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THEORETICAL MODEL FOR ELECTRICITY MARKET PRICE FORECASTING

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Abstract

The developed electricity market price forecasting model is presented in this paper. The following structural parts of the model are segregated and shortly described – determination of the aim of market price forecasting, analysis of features of electricity market price, identification of factors forming electricity market price and influencing on its changes, segregation of the most significant factors, gathering of statistical information and its primary processing, selection of forecasting method, calculation of forecasts, assessment of accuracy of forecasts, presentation of recommendations. Indicators and methods, allowing disclosing electricity market price features (volatility, spikes, mean-reversion, and seasonality), are listed. Factors, forming electricity market price and making its changes, are segregated and grouped under their relation with electricity supply, demand and market structure criteria. Methods, allowing segregating the most significant electricity market price factors, are mentioned. Electricity market price forecasting methods are designated and criteria, how to choose the method are ascertained. Indicators for assessment of electricity price forecasts accuracy are aggregated.

Keywords: electricity market price, forecasting, price features, price factors, forecasting method, forecasts accuracy.

JEL Classification: C22, C32, C51, C52, L90, E37.

Introduction

Topicality of the article. The topic of electricity market price forecasting is an important issue of various entities over the world. Electricity market price forecasts are relevant for electricity producers adopting strategic and tactical decisions how much and when to produce and sell electricity to consumers. Besides, electricity price is a mean that is ticketed for improvement the performance results of electricity producers. Investors concern electricity price development tendencies and price forecasts seeking to accept rational investment decisions and to substantiate an expected investment return. Brokers use price forecasts in pricing of derivatives. Naturally, price status in future is essential for policy makers, who use this information in preparing national strategies for optimal integration of future energy technologies; as well price forecasts facilitate acceptability of decisions related to economy management. Thus, the topic how to foresee the movement of electricity market price is critical. The profound interest has arisen already in 1990s, when the first power exchanges and competitive electricity markets started to operate. Today various aspects of electricity price forecasting are analyzed. Electricity price forecasting methods and models are the most broadly investigated scope of the issue. It has to be acknowledged that developed methods and models are comprehensive in mathematical sense and they are accurate; however one can notice that there is a lack of economic interpretation of the results received using these methods (models).

Novelty of the article. Seeking to solve the problem of low linkage between purely mathematical model and economic interpretation of results, a generalization of scientific literature regarding electricity price forecasting issue is performed; a system of electricity price forecasting factors is prepared and integrated into the structure of electricity price forecasting model. It has to be mentioned that such an approach is not fully new; however, its novelty emerges in a way that a systematic approach to the issue is expressed.

The object of the article is electricity market price that means the settlement price for the electricity traded in a day-ahead electricity market, and is the price at the intersection of the aggregated supply and demand curves.

The aim of the article is to prepare a framework that will enable to foresee electricity market price development in future and thus will substantiate the adequacy of accepted decisions, done by market participants, to qualified aims.

Seeking to implement the aim the following *tasks are set*:

- to segregate the structural parts of electricity market price forecasting model based on the analysis of scientific literature;

- to prepare the system of indicators appropriate for electricity market price forecasting based on generalization of scientific literature on issue of electricity price forecasting factors;
- to overview electricity market price forecasting models and methods;
- to summarize indicators of electricity price forecasting errors.

In order to exercise these tasks scientific literature generalization *method* is applied.

Structure of electricity market price forecasting model

Considering researches of various authors (Schwager, 1995; Armstrong, 2001; Shahidehpour *et al.*, 2002; Evans, 2003; Hoshmand, 2010) the process of electricity market price forecasting is recommended to be performed following seven stages (Figure 1).

