ANALIZA CZYNNIKOWA CEN DNIA NASTĘPNEGO NA RYNKU ENERGII ELEKTRYCZNEJ W POLSCE

Streszczenie

Artykuł przedstawia wyniki analizy wybranych czynników (cech) kształtujących ceny energii elektrycznej dnia następnego. Ma na celu przybliżenie i lepsze zrozumienie procesów kształtujących ceny rynkowe energii elektrycznej w Polsce. Analizę oparto m.in. na badaniu zmienności cen energii elektrycznej i wyliczono w tym zakresie następujące współczynniki: wahań cen, ich zmienności statystycznej, odchylenia standardowego oraz dziennej szybkości zmiany cen, związanej z porównywaniem ich średnich dziennych wielkości. Wartości krytyczne rynkowej ceny energii elektrycznej zostały obliczone w celu oszacowania wielkości skoków cenowych. Analiza pokazuje, że zmienność cen energii elektrycznej na rynku polskim jest umiarkowana. Zaobserwowane zjawisko skoków cen dnia następnego na rynku energii elektrycznej w Polsce opisuje nieco ponad 3% ogólnej zmiany cen w całym analizowanym okresie.

Słowa kluczowe: rynek dnia następnego, cena, skoki cenowe, zmienność.

POLISH DAY-AHEAD ELECTRICITY MARKET PRICES. FEATURES ANALYSIS

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Abstract

The goal of this article is to better understand electricity market price formation processes in Poland through an analysis of the features (volatility and spikes) of Polish day-ahead electricity market prices. The following indicators have been calculated to determine electricity market price volatility: the oscillation coefficient; the coefficient of variation; the standard deviation indicator; the daily velocity indicator, which is based on the overall average price; and the daily velocity indicator, which is based on daily average price. Critical values for electricity market price have been calculated to evaluate price spikes. This analysis reveals that Polish electricity market price volatility is moderate. Electricity price spikes have been an observable phenomenon in Polish day-ahead electricity markets, encompassing 3.15% of the time period analysed in Poland.

Keywords: day-ahead market, price, spikes, volatility.

1. INTRODUCTION

In the late nineties, when electricity sector reforms become prominent in Europe and electricity was acknowledged as a commodity, the process of restructuring the electricity sector began. New laws were passed in many European countries and internal electrical power markets started to emerge.

As early as 1999, the Polish Power Exchange (POLPX, Giełda Energii S.A., later renamed Towarowa Giełda Energii S.A.) was established. As an organised part of the electricity market, the POLPX has offered participants a range of benefits, including equal access to market information; clear, transparent and consistent rules for concluding commercial transactions for all participants; reduced costs of negotiation (i.e., automation of the best offer searching process); a high level of flexibility in conclusion of transactions; and effective management of commercial risks, resulting from fluctuation of the electricity demand price and volume. Currently, the POLPX operates the commodity derivatives market, intraday market, property rights market for renewable energy sources and co-generation, CO_2 emission allowance market, and day-ahead market. The day-ahead market (a physical spot market for electrical power) was the exchange's first market, launched six months after the POLPX's registration. The role of the day-ahead market is to establish prices of electrical power for other contracts concluded on the wholesale power market in Poland, allow market participants to initially balance their contractual positions, allow indirect pricing of the value of power enterprises (primarily generators) through pricing of the commodity that they are producing (i.e., electrical power), and provide signals to generators in the domain of building new generation capacity. Currently, the day-ahead market of the POLPX is composed of 24-hour markets, each quoting one type of hourly contract. Additionally, the day-ahead market quotes three block contracts (PASMO, Euroszczyt and Offpeak) [23].

Since some time has elapsed since day-ahead electricity markets began operating in Poland, it is worthwhile to assess how electricity prices in a day-ahead electricity market has changed, what features it acquired and what factors have contributed to price fluctuation. This assessment is the goal of this article. The primary objectives of this study are

- to review the scientific literature on features of day-ahead electricity market prices;
- to discuss factors that have an impact on day-ahead electricity market prices;
- to segregate indicators that allow an assessment of electricity market price features, i.e., volatility and spiking;
- to perform an empirical examination of the features of electricity market prices that have formed in Poland; and
- to analyse factors that have influenced Polish electricity market prices.

