. For example, [11] focuses on one of the simplest methods related to averaging time series. The aim is to get a clear enough idea of the trend and to smoothen the series. Another approach used by [12] and [13] is SimpleExponentialSmoothing (SES).

The need for more accurate forecasting and the impossibility to identify absolutely all factors influencing the studied quantities, motivates the use of neural networks. Particular importance is attached to the fact that in nonlinear processes the accuracy of neural networks significantly exceeds that of other methods [14], [15], [16]. Other authors, in turn, show that statistical analysis as an integral part of neural models provides a valuable tool for designing simple but efficient neural models for building energy applications [17].

Of course, none if the ideas, no theory or tool for studying certain processes should be favored – each of them has its advantages in individual cases. In his work, for example, [18] linked the ideas in gray models to those of neural networks and used this technique to predict the electricity consumption of many countries in the Asia-Pacific region.

4. Study of the price of electricity and forecasting of consumption in the industry sector, using neural networks

Changes in electricity consumption depend on many factors – gross domestic product, energy intensity, population number and income, expected temperatures for the respective period, energy efficiency, prices of energy sources, etc. The price of electricity, in turn, also depends on many factors – prices of energy sources, the use of innovative technologies, the efficiency of electricity production itself, losses in the transmission and distribution networks, even speculations in the electricity markets. Identifying, studying and predicting those factors, as well as the factors that predetermine them, is an extremely laborious and complex task. This complicates the use of standard mathematical approaches. In cases where there are unknown connections between objects or processes or they are subject to conditions of a probabilistic nature, it is appropriate to use artificial intelligence techniques. Neural networks with a straight signal propagation were used in the present study.

Artificial neural networks are a powerful tool in building artificial intelligence systems. They are based on the idea of making a structural and functional analogy with the workings of the human brain – the neurocybernetic approach. They use mathematical models describing and simulating the work of

![Figure 2. A neural network with one hidden layer and one output neuron.](image)
nerve cells, whose main task is the reception, processing and transmission of the signal to other cells or decision and reaction centers. It is the aggregation of several organized artificial structures (artificial neurons) that we call an artificial neural network.

According to Cybenko’s theorem [19], we use a neural network with one hidden layer. A sigmoid transfer function is used in the body of neurons. The result is obtained through an output neuron, through the axon of which we expect the signal associated with the predicted consumption.

**The selected approach is based on the following sequence:**

1. Creation of an artificial neural network Net_Ci for forecasting the behaviour of electricity prices for the Industry sector in Bulgaria. The training of the network is based on the current behavior of prices considered as a time series.
2. Forecasting future electricity prices through Net_Ci neural network.
3. Creating an artificial neural network Net_Industry, realizing the connection of the consumption in the industrial sector with the electricity prices, determined for the sphere of the economy.
4. Forecasting electricity consumption through Net_Industry, based on the electricity prices forecasted through the neural network Net_Ci.

**For training and modeling the neural network Net_Ci** the time series of the price of electricity for the industry for the period 2007 – 2018 was used (table 1). The data are taken from the information system INFOSTAT [20], which is the official source of information of the National Statistical Institute of Bulgaria.

The artificial neural network Net_Ci was created, containing one hidden layer with 17 neurons (fig. 3).

**Figure 3.** Net_Ci neural network architecture for predicting electricity price for the Industry.

The type of training that turned out to be the most effective for the task is the Levenberg-Marquardt algorithm. The transfer function of neurons in the hidden layers is a hyperbolic tangent:

\[ g(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \]

The transfer function of the output neuron in all networks is the linear:

\[ g(x) = x \]

The graphs of the network function which shows the approximation of the development of electricity price over time according to the neural network is shown in Fig. 4.

![Table 1. Electricity prices for the Industry sector for the 2007-2018 period.](image_url)
After the conducted training, the neural network Net_Ci forecasted value of 0.2134 BGN / kwh with a reported real value of 0.2279 BGN / kwh for the forecast 2019. At that, the absolute error is 0.0145 BGN / kwh.

The second created neural network Net_Industry is for forecasting electricity consumption in the industrial sector. For its training the data presented in table 2 are used [21].

Its training required 1000 iterative epochs in which we used a Bayesian regularization algorithm. For the transfer function on the neurons in the hidden layer, hyperbolic tangent was again used, and for the one in the output neuron – the linear one \( g(x) = x \).

The Net_Industry neural network found consists of 130 neurons in the hidden layer. The architecture is presented in fig. 5.

The graph of the network function which shows the approximation of the behavior of the consumed electricity depending on its price is presented in fig. 6.

| Year | Consumption (thousand TOE) |
|------|---------------------------|
| 2007 | 3811.0                    |
| 2008 | 3453.8                    |
| 2009 | 2442.1                    |
| 2010 | 2550.0                    |
| 2011 | 2696.4                    |
| 2012 | 2566.6                    |
| 2013 | 2595.5                    |
| 2014 | 2617.5                    |
| 2015 | 2719.6                    |
| 2016 | 2655.5                    |
| 2017 | 2753.6                    |
| 2018 | 2730.6                    |

**Table 2.** Energy consumption in the Industry sector for the 2007-2018 period.
Figure 6. Graph of network functions of electricity consumption in the Industrial sector.

During the training of the Net_Industry neural network, a minimum error of 1.5376e-7 thousand tonne of oil equivalent (TOE) was reported. Using the price of electricity forecasted by Net_Ci, Net_Industry forecasts consumption in the Industry sector for 2019 amounting 2567.9 thousand TOE.

5. Conclusion
Forecasting electricity consumption on a national level is extremely important for the planning and management of the National Electric Energy System. It depends on many macroeconomic and demographic indicators, social parameters, climate conditions and more. Their study and prediction with standard mathematical methods is a complex task. The article presents a study conducted using one of the most popular techniques of artificial intelligence, namely – neural networks. Two neural networks have been created which model the dynamics of changes in the price of electricity and its consumption in the industrial sector. The conducted study found that the price of electricity is expected to continue to rise in the future, and with it its consumption in the economy.

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