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The Role of Residual Demand in Electricity Price Analysis and Forecasting: Case of Czech Electricity Market

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ABSTRACT

Most of scientific papers dealing with power price predictions base their work on various statistical time series models. In this paper we propose a new, purely fundamental, approach to the issues of electricity price analysis and forecasting. While precise replication of real power market processes is very complicated, we show that even relatively simple fundamental model is able to explain large part of price movements on the electricity markets. Analysis presented is based predominantly on the merit order theory and introduces the concept of residual demand as a crucial variable for explaining hourly electricity price movements. While the analysis shown in this paper is applied to the Czech Electricity day-ahead market, it can be well replicated also for the other relevant European power market areas. Tests of fundamental approaches towards power price forecasting have shown very promising results and we believe they deserve more attention from the electricity market researchers.

Keywords: Electricity Market, Electricity Prices Forecasting, Merit Order Theory
JEL Classifications: Q41, Q47

1. INTRODUCTION

Large number of papers deals with the issue of short-term electricity price forecasting and includes various factors responsible for the electricity price movements in their analysis (Contreras et al., 2003; Weron and Misiorek et al., 2008; Aggarwal et al., 2009; Vijayalakshmi et al., 2014). While many researchers attribute significant role to electricity demand and in some cases supply capacity in power price forecasting (Würzberg et al., 2013; Grote et al., 2015), it is challenging to include all the relevant variables in a forecasting model. However, portion of demand which needs to be served by the price setting, traditional thermal generation units can increase or decrease also due to the unpredictable renewable generation or scheduled maintenance and outages of other generators with low variable costs, particularly the nuclear generating units. We believe these factors have to be properly accounted for in the electricity price research and forecasting.

In this work we assess the cumulative impact of hourly demand, renewable generation and nuclear outages on the day-ahead hourly electricity prices in Czech Republic. Analysis, which has some similar traits with the approach presented in this paper, has been performed on the Nordic power market with large share of hydropower (Vorononin and Partanen, 2012).

Other issue, we believe is not sufficiently accounted for in the works dealing with the subject of electricity price forecasting, is the impact of neighbouring countries on the market analysed (Cuaresma et al., 2004; Weron, 2006). This is particularly true in cases of the smaller markets, such as Czech Republic, with a large neighbour, such as Germany. If some short-term important developments in the larger market do happen, the impact on electricity prices in neighbouring regions can be substantial.

The aim of this work is to cover for the above mentioned crucial fundamental factors and present a very simple, one factor, price explaining model based on residual demand variable (hourly demand minus hourly generation with low variable costs). Suggestions on how to further improve the model and create a functioning forecasting tool on the basis of this work are included in the end of this paper.

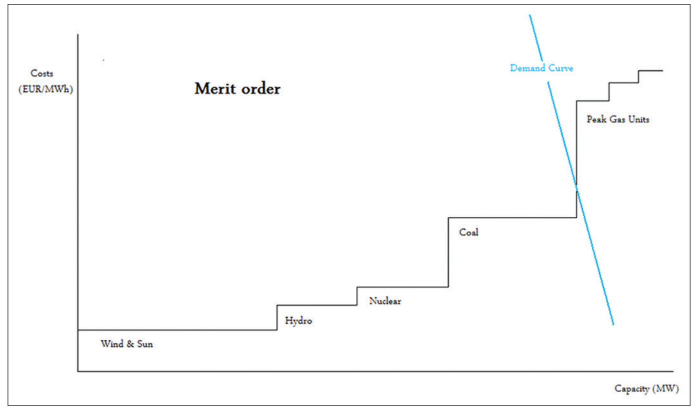
2. THEORETICAL FRAMEWORK BEHIND THIS WORK

Relationship between demand and prices has been confirmed by many different industries and electricity sector is not an exception. Demand and supply forces meet on the competitive electricity market and settle the wholesale prices. While supply capacity has been historically relatively stable in the industry, demand shows significant fluctuations in time and together with the volatile fuel costs can be perceived as the main factor behind electricity price movements. However, analysis is further complicated particularly by the advance of renewable sources in the EU during the last decade and changes in generation portfolio due to maintenance and outages of the production units.

2.1. The Merit Order Theory

The merit order theory is a basic theoretical concept of price formation on the electricity market (Yang et al., 2013). All the generating units can be ordered based on their variable costs. This ordering results in the merit-order curve (Moller, 2010). It ranges from the lowest variable cost merit-order units as are hydro, renewable and nuclear capacities to the high cost merit-order peak-load units as is shown in Figure 1.

Figure 1: Merit order curve, setting price formation mechanisms on the power markets



Since the merit order can be understood as a supply curve applied to the electricity sector, its intersection with demand sets the prices on the liberalized and competitive electricity markets. With demand and in certain cases also supply capacities changing from hour to hour, so do the prices.

This concept is thus important for understanding the electricity price movements. It shows why increased renewable generation lowers the prices on the market significantly as it shifts the whole supply capacity curve to the right. Maintenance or outages of power units then have an opposite effect. Shortage of a certain amount of low variable cost capacity should theoretically have exactly the same impact on power prices as an increase in electricity demand of the same amount.

Many papers use country electricity demand as the most important explaining variable in power price analysis and forecasting. There are two particular reasons why we believe this is not sufficient from the fundamental perspective:

- Country demand variable doesn't take into account demand changes in the neighbouring countries. In the context of well-interconnected European power markets this issue can't be neglected. The main reason why electricity demand in different countries can show specific patterns is different holiday schedule in different countries. Public holidays in Germany significantly decrease power price not only in Germany itself but also in surrounding smaller countries, such as Czech Republic. This decrease wouldn't have been captured by most of the time series models available. This issue is of particular importance when forecasting electricity prices in smaller countries with large neighbouring markets. From the time series analysis perspective, matters are further complicated by the fact that many of the public holidays occur irregularly. However, there are many other ways of how a larger electricity market can affect smaller neighbours in the short term. The most common one is through increased renewable generation during certain periods of time.
- Merit order curve shows that short-term electricity prices depend on the amount and costs of traditional generation needed to cover the demand at every hour. However part of the demand at every hour is covered by other sources with low variable costs, particularly renewable generation, hydro and nuclear units. Increase in generation from low variable costs units mentioned has exactly the same impact on price as decrease in electricity demand of the same magnitude. Therefore we introduce the concept of residual demand (hourly demand minus hourly generation with low variable costs) as the main variable responsible for electricity price movements.

Based on the reasons stated above, we propose to divide power generation capacities into units with low variable costs and low possibilities for production optimization such as renewable and nuclear capacities (N+RES) and price setting generation, with higher variable costs and higher possibilities for production optimization such as coal and gas power plants. N+RES production then can be taken as given, while the amount and costs of other (residual) generation needed to cover electricity demand at every hour sets the prices on the power exchanges. Thus we define residual demand at every hour as hourly electricity demand (in MWh) minus hourly generation from N+RES units (in MWh). In the flowing parts of this work we analyse impact of hourly residual demand on hourly electricity spot prices.

2.2. Illustration of Relationship between Residual Demand and Electricity Prices

In this part we show the theory and concept outlined in this work in a clear and illustrative manner. Theoretical mechanisms explained in the previous parts are shown on the example of a 7 days period starting from 27th September until 3rd October 2013 in Germany. The period was chosen to include 3rd of October, which is a public holiday (the day of National Unity in Germany).

Figure 2 shows demand by hour in Germany during the week mentioned and shares of it, which were covered by N+RES and residual generation.

Figure 3 then shows the short-term relationship between wind generation itself and power prices. No relation is visible and there is also no reason why there should be any, since when wind generation is high during high demand periods, the prices are still relatively high. If wind generation is high when electricity demand is low, prices drop significantly.

However, the relationship between spot prices and residual demand (defined as hourly demand - nuclear generation - renewable generation) presents a completely different picture as can be observed in Figure 4. Spot prices in Germany during the week chosen have followed rises and drops in residual demand almost precisely, which is also in line with the basic theory of electricity markets price formation.

Figure 4 show that renewable generation affects spot prices to the extent it affects residual demand variable. The relationship between power prices and residual demand is also significantly higher than between power prices and power load. While these figures are presented for illustrative purposes only, the importance of the residual demand variable is assessed based on the longer period data analysis in the next part of this work.

Further analysing the chart shown in Figure 4 we see what happened in Germany during the public holiday on Thursday, October 3rd 2013. On this day, it seems that a previously strong relationship between residual electricity demand and electricity prices started to disappear. We believe this happened due to the reason that Germany is not an isolated market and power flows between Germany and France, countries of Benelux or Central Europe is quite high. While there was a National holiday in Germany, a normal working day occurred in all the surrounding countries. As these also affect prices in Germany, they have pushed the prices upwards relatively to electricity demand observed in Germany on this date.

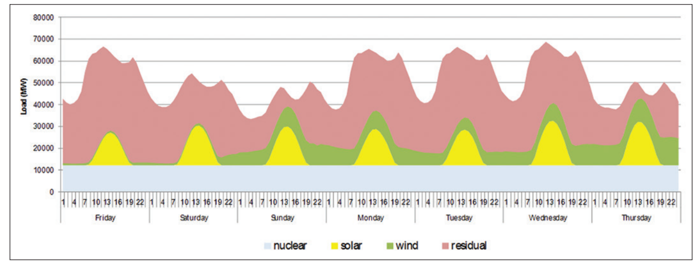
Theory outlined is the basis for development of a simple electricity price explanation model, which is presented in the following parts of this work.

3. CZECH ELECTRICITY MARKET

Czech and Slovak electricity markets have coupled in 2009 and became integrated with large interconnection capacities between them. Higher level of integration is important to enhance competition in both countries as there is very high level of concentration on generation level in both of them with around 75% of country market share belonging to the largest producers (CEZ, Slovenske Elektrarne) whereas no other company owns more than 5%. Thus, already high connection to Germany (from Czech Republic) and Hungary (from Slovakia) is planned to be further increased in the future. This should help to gradually converge prices in Czech Republic and Slovakia to the German level.

Liberalization of the wholesale power market in Czech Republic started in 2005. As a result there is no price regulation on the wholesale level. Electricity is traded at the energy exchange, Power Exchange Central Europe, a.s. (PXE) under bilateral contracts,

Figure 2: Germany, 27th September-3rd October 2013, power load with shares of nuclear, renewable and residual generation



Data source: German grid operators, entsoe.eu, own analysis

Figure 3: Germany, 27th September-3rd October 2013, relation between wind generation and spot prices

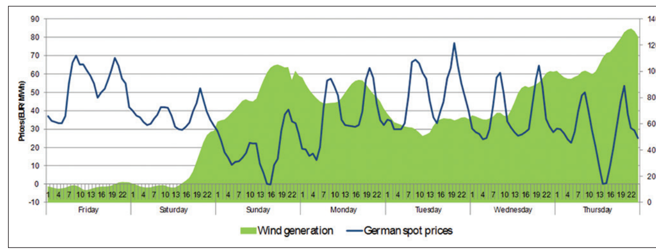
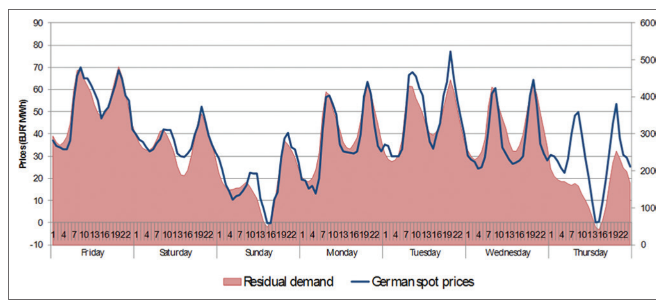


Figure 4: Germany, 27th September-3rd October 2013, relation between non-base load and spot prices



Data source: German grid operators, energinet.dk, entsoe.eu

and in spot markets organized by the market operator OTE, a.s. The terms of bilateral contracts vary, an electricity producer and electricity trader usually enter into one-year agreements. Thus there is a coexistence of PXE with physical and financial trading options, OTC bilateral contracts and spot markets organized by the market operator in CZ-SK region. The analysis presented in this work is based on the spot market, which is organized by OTE a.s. which also provides data of the historical day-ahead spot prices in Czech Republic.

Czech Republic is an exporter of substantial amount of electricity with demand on the level of 63 TWh and production of 80 TWh yearly. Nuclear is important part of generation portfolio in the country producing more than 30% of electricity. Besides Nuke, there is a large portion of lignite generation in Czech Republic. The overall production portfolio variable costs are thus lower compared to the European average, particularly as the share of renewable solar electricity has also increased rapidly in 2009-2012 period. Prices on the market are also generally slightly lower than in Germany which serves as a reference market for Czech Republic (Energy regulatory office of Czech Republic, 2012).

4. METHODOLOGY

Based on the theoretical concept outlined in Part 2 of this work we propose building a residual demand variable and then assess relation of this variable with the hourly electricity market prices. Following datasets were assembled to create the residual demand variable for the Czech electricity market in 2016[1]:

1. Hourly load for Czech Republic,
2. Hourly Wind, Solar, Hydro and Nuclear generation for Czech Republic,
3. Hourly load for Germany and Austria,
4. Hourly wind and solar generation for Germany and Austria.

Three different variables were then created from these datasets and their ability to explain the Czech hourly electricity prices (in EUR/MWh) were compared:

1. Hourly Czech electricity demand variable derived from Czech load for every hour,
2. Hourly residual demand variable created using load, wind and solar generation data for Czech Republic, Germany and Austria,
3. Residual demand variable created using data described in (2) with the addition of nuclear and hydro generation for Czech Republic into the model.

Thus 3 variables, each consisting of 8784 hourly data points of 2016, were created and their relationship with electricity prices was assessed separately. Variable 1 is a simple hourly demand of Czech Republic (in MWh) derived from the Czech hourly load (in MW). This is just a common variable usually included into various electricity price-forecasting models.

Variable 2 is based on residual demand concept outlined in this work. It is calculated from hourly demand less renewable generation for Czech Republic, Germany and Austria as follows:

$$RD_1=[L(c)-R(c)]+[L(g)+L(a)-R(g)-R(a)]/k \quad (1)$$

L(c), L(a), and L(g) are hourly demand data for Czech Republic, Austria and Germany. R(c), R(a), and R(g) are hourly wind and solar combined generation for Czech Republic, Austria and Germany. k is a coefficient which is designed to diminish the weight of the foreign data in comparison to the domestic part of the formula. Different values of coefficient k can be chosen, however in the base case scenario we derive its value in a way to give the domestic and foreign part of equation equal weight. This was achieved with k on the level of 6.93.

Variable 3 is similar to the previous case, however adds also hydro generation and nuclear generation perspective to the previous formula as follows:

$$RD_2=[L(c)-R(c)-H(c)-N(c)]+[L(g)+L(a)-R(a)-R(g)]/k \quad (2)$$

1 Data were assembled from the following sources: www.ceps.cz, www.apg.at, www.entsoe.eu, http://www.tennet.eu/, www.transnetbw.de, http://www.amprion.net/, http://www.50hertz.com/

Where H(c) is hourly hydro generation and N(c) is hourly nuclear generation dataset for Czech Republic variables 2 and 3 are similar however the latter one includes also information regarding nuclear and hydro generation in Czech Republic.

Even more fundamental power market information could have been added in the variables proposed (particularly information regarding Slovak power system or German nuclear generation). These weren't included particularly due to unavailability of the data needed or low data quality. Based on our experience, inclusion of more information into the explanatory variable in most cases leads to further improvements in the quality of the relation.

To assess the relationship between electricity prices and the residual demand variables built we use a simple polynomial regression model. The trend curve derived is meant to replicate the average merit order in Czech Republic during the year 2016. Polynomial function of the 3rd degree is suitable for replication of merit orders in general, as the prices tend to spike on the low and high end when extremely tight or loose conditions on the market are observed. This is confirmed by the charts presented in the following part of this work. While non-linear regression should theoretically provide even better results in replicating the merit order curve (as there is no reason why it should follow any regular pattern) in practice we have been able to achieve good results with much simpler polynomial regression model.

5. RESULTS

Relation of the residual demand variables with spot electricity prices is analysed in this part.

5.1. Assessing the Relation between Residual Demand Variables and Electricity Prices

As was explained in the previous part of this work, three explanatory variables were designed to establish and analyse their relationship with hourly electricity prices separately. First is a simple hourly demand variable and the other two are residual demand variables with the second one containing more market information.

Figure 5 depicts the relationship between hourly electricity demand and spot prices in Czech Republic during the year 2016. The strength of the relation is measured by the R^2 coefficient of 0.33, which means only limited relationship between the variables analysed.

This limited relationship is confirmed also by Figure 6. It is clear that with rising demand, prices tend to increase in general, however, the relationship doesn't show any distinct shape or more definitive pattern.

Thus, while hourly demand dataset shows certain correlation with electricity spot prices, it explains movements on the market to the relatively low extent only.

Figure 6 depicts the relationship of residual demand 1 dataset with Czech electricity prices and shows significantly improved correlation with coefficient of 0.55.

Shape of the relation between variables analysed is also improved significantly. It shows distinct decrease of prices on the low end and increase on the high end, which supports usage of polynomial model of 3rd degree to capture this relation.

Further model improvements are visible with residual demand 2 variables which includes also information regarding Czech nuclear and hydro generation for every hour of 2016. R^2 coefficient improves to 0.652 in this case, which means much stronger relationship between the variables analysed.

Figure 7 also provides a good basis for deriving average merit order curve for Czech electricity market in 2016.

As was mentioned already, with addition of further information into residual demand explanatory variable, the model results could be probably further improved. However, even in this state the relationship is quite high for a one-factor model. This analysis has also significant meaning for other works dealing with electricity price analysis and forecasting, as there is a possibility that using residual demand variable as shown in this work in place of simple demand variable could substantially improve prediction accuracy of electricity price forecasting models in general.

5.2. Assessing Limitations of the Model Proposed

The aim of this work is to show the meaning of residual demand variable in electricity price analysis and forecasting. To create a functioning electricity price forecasting model, based on this work, further information and other variables have do be added. In this part we discuss limitations of the simple model presented and areas where we see substantial potential for further improvements.

Figure 5: 2016 hourly Czech spot prices (EUR/MWh) vs. hourly electricity demand (MWh)

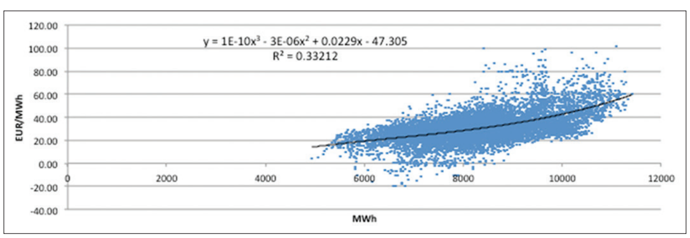


Figure 6: 2016 hourly Czech spot prices versus electricity residual demand I dataset (MWh)

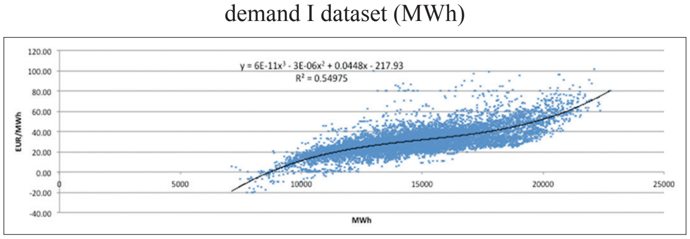
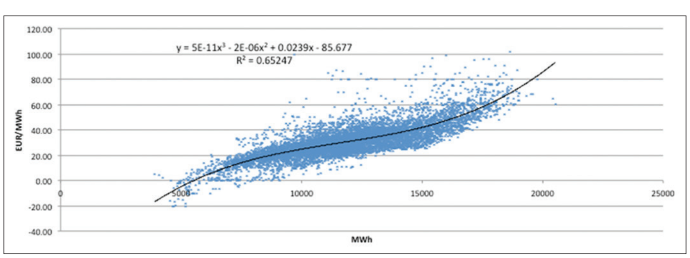


Figure 7: 2016 hourly Czech spot prices versus electricity residual demand II dataset



5.2.1. Start-up costs

When bidding on the electricity market, generators have to take into account that switching off and starting again their production units is associated with large costs. Therefore, it is often more cost efficient for them to leave units switched on even at times when market price is lower than their variable costs. This is also the reason behind negative prices on the market. By this logic we would see higher prices relatively to the residual demand variable particularly during the Monday peak hours and lower relative prices during the Friday and Saturday hours, when generators bid lower compared to their variable costs so that they don't have to switch off their production units. Figure 8 shows what we have observed on the market in 2016 in this respect:

Model errors are positive (meaning modelled prices are higher than the prices observed) particularly during the night hours, while the highest positive error is observed during the early morning hours on Mondays. This is precisely in line with the logics explained above, as these are the hours when generators would bid below their variable costs. On the other hand, during the peak hours, the model shows negative error, modelled prices are lower than the prices observed, which again can be explained by the start-up costs of the generating units. The most substantial difference is visible during peak hours on Mondays, when most of the peak generators have to be switched on after the weekend. Therefore we believe that adding start-up costs to the model would mean a crucial improvement, further increasing its precision. There are several ways of how to estimate and include start-up costs, however this issue is beyond the scope of this work.

5.2.2. Fuel costs

Other important fundamental market consideration, which wasn't accounted for in the model provided, are fuel costs. As the model is based on full year of 2016 (8784 h), which was quite turbulent, fuel costs have changed significantly from the beginning to the end of the year. With higher fuel costs, variable costs of generating production increase and generators bid higher relatively to residual demand variable. In 2016 fuel prices were lowest in February and highest in the end of the year. Therefore we would expect to see positive model error in the beginning of the year and negative in the end of it. This is precisely what is shown in Figure 9.

Adding fuel cost variable into the model is easier compared to start-up costs but was left out of the analysis to show the relationship between residual demand and electricity prices alone.

The structure of the market changes rapidly, new generation units are built, fuel costs go up and down and market becomes more efficient every year. This has to be taken into account when analysing short-term electricity prices from one period to another. Ideally the period analysed by the method proposed shouldn't be too long, ideally up to a year. The shorter the period taken, the better the results of the model are. Other options are adding

Figure 8: Average model error by hour of the week (EUR/MWh)

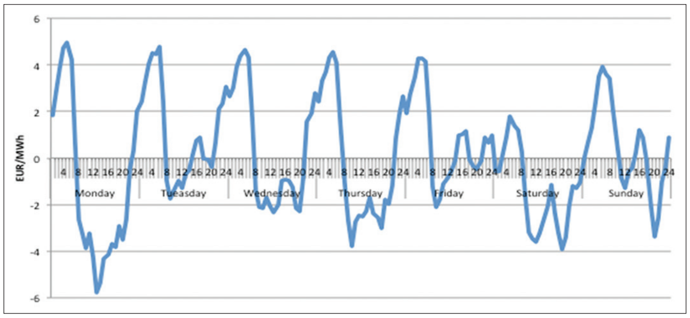
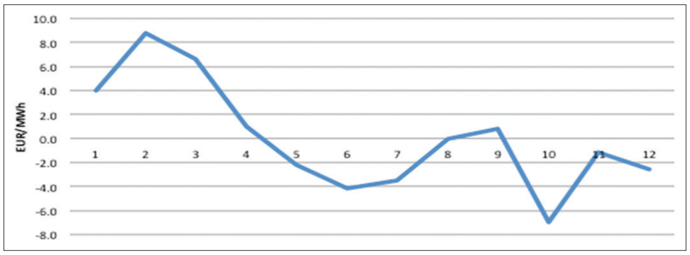


Figure 9: Average model error by month of the year



more weight to the newer data when creating the model or adding structural fundamental variables, which is very complicated from the modelling perspective.

5.3. Proposing Steps to Create Power Price Forecasting Model Based on the Residual Demand Model Introduced

Fundamental power market analysis and forecasting is significantly complicated by the amount of data that needs to be assembled and processed to provide even a simple model of the market moving processes. Therefore, the crucial quality of every fundamental model is its efficiency. Large amount of information has to be structured and grouped into variables in a way that enables usable model creation.

The model described in this work consists of one explanatory variable only. This variable is still able to cover large amount of market information while leaving enough space to add various other market related explanatory datasets into the model. Even such one variable model is able to explain large part of electricity market price movements. With the addition of other market related information, its error can be further significantly diminished.

Proposed attitude to the fundamental electricity price analysis and forecasting is based on the following steps:

- Assembling large amount of relevant power market information,
- Grouping this information in a structured way,
- Creating variables out of the datasets in a way that respects theoretical and practical concepts of power market price formation mechanisms (particularly the merit order theory),
- Creating the model out of the variables proposed.

The most important and difficult task is to include all the relevant fundamental information into the price-forecasting model in a way that is not prohibitive from the fundamental modelling perspective. This is possible only with very careful and structured process of combining different datasets into grouped variables in a similar way as was shown in this work. Every such variable should be responsible for different perspective of power market analysis. It is of particular importance that the number of such variables is constrained.

In this article we have shown how to include significant part of power market information in just one variable, which is able to explain significant part of electricity price movement. However there is still a lot of power market information which is missing in this simple model proposed and would need to be included to develop a useful price forecasting tool. Such information includes particularly the following:

- Start-up costs,
- Information regarding supply and demand conditions in other European countries (e.g. hydro reservoirs situation in the Nordic countries is very important for the whole Europe),
- Fuel prices (such as gas and coal),
- Transmission line capacities,
- Information regarding unavailability of thermal generation units.

We believe that particularly incorporation of start-up costs could benefit the model proposed substantially.

6. CONCLUSIONS

Relationship between the residual demand variable, developed based on the merit order theory, and electricity spot prices is analysed in this paper. It is shown that renewable generation, nuclear maintenance, cross border power flows and other power supply conditions combined together present an important factor in formation of spot electricity prices as the residual demand variable explains electricity price movements significantly better than the simple hourly demand dataset. This work is based on Czech electricity market in 2016 but is applicable also to other markets and other time periods.

Results of this work are important for the theory of electricity price formation and can be used as a basis for developing functioning fundamental electricity price forecasting model. Generally, replacement of a simple hourly demand dataset with residual demand variable (as shown in this paper) should lead to improvement also of the other models dealing with the similar subject.

REFERENCES

Aggarwal, S.K., Mohan, S.L., Kumar, A. (2009), Electricity price forecasting in deregulated markets: A review and evaluation. Electrical Power and Energy Systems, 31(1), 13-22.

Contreras, J., Espınola, R., Nogales, F.J., Conejo, A.J. (2003), ARIMA models to predict next-day electricity prices. IEEE Transactions on Power Systems, 18(3), 1014-1020.

Cuaresma, J.C., Hlouskova, J., Kossmeier, S., Obersteiner, M. (2004), Forecasting electricity spotprices using linear univariate time-series models. Applied Energy, 77(1), 87-106.

Energy Regulatory Office of Czech Republic. (2012), National Report of the Energy Regulatory Office on the Electricity and Gas Industries in the Czech Republic for 2011.

Grote, F., Maaz, A., Drees, T., Moser, A. (2015), Modelling of electricity pricing in European market simulations, European Energy Market (EEM). 12th International Conference. p1-5.

Misiorek, A., Trueck, S., Weron, R. (2006), Point and interval forecasting of spot electricity prices: Linear vs. Non-linear time series models. Nonlinear Analysis of Electricity Prices, 10, 1-36.

Moller, C.H. (2010), Balancing Energy in the German Market Design, Dissertation Thesis, and University of Karlsruhe. Available from: https://www.publikationen.bibliothek.kit.edu/1000019393/1413686.

Vorononin, S., Partanen, J. (2012), A Hybrid Electricity Price Forecasting Model for the Finnish Electricity Spot Market. Available from: http://www.forecasters.org/proceedings12/VORONINSERGEYISF2012.pdf.

Vijayalakshmi, S., Ajaya, K.P., Badri, N.R. (2014), Forecasting electricity prices in deregulated wholesale spot electricity market: A review. International Journal of Energy Economics and Policy, 4(1), 32-42.

Weron, R. (2006), Modeling and Forecasting Electricity Loads and Prices: A Statistical Approach. Chichester: Wiley Finance Publication.

Weron, R., Misiorek, A. (2006), Short-term electricity price forecasting with time series models. A review and evaluation. In: Complex Electricity Markets: The European Power Supply Industry. Lodz: IEPL & SEP. p231-254.

Weron, R., Misiorek, A. (2008), Forecasting spot electricity prices: A comparison of parametric and semiparametric time series models. International Journal of Forecasting, 24, 744-763.

Würzburg, I., Labandeira, X., Linares, P. (2013), Renewable generation and electricity prices: Taking stock and new evidence for Germany and Austria. Energy Economics, 40(1), 159-171.

Yang, H.E., Hildmann, M., Herzog, F., Andersson, G. Modeling the merit order curve of the European energy exchange power market in Germany. IEEE Transactions on Power Systems, 28(3), 3155-3164.