Scientific literature analysis and statistical data analysis are used to meet these objectives.

2. OVERVIEW

Changes in the power sector necessarily influence electricity prices. Electricity prices has acquired several fairly new features in recent years. According to many researchers [6; 15; 26; 29 14], electricity market prices acquire the following features:

- high frequency;
- negative prices;
- volatility;
- seasonality and other periodicity;
- mean-reverting;
- jumps; and
- spikes.

Day-ahead electricity price forms frequently. The frequency of electricity market price change depends on the rules agreed upon by market participants in the power exchange. In NordPool (the Scandinavian electricity market), POLPX (Poland), BaltPool (Lithuania), the European Energy Exchange and many other power exchanges, the electricity market price is set for each hour of the day, whereas in Australia and New Zealand, it is set for every half hour. Thus, 24 or 48 prices are set during a day.

Electricity market price might be both positive and negative. Ordinarily, electricity market producers provide market bids at prices that correspond to their marginal production costs. In special cases, producers seeking to remain in the market and reluctant to stop electricity production can decide to supply electricity at prices that are below their marginal cost. In extreme case, producers agree to pay for the electricity that they produce and supply it to the consumer. This situation causes negative price forms in the market, where consumers have not paid for electricity consumed. Controversially, the more consumers consume electricity, the more producers will pay for electricity consumed. Sewalt and de Jong [27] emphasise that negative prices mean that the destruction of the commodity has more value than its creation, i.e., for a period of time, electricity may be a waste product and is dumped on the market.

There are several reasons for negative market price formation, but usually negative price forms, when demand for electricity is low. Demand for electricity is low during public holidays, during weekends, and at night; it is also low when economic activity slows [27; 25]. However, electricity producers also influence negative electricity market prices. In order to stay in the market and avoid shutting down, producers might choose to bid below the marginal price. It can be economically reasonable for the owner of a less responsive generating unit (those fuelled by coal, natural gas, or steam, for example) to offer negative prices in an effort to avoid the costs that will arise from shutting down the power plant for a few hours, until demand for electricity increases [10].

In recent years, negative electricity market prices in some electricity markets (South Australia, western Texas, Germany, and North Europe) have become more common because of the rapid development of wind power plants (PPs). In western Texas, for example, during the first half of 2008, electricity was traded at negative prices more than 20% of time. As shown by Schneider & Schneider [25], the main reason for negative prices to appear has been the growing share of electricity production occupied by wind energy. Giberson [10] asserts that negative electricity prices form in the market because of support provided to wind-generated electricity. The total amount of support depends on the quantity of electricity supplied; therefore, producers are not interested in delivering less electricity. As Giberson [10] argues, it is economically rational for PP owners to produce as long as the subsidy provided to wind electricity exceeds operating costs plus the negative price producers have to pay the market. Market observations show that wind electricity producers are ready to accept prices down to about minus 35 USD/MWh before they shut down a plant.

Other reasons for negative prices mentioned by Schneider and Schneider [25] include low population density in the region and a restricted electricity network, which reduces the ability to send surplus electricity to neighbouring regions. According to Fanone, Gamba and Prokopczuk [8], a remarkably negative electricity price, known as a 'negative price spike', might occur not only when demand is very low but also when interconnection failure occurs. The results of an empirical analysis published by Genoese *et al.* [9] show that either a low system load in conjunction with moderate wind generation or a moderate system load in conjunction with high wind generation are essential preconditions for negative electricity price formation.

Negative electricity prices are acceptable for consumers, but they signal lower profitability to investors; investment volume can therefore start to fall. Problems will arise when electricity demand is high but because of unfavourable natural conditions, wind PPs are not able to produce enough electricity. For this reason, consumers' needs are satisfied only at very high cost.

The scientific literature and world experience provide various ways to reduce the number of hours or even days when negative prices occur in the market. First, to strengthen transmission lines, a reinforced electricity network could create the necessary conditions to supply electricity to industrial regions, but this network would require additional investment. Northern Europe countries have dealt with the negative price problem by expanding electricity trading. When Denmark produces surplus wind electricity, it delivers the surplus electricity to Norway and Sweden, where wind electricity is used to pump water into Norwegian and Swedish reservoirs and later, when the wind is not blowing, released to drive hydro PPs. Extreme negative electricity prices are avoided by introducing minimum prices. In Scandinavian countries, for example, the minimum price is minus 200 EUR/MWh (Archer Energy, 2009; [17].