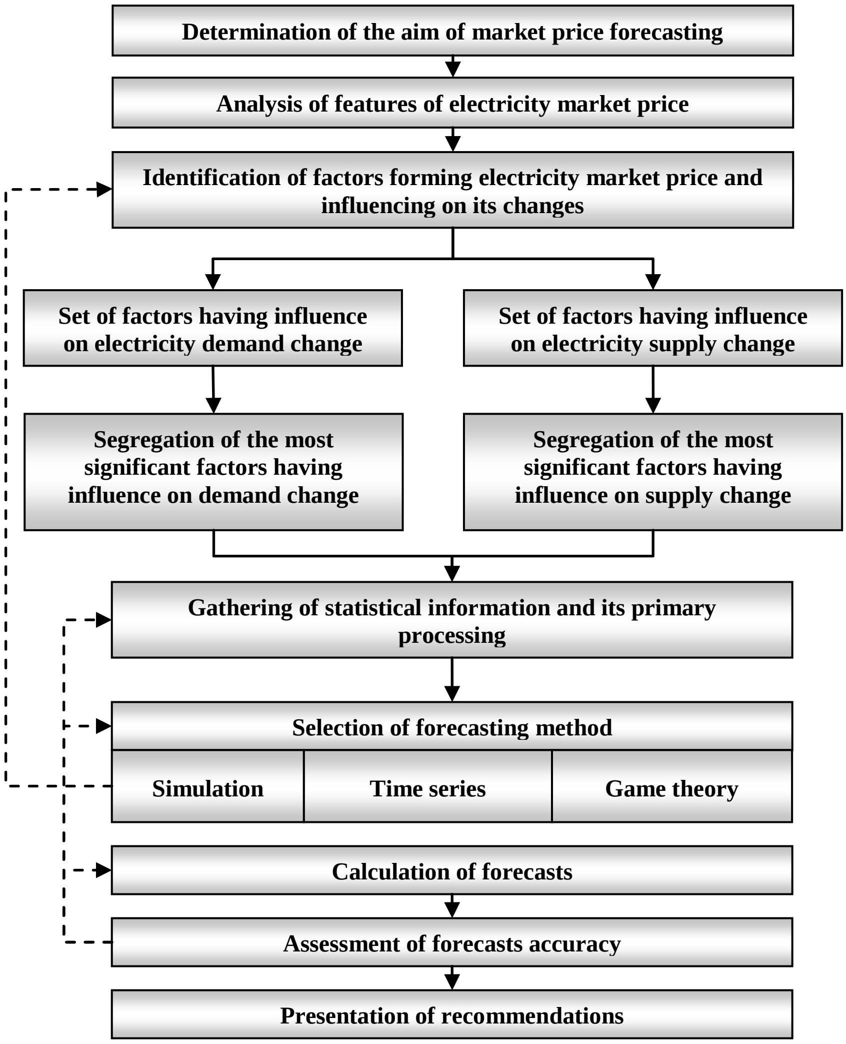

Figure 1. Electricity market price forecasting structure and stages of implementation

In the stage of determination of the aim of market price forecasting it is required to indicate the aim for which electricity market price forecasts are prepared and the scope, where forecasts will be used. Various economic subjects can use electricity market price forecasts achieving different aims:

- *for electrcity producers* electricity market price forecasts are relevant accepting strategic and tactical electricity production and selling to consumers decissions; price is one of the ways appropriate to improve activity results of electricity producers;
- *for investors* tendencies of electricity price development in future are topical, since considering to them it is easier to accept investment decissions and substantiate expected return of investment;

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- *for policy makers* electricity price development tendencies are relevant during the time, when plans and strategies are arranged; as well considering to the acquired information about prices in future it is easier to accept management decissions of the national economy.

In the stage of analysis of electricity market price features it is essential to perform a research of electricity market price features. A comprehensive analysis of electricity market price features, which were discussed by A. J. Conejo *et al.* (2005), Ch. R. Knittel & M. R. Roberts (2005), J. Seifert & M. Uhrig-Homburg (2007), D. J. Swider & Ch. Weber (2007), N. V. Karakatsani & D. W. Bunn (2008), should encompass the analysis of the following market price features:

- volatility;
- spikes and jumps;
- mean-reverting;
- seasonality and other periodiocity.

Indicators that can be applied to disclose electricity market price volatility are presented in Table 1.

Table 1. Electrcity market price volatility indicators

Author	Name of indicator	Equation	Assessment of value of indicator
S. Danilenko (2007)	Dispersion	$\sigma^2 = \frac{1}{n-1} \cdot \sum_{i=1}^{n}(x_i - \bar{x})^2$, when $\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i$	The higher the value the more volatile electricity price is.
F. A. Wolak (1998)	Standard deviation	$\sigma = \sqrt{\sigma^2}$	
J. J. Lucia & E. S. Schwartz (2002)	Standard volatility	$V = \sigma \cdot \sqrt{365}$	
M. P. Muñoz & D. A. Dickey (2009)	Square of difference of two neighbouring values	$V = (x_t - x_{t-1})^2$	
K. B. Paulavičius (2010)	Coefficient of oscillation	$K_R = \frac{x_{max} - x_{min}}{\bar{x}} \cdot 100\%$	
V. Bobinaitė (2011)	Coefficient of variation	$V = \frac{\sigma}{\bar{x}} \cdot 100\%$	till 10% – variation low; 10% – 20% variation medium; 20% – 30% variation high; 30% and more variation is very high.
Y. Li & P. C. Flynn (2004), H. Zareipour *et al*. (2007)	Daily velocity indicator, calculated under the average price of electricity during a day	$\mathrm{DVDA}_{iP} = \frac{1}{M} \cdot \frac{\sum_{j=1}^{M-1} \lvert P_{i,j+1} - P_{ij} \rvert + \lvert P_{i-1,M} - P_{i,1} \rvert}{\frac{1}{M} \cdot \sum_{j=1}^{M} P_{ij}}$	The higher the value the more volatile electricity price is.
	Daily velocity indicator, calculated under the average price of electricity during a certain time period	$\mathrm{DVOA}_{iP} = \frac{1}{M} \cdot \frac{\sum_{j=1}^{M-1} \lvert P_{i,j+1} - P_{ij} \rvert + \lvert P_{i-1,M} - P_{i,1} \rvert}{\frac{1}{M \cdot N} \cdot \sum_{i=1}^{N} \sum_{j=1}^{M} P_{ij}}$	

here: σ^2 – dispersion; n – number of observations; $\bar{x}$ – average of time series; x_t – value of observation at the moment t; x_{t-1} – value of observation at the moment t-1; x_{max} – maximum value of variable, x_{min} – minimum value of variable; N – number of days during a certain time period; i – index of the day, usually i = 1, 2, …N; M – number of time periods per day; if this is hourly price, then M = 24; J – index of time period, usually j = 1, 2, …M; P_{ij} – electricity price at time moment j of a day i

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As it is seen from Table 1, electricity price volatility is disclosed by calculating the following indicators – dispersion, standard deviation, coefficient of oscillation, coefficient of variation, daily velocity indicators and others.

Table 2. Indicators for identification of price spikes

Author	Indicator	Formula of indicator	Valuation
X Lu *et al*. (2005)	Critical value of price	$P_K = \bar{x} \pm 2 \cdot \sigma$	If P>P_K, when $P_K = \bar{x} + 2 \cdot \sigma$, or P<$P_K$, when $P_K = \bar{x} - 2 \cdot \sigma$, then P corresponds definition of price spike. Critical values of price might be set using rules of $3 \cdot \sigma$ and $4 \cdot \sigma$.
	Negative price	P<0	All negative prices represent price spikes.
J. J. Lucia & E. S. Schwartz (2002)	Coefficient of asymmetry	$A_S = \frac{\mu_3}{\sigma^3}$	If As>0, price acquires extremely high values more often than extremely low ones.

here: σ – standard deviation; $\bar{x}$ – average electricity price; μ_3 – third order central moment.

Table 2 shows, that seeking to disclose price spikes, critical value of electricity price has to be calculated. All electricity prices that are below and above critical value of electricity price are assumed to be price spikes.

Seaking to disclose mean-reversion of electrcity market price, rescaled range analysis (R/S analysis) and detrended fluctuation analysis (DFA analysis) are performed (Weron, 2006).

Considering the results of serial correlation, the conclussion about seasonality of electricity market price can be disclosed (Weron, 2006).

In the stage of factors forming and making electricity market price to fluctuate all factors are segregated and classified under three criteria: 1) under the relationship with electricity demand, 2) under the relationship with electrcity supply and 3) under the criteria of market structure and regulation (see Table 3).

Table 3. Factors forming and making electricity market price to fluctuate (Hughes & Parace, 2002; Catalão *et al*., 2007; Mjelde & Bessler, 2009; Muñoz & Dickey, 2009; Ferkingstad *et al*., 2010; Singhal & Swarup, 2011; RWE, 2012)

Electricity demand factors and indicators	Electricity supply factors and indicators
Fluctuations of economic activity level (growth rates of real GDP)	Changes of fuel (oil, natural gas, uranium, natural gas, coal) prices used in electricity generation
Fluctuations of price level (growth rates of consumer price index and GDP deflator)	The structure of resources used in electricity production
Seasonality of electricity demand	CO_2 price changes
Demand elasticity of electricity price	Wind speed
Fluctuations of air temperature	Amount of precipitation, water resource level
Prices of electricity substitutes (natural gas, biofuel)	Temperature
Behavior of electricity consumer during public holidays, weekends and working days	Cloudiness
Changes of retail electricity prices	Exchange rate (EUR/USD)
	Capacity installed in PPs and capacity utilization level
	Changes of electricity import volume
	Technical state of PPs and generation unit availability
	Planned and unplanned generation outages
	State of transmission and distribution lines
	Situation (including prices) in neighboring electricity markets
	Electricity bidding strategies, system load
Market structure and regulation	
Price caps of wholesale and retail electricity prices	
Method of wholesale price calculation	

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Taking into consideration the world experience, not all indicators mentioned in Table 3 are used to forecast electrcity market price. Usually, electrcity market price is forecasted including into the forecasting models the following indicators – historical electricity market prices, loads, volume of electrcity consumption, prices of fuels (oil, natural gas, uranium and coal) used in electricity production, air temperature, water resources and exchange rates.

In the stage of identification of the most significant electricity market price factors, the most important price factors are selected. Sensitivity analysis (Aggarwal *et al.*, 2009) and correlation analysis (Singhall & Swarup, 2011) are among the methods that can be used to identify the most significant electricity market price factors.

In the stage of statistical information collection and its primary processing stage it is necessary to collect all quantitative and qualitative information about price factors. Quantitative information is necessarily to be processed and prepared for further analysis (Pilinkus, 2010).

In the stage of selection of forecasting method it is eesential to select method(s), with reference to which electricity market price forecasts will be calculated. According to V. Rutkauskas (2005), forecasting method is selected sustaining to the following criteria:

- forecasting method should be adaptive;
- forecasting method should be flexible;
- factors-causes and factors-results should be clearly detached in forecasting method, i.e. forecasting method can't be contradictory;
- forecasting method must be constructive.

The analysis of scientific literature shows that various methods can be used to forecast electricity market price. Aggarwal *et al.* (2009) segragate three large groups of methods used in electricity market price forecasting. They are the following – game theory, time series and simulation methods.

The reflections of game theory can be found in W. Lise & G. Kruseman (2008), M. Bonacina & F. Giulli (2008), and D. Pozo (2011) works. These scientists analyzed hypothetical (Pozo, 2011) and actual (Lise & Kruseman, 2008; Bonacina & Giulli, 2008) electricity markets. Usually scientists analyzed the oligopoly markets and the results received were compared with ones that were obtained in perfectly competitive markets. The following oligopoly models were analyzed – Bertrand, Forchleimer, Stackelber and Cournot.

Time series methods are usually used to forecast electricity market prices in a short-run. Stochastic (AR, ARX, ARMA, ARMAX, PARMAX, NARX, GARCH, GARCH-M, EGARCH, EGARCH-M), artificial intellegance (neural networks) and regression (multiple regression and causality) methods are prescribed to this group of methods and are commonly applied. Stochastic methods are commonly used because of the actual observations that many economical statements and methods usually contradict each other and are very abstract. Here two groups of stochastic forecasting followers can be segregated. The purely stochastic forecasting followers state that seeking to foresee the development of variable in future it is enough to analyze its dynamics in the past. The results of their analysis show that if some variables (electricity import volume) are included in the stochastic models, the forecasts accuracy does not improve. Some factors, such as air temperature, and weather conditions are variables of electricity demand; therefore after the involvement of these factors into the model, the forecasts will be rarely accurate. As a result purely stochastic followers (Cuaresma, *et al.*, 2004; Conejo *et al*., 2005) assume that historical electricity prices are this type of information that is necessary to forecast electricity market price. Other group of stochastic forecasting followers (Lira *et al.*, 2009; Weron & Misiorek, 2008) considers that additional to historical electricity prices exogenous variables (electricity consumption volume, weather temperature, oil and natural gas prices, water level in reservoirs) can be added. The results of forecasts show that this contributes to improvement of accuracy of electricity market price forecasts. The involvement of exogenous variables into the model ensures some economical reasoning for the forecasts.

Neural network is a very popular short-run electricity market price forecasting method. It was used by B. Ramsay & A. J. Wang (1998), Shahidehpour *et al.* (2002), Conejo *et al.* (2005), Catalão *et al*. (2007), D. Singhal & K. S. Swarup (2011) and in many other authors works because of the following reasons:

- method is fairly explicit, its implementation is not complicated;
- in many cases forecast accuracy is better than using stochastic time series methods;
- complex and not linear relationships are revealed by this method;
- method is applied in the cases when forecaster has enough data; method is used when the problem is complex to describe and additional special knowledge is required;

- there is possibility to learn.

Despite the advantages the method has some disadvantages:

- data are necessary to be processed and prepared for the analysis. This takes some time.
- this is a "black-box method, since it is difficult to logically explain the decisions accepted by neural networks.

Naturally, simulation methods can be applied. However, these methods requires very detailed information about factors of electricity market price, they are expensive and complicated.

In the stage of calculation of forecasts of electricity market price the selected method is applied to solve the problem.

In the stage of accuracy assessment of forecasts the accuracy of received results is tested. MAPE, MAE, RMSE and other indicators are calculated for this purpose. Electricity market prices quickly changes and 24 or 48 electricity prices per one day are formed; therefore seeking to calculate errors it is sufficient to take data of one week. This is corresponds to 168 observations. When 168 observations are analyzed, then the error indicator is ticked by letter "W". In Table 4 equations of indicators for forecast accuracy are presented.

Table 4. Electricity market price forecasts accuracy assessment indicators (Shahidehour *et al.*, 2002; Cuaresma *et al.*, 2004; Weron & Misiorek, 2008; Bajpaj, 2010; Rebennack *et al.*, 2010)

Accuracy indicator	Equation of indicator	Assessment of value of indicator
Mean absolute percentage error	$WMAPE=\frac{1}{168}\cdot\sum_{i=1}^{168}\left\lvert\frac{y_t-F_t}{y_t}\right\rvert\cdot 100\%$	Forecast is very accurate if WMAPE does not exceed 10%. Forecast accuracy is not sufficient if WMAPE exceed 50%.
Adjusted mean absolute percentage error	$WMAPE=\frac{1}{168}\cdot\sum_{i=1}^{168}\left\lvert\frac{y_t-F_t}{\bar{y}}\right\rvert\cdot 100\%$	
Mean absolute error	$WMAE=\frac{\sum_{i=1}^{168}\lvert y_t-F_t\rvert}{\sum_{i=1}^{168}y_t}\cdot 100\%$	The lower the better.
Adjusted mean absolute error	$WMAE=\frac{\sum_{i=1}^{168}\lvert y_t-F_t\rvert}{168}$	The lower the better.
Root of mean squared error	$WRMSE=\sqrt{\frac{1}{168}\cdot\sum_{i=1}^{168}(y_t-F_t)^2}$	The lower the better.

In the last stage recommendations to forecast users are provided.

Conclusions

1. Theoretical model for electricity market price forecasting is developed. It consists of the following structural parts: determination of the aim of market price forecasting, analysis of features of electricity market price, identification of factors forming electricity market price and influencing on its changes, segregation of the most significant factors, gathering of statistical information and its primary processing, selection of forecasting method, calculation of forecasts, assessment of accuracy of forecasts, presentation of recommendations.
2. Indicators and methods to disclose features of electricity market price are listed. Dispersion, standard deviation, oscillation, variation and daily velocity indicators can be applied to disclose price volatility. Critical price value should be calculated to disclose price spikes. R/S and DFA analysis are used to disclose mean-reversion. Serial correlation analysis is applied to show price periodicity.

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3. Factors, forming electricity market price and having impact on its changes, are segregated and grouped under the following three criteria – electricity demand, supply and market structure. It is set that electricity demand changes because of the following reasons – change of economic activity, GDP deflator, air temperature, prices of electricity substitutes and changes of retail electricity price. Electricity supply changes because of the occurrence of the following factors – changes of fuel used in electricity generation prices, air temperature, changes of CO_2 prices, mix of electricity generation sources, exchange rate, changes of installed capacity in PPs and capacity utilization level and changes of electricity import volume.
4. Three groups of electricity market price forecasting methods are segregated. They are game theory, time series (stochastic, regression, and neural networks), and simulation methods. It is set that time series methods are among the most widely used methods to forecast short-run electricity market prices.
5. Indicators of forecasts accuracy are segregated. It is set that the accuracy of forecasts is assessed calculating the following indicators – mean absolute percentage error (MAPE), mean absolute error (MAE) and root of mean squared error (RMSE).

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