Volatility is one of the commonly noted features of electricity market prices. Volatility refers to unpredictable fluctuations of a price [33]. According to the results of various analyses, the price of electricity is simply a price that is characterised by very high volatility and that is found neither in securities nor in other commodity markets. The USA Federal Energy Regulating Commission published a report affirming that electricity price volatility is 300%; in comparison, the volatility of other commodity prices does not exceed 100%, and the volatility of stock prices is 20% or even lower [11].

Bessembinder and Lemmon [2] and Zareipour *et al*. [33] determined that electricity price volatility is higher when demand is high. Interesting results have been proposed by Knittel and Roberts [15], who noted that electricity market price volatility increases more with positive shocks than with negative shocks. Scientists call this effect the "inverse leverage effect".

The European Commission has produced a report on the liquidity and efficiency of EU wholesale energy markets. This report states that electricity price volatility has been influenced by many factors [30]:

- capacity withdrawal;
- fluctuations of CO_2 prices;

- cross-border congestion;
- fluctuations of coal prices;
- erratic production in wind PPs;
- manipulations of the market;
- fluctuations of oil prices; and
- demand seasonality.

However, according to the opinions of respondents, capacity withdrawal and fluctuations of CO_2 prices have been the primary factors affecting electricity price volatility.

Wolak [32] found that price volatility depends on the following rules of participation in the market:

- prices have been more volatile in countries where participation in the market is mandatory as opposed to voluntary; and
- prices have been more volatile in those electricity markets where private capital instead of public capital dominates. The evidence presented suggests that markets with less participation by government-owned companies also have lower average electricity prices.

Other reasons cited by Shahidehpour *et al.* [28] largely agree with Wolak [32] and the Moffatt Associates Partnership [30]. According to them, prices become volatile because of

- volatility in fuel prices;
- load uncertainty;
- fluctuations in hydroelectricity production;
- generation uncertainty (outages);
- transmission congestion;
- the behaviour of market participants; and
- market manipulation.

The examination by Shahidehpour *et al.* [28] revealed that electricity prices are more volatile at high load levels than at other levels.

Electricity market prices are seasonally and periodically sensitive. Scientists have noted that electricity market prices follow regular fluctuations, changing throughout the day to reflect the patterns of daily life. Particular price is early in the morning; later, when demand for electricity increases, the price increases, but at the end of the working day, it decreases. There is also price fluctuation from the work week to the weekend, with higher prices during work week. Usually, early morning and late evening prices coincide. How much these prices differ from prices established in the middle of the day constitutes the price gap [15].

Seasonality is also reflected in electricity market prices, as demand for heating, cooling and other purposes change. In northern California, for example, electricity consumption increases in the summer when it is used for cooling purposes. Prices during peak consumption periods might increase by several times in summer. Electricity prices also depend on restrictions in the electricity network. When there is a failure in the network or the network is undergoing maintenance, some regions might be separated from the rest of the market. In such cases, market players take advantage of the situation. As a result, electricity market prices can increase more than tenfold.

Lucia and Schwartz [19], through analysis of historical data from Scandinavian countries, found that electricity price volatility, calculated by applying standard volatility indicator, was 189%. They noticed that price volatility differed seasonally. Prices were more stable during the cold season (σ=54.2), but the price volatility increased during the warm season (σ=75.8). Nakamura *et al*. [21] found similar results; they calculated that in Ontario, volatility is generally higher in summer months than in other months and that price volatility is much higher in Ontario than in the New England, New York, and PJM (PJM Interconnection LLC) electricity markets. Furthermore, Zareipour *et al*. [33] have shown that the Ontario electricity market is one of the most volatile electricity markets in the world. R. Booth's calculations have revealed that electricity price volatility has been especially high in Australia, above 900% [11] . Higgs and

Worthington [11] repeated Booth's analysis of price volatility in Australia, confirming his conclusion that electricity price volatility was 14 times higher during hours of price spikes than during periods that the market was "calm".

Wolak [32] points out that a combination of natural resources used in electricity production is a factor that can explain the average electricity price and price volatility. It is noticed that prices tend to be much more volatile in countries where fossil fuel technologies have been widely used (i.e., Australia, England and Wales), but average prices in these countries are tend to be more stable than prices in hydropower dominated markets. Wolak [32] argues that the average electricity price in Scandinavian and New Zealand depends on water availability. If there is little water, then the reservoirs tend to be low. Thus, hydropower generators tend to be restricted to selling electricity during the winter. Electricity prices remain high until spring and summer. Australia, England and Wales are not as sensitive to local weather conditions; instead, the average electricity price depends on the price of fossil fuel. Since the natural gas, coal and oil markets are well integrated and prices of these fuels have been stable for many years, the average price of electricity from fossil fuels has therefore been stable as well.

Mean-reversion is another feature of electricity market prices. Many researchers [31; 15; 13; 11] have found that electricity market prices exhibit mean-reversion, on the basis of observations in Australia, northern California and Switzerland.

Electricity market prices exhibit price jumps and price spikes. There are many reasons that price jumps and spikes emerge in the market. According to many findings [5; 18; 26] short- and long-term price spikes occur for the following reasons:

– the shutdown of a power plant;
– failure in transmission network;
– insufficient transmission or generation infrastructure due to either underestimated demand forecast or a lack of market stimulation for new market entries;
– unexpected changes in weather conditions;
– non-price-responsive consumers; and
– the practice of market power by generation companies at higher demands and with transmission limits.

Hughes and Parece [12] provide a more generalised list of factors that influence price spike formation:

– supply factors;
– demand factors; and
– market organisation and design.

According to Hughes and Parece [12], supply shifts might occur as a consequence of installed capacity, outages, changes in generating resource mix, or transmissions constraints. Demand shifts after changes in weather conditions and retail electricity prices, slow down or improvement in economic activity. Market organisation and design can also affect price spikes; retail and wholesale price caps can be attributed to this group of factors. Wholesale price caps prevent extreme price spikes but have adverse effects on reliability and increase the frequency of price spikes. Retail price caps prevent increases in retail price; they aggravate wholesale price spikes because they prevent retail prices from discouraging demand.

Higgs and Worthington [11] calculated that in Australia, the probability of a spike on any given day ranges between 5.16 and 9.44%. Lu *et al.* [18] point out that the probability of a price spike increases during peak consumption periods and during the workday, as well as in cases when there is high demand.

Using historical data of the PJM power market, Shahipidour *et al*. (2002) found a relationship between price spikes and loads: the higher the load, the larger the probability of spikes is.

3. METHODOLOGY

3.1. Indicators for disclosure of day-ahead electricity market price volatility

Volatility is a measure of the change in the price of electricity over a given period of time [28]. Analysis of commodity price volatility is usually based on the concept of absolute, relative and logarithmic returns.

Let P_t be the spot price of a commodity at time *t*. Then, the absolute return of the commodity price over the time period *h* is calculated as follows (1):

$$D_h = P_t - P_{t-h}. \quad (1)$$

Danilenko [7] indicates that absolute returns have rarely been used in price volatility analysis. She points out that priority should be given to relative and logarithmic returns, which show changes in commodity price over a given time.

Relative or arithmetic return over the time period *h* is defined as [7; 33] (2):

$$R_{t,h} = \frac{P_t - P_{t-h}}{P_{t-h}}. \quad (2)$$

The logarithm return is calculated as follows [7; 33] (3):

$$r_{t,h} = \ln\left(\frac{P_t}{P_{t-h}}\right) = \ln(P_t) - \ln(P_{t-h}). \quad (3)$$

Generally, price volatility is determined by calculating the value of the dispersion indicator (4):

$$\sigma^2_{h,T} = \frac{1}{N_0 - 1} \cdot \sum_{t=1}^{N_0} (r_{t,h} - \bar{r}_{h,T})^2, when\, \bar{\mathrm{r}}_{\mathrm{t,h}} = \frac{1}{N_0} \cdot \sum_{i=1}^{N_0} r_{t,h}. \quad (4)$$

where: $\sigma^2_{h,T}$ – dispersion indicator;

N_0 – the number of $r_{t,h}$ observations;

$\bar{r}_{t,h}$ – arithmetic average of $r_{t,h}$.

The higher the value of the indicator, the higher the price volatility is.

Nakamura *et al*. [21] and Zareipour *et al*. [33] have calculated a standard deviation indicator of logarithmic returns to determine price volatility (5):

$$\sigma_{h,T} = \sqrt{\frac{\sum_{t=1}^{N_0} (r_{t,h} - \bar{r}_{h,T})^2}{N_0 - 1}}. \quad (5)$$

Zareipour *et al*. [33] have determined this indicator as a historical volatility indicator.

Wolak [32] has used a standard deviation indicator for the disclosure of price volatility as well. However, unlike Zareipour *et al*. [33], who incorporated logarithmic returns into the formula for standard deviation, Wolak [32] has incorporated actual prices of electricity. Thus, following Wolak [32], electricity market price volatility has been calculated with the following formula (6):

$$\sigma = \sqrt{\frac{\sum_{t=1}^{m} (P_t - \bar{P}_t)^2}{m - 1}}. \quad (6)$$

where: m – number of price observations;

$\bar{P}_t$ – average price of electricity.

Lucia and Schwartz [19] used a standard volatility indicator for the measurement of price volatility (7):

$$V = \sigma \cdot \sqrt{365}. \quad (7)$$

Muñoz and Dickey [20] have described electricity market price volatility with an indicator that is calculated as the square of the difference of two near-standing prices (8):

$$V = (P_t - P_{t-1})^2. \quad (8)$$

A price velocity indicator has also been used to identify the volatility of electricity market prices. The indicator has been made according to the concept of absolute returns. Following Li and Flynn [16] and Zareipour *et al*. [33], two velocity indicators might be calculated:

- The daily velocity indicator, which based on the overall average price (9):

$$DVOA_{iP} = \frac{1}{M} \cdot \frac{\sum_{j=1}^{M-1} \left| P_{i,j+1} - P_{ij} \right| + \left| P_{i-1,M} - P_{i,1} \right|}{\frac{1}{M \cdot N} \cdot \sum_{i=1}^{N} \sum_{j=1}^{M} P_{ij}}; \quad (9)$$

- The daily velocity indicator, which is based on the daily average price (10):

$$DVDA_{iP} = \frac{1}{M} \cdot \frac{\sum_{j=1}^{M-1} \left| P_{i,j+1} - P_{ij} \right| + \left| P_{i-1,M} - P_{i,1} \right|}{\frac{1}{M} \cdot \sum_{j=1}^{M} P_{ij}}. \quad (10)$$

where: N – the number of days in the corresponding time period;
i – the index of day, generally i = 1, 2, …N;
M – the number of time periods during one day; for hourly power price M = 24;
J – the index of the time period, generally j = 1, 2, …M;
P_{ij} – electricity price at j time period in i day.

A coefficient of variation for disclosure of electricity market price volatility has been applied as follows [3 and 4] (11):

$$V = \frac{\sigma}{\bar{x}} \cdot 100\%. \quad (11)$$

where: V – coefficient of variation;
σ – standard deviation;
$\bar{x}$ – average price of electricity.

The value of the coefficient of variation has been qualified with the following [1]:

- up to 10% – variation is low;
- from 10% to 20% – variation is moderate;
- from 20% to 30% – variation is high; and
- 30% and above – variation is very high.

Paulavičius [22] argued that variations in price might be assessed by calculating an indicator of oscillation (12):

$$K_R = \frac{x_{\max} - x_{\min}}{\bar{x}} \cdot 100. \quad (12)$$

where: x_{max} – maximum price of commodity during the analysed time period;
x_{min} – minimum price of commodity during the analysed time period.

Thus, an analysis of the scientific literature shows that there is no single measure (indicator) for disclosure of electricity market price volatility. Following Danilenko [7] and Zareipour *et al.* [33], electricity market price volatility analysis will be performed using the concept of logarithmic and absolute returns. Regardless of which indicator is used for volatility disclosure, the identification of this feature of electricity market pricing is relevant and provides valuable information in predicting future electricity price development.

3.2. Indicators for disclosure of electricity price spike

To determine electricity price spikes, several indicators might be used (see Table 1).

<<INSERT TABLE 1 HERE>>

Usually, electricity price spikes are identified considering the critical value of price. It is assumed that all prices higher or lower than the critical value of price have been accepted as price spikes. Taking into consideration the variation gap (which shows the interval within which electricity market prices fluctuate), the average electricity price and the standard deviation, the critical value of price can be calculated by applying the rule of $2 \cdot \sigma$, $3 \cdot \sigma$ or $4 \cdot \sigma$. Observing that some price data drift far from the average level, it is worthwhile to maintain that price spikes are all prices that drift from average level throughout $3 \cdot \sigma$ and $4 \cdot \sigma$.

Negative prices are also assumed to be price spikes. Currently, not all markets allow negative prices to form, so negative price spikes cannot be found in all markets.

Based on indicators defined above, the calculations have been performed using hourly electricity market price data from day-ahead electricity markets in Poland.

3.3. Data sources

Hourly electricity prices formed in day-ahead electricity markets in Poland were obtained from the Polish power exchange, POLPX (www.polpx.pl). The dataset used in this article covers the time period from 1 January 2010 to 30 September 2011. The dataset was separated into several subsets corresponding to the calendar seasons; this categorization allows the assessment of how electricity price volatility and price spikes develop during various time periods.

4. RESULTS AND DISCUSSION

***Results of analysis of Polish electricity price volatility*.** The calculations for disclosure of electricity price volatility (as well as price spikes) in Poland have been performed using the data provided in figure 1.

<<INSERT FIGURE 1 HERE>>

As can be seen from information provided in figure 1, electricity market prices have become volatile in Poland. Using the methodology provided above, electricity price volatility was found to be rather low: the value of the coefficient of variation is 15.73%. The calculated standard deviation coefficient was 6.8 EUR/MWh, showing a major distribution of electricity market prices near the average price level.

The calculated coefficient of variation ranges revealed broad ranges of price development. In the December-February 2011 period, the difference between the highest and the lowest price was 88 EUR/MWh.

Additional indicators of price volatility and their values are provided in Table 2.

<<INSERT TABLE 2 HERE>>

As presented in Table 2, electricity market prices in Poland were the most volatile during winter 2010-2011, which was an exceptionally long and cold winter (value of coefficient of variation – 26.79%). Market price volatility during other periods was lower (average coefficient of variation was equal to 14.15%). The results of a comparative analysis of electricity prices during 2010 and 2011 reveal that in 2011, prices were very similar to those in 2010, with the exception of the winter 2011 period. Climate factors play a significant role in increasing electricity market prices, which have a tendency to increase in autumn and winter. The average electricity market price increased by 8.5% in winter 2011, compared with prices in spring 2010.

When the heating season starts and thermal PPs start to produce more heating energy and less electrical energy, the electricity supply in the power exchange decreases, and the electricity market price and its volatility increase. For example, the participation of thermal PPs in the Polish power exchange in autumn 2010 influenced the formation of the maximum price, which increased by a quarter to 72.28 EUR/MWh, while price volatility decreased by nearly 2 percentage points (from 13.56% to 15.77%).

In order to determine electricity price volatility, additional indicators ($DVOA_{iP}$, $DVDA_{iP}$ and standard deviation) were calculated. Developments of volatilities, which are based on the abovementioned indicators, are presented in figure 2 and figure 3.

<<INSERT FIGURE 2 AND FIGURE 3 HERE>>

As presented in figure 2, electricity market prices were volatile in Poland, mostly during winter. The $DVDA_{iP}$ indicator revealed that the average electricity market price change was about 7% of the average daily price. The most volatile electricity market price was on 15 December 2010, with a value of $DVDA_{iP}$ indicator closed to 0.15. This result shows that the average price change was 15% of the average daily price. The development of the $DVOA_{iP}$ indicator reveals that the most volatile electricity price was at the beginning of 2011, when the value of the $DVOA_{iP}$ indicator was more than 0.15. This result indicates an average price change of 15% of the long-term average price for the period of 1 January 2010 to 30 September 2011.
Development of a standard deviation indicator confirms this conclusion about electricity price volatility in Poland.

As presented in figure 3, the most volatile electricity prices were in January 2010 (max. standard deviation – 0.15), December 2010 (max. standard deviation – 0.17) and September 2011 (max. standard deviation – 0.13). Figure 3 shows that volatility increased in autumn 2010 and winter 2011.

Results of Polish electricity price spikes analysis. Electricity market prices are also characterised by price spikes. In order to evaluate this feature, critical values of price have been calculated. The results are provided in Table 3.

<<INSERT TABLE 3 HERE>>

On the basis of the information provided in Table 3, it could be argued that price spikes in the Polish electricity market comprise all prices below 28.50 EUR/MWh and above 57.96 EUR/MWh during the period of January 2010 to September 2011 (if 2 standard deviations are taken into account). Price spikes were present for 3.15% of the time period analysed. As shown in Table 3, price spikes usually occur in spring, encompassing 2.01% of the time period analysed. Price spikes were present for 0.16% of the time in summer; 0.29%, in autumn; and 0.68%, in winter. These results show that particularly high and low prices in the Polish power exchange dominated 0.99% of the time, occurring mostly in the spring.

Since every season has its own average electricity price and price volatility, it is not surprising that critical values of price differ seasonally (see Table 3). For example, in spring 2010, price spikes were above 49.69 EUR/MWh and below 30.37 EUR/MWh. In autumn 2010 and winter 2011, when the average electricity price and price volatility increased, the upper bound of price spikes increased to 57.13 and 68.42 EUR/MWh, respectively, and the lower bound increased to 29.73 and 20.68 EUR/MWh, respectively. These examples have revealed that when the average price of electricity and price volatility changes, the conception of price spikes transforms as well.

It is worth noting that the duration of price spikes is increasing in Poland. While price spikes were present for 4.45% of the winter period in 2010, they were present for 10.69% of the winter period in 2011.

The volatility of electricity market prices in Poland is rather low during the summer, when most of the power plants have their seasonal repair period, leaving the supply of electricity unsatisfied. Therefore, the diversification of possible electric power sources, number of suppliers and lower demand on electricity could stabilise the market electric energy prices situation in Poland during the summer.

5. CONCLUSIONS

The electricity market price stability, expressed by the average electricity price indicator, seemed to be stable in Poland, where card coal and lignite dominates in the electricity production structure. The average electricity market price across seasons was 40.03 EUR/MWh (spring 2010) and 45.69 EUR/MWh (spring 2011).

The differences between minimum and maximum prices (i.e., variation gap indicator) were quite low in Poland. The value of the variation gap indicator fluctuated in a range of 31.50–44.01 EUR/MWh (except for winter 2011).

Volatility, estimated with the standard deviation indicator and variation coefficient, revealed that electricity price volatility is usually moderate in Poland.

Developments of Polish $DVDA_{IP}$ and $DVOA_{IP}$ indicators reveal that electricity market price volatility is rather seasonal in Poland. Electricity market volatility has a notable tendency to increase in winter in Poland, then to fall, and then to start to increase again in autumn.

The results of this analysis of price spikes (when $2 \cdot \sigma$ is considered) reveal that price spikes haven't been very frequent in Poland, but extremely high and low prices (when $3 \cdot \sigma$ is considered) have been evident. They have been observed quite frequent in the spring.

Some general conclusions and remarks as a results of this analysis of Polish day-ahead electricity market prices were pointed out:

1. The introduction of competition in the wholesale electricity market influences electricity prices, which are currently acquiring fairly new features. Results of a scientific literature analysis have shown that electricity market prices might attain the following features: high frequency, mean-reverting, negativity, seasonality, volatility, spiking, and jumping.
2. The results of the analysis of scientific literature and world observations have revealed that the formation of segregated features fully depends on electricity demand, supply, factors influencing them and market structure. Electricity prices become volatile for the following reasons: capacity withdrawal, fluctuations of CO_2 prices, cross-border congestion, fluctuations of coal prices, erratic production in wind PPs, level of water resources, manipulations in the market, fluctuations of oil prices, demand seasonality, rules of participation in the market, and air temperature. Short- and long-term price spikes form for the following reasons: shutdown of a power plant, failure in the transmission network, insufficient transmission or generation infrastructure due to either underestimated demand forecast or a lack of market stimulation for new market entries, unexpected changes in weather conditions, non-price-responsive consumers, the practice of market power by generation companies at higher demands and with transmission limits, market organisation and design.
3. Various indicators can be used to determine the features of electricity market prices. Conclusions about price volatility can be drawn from analysing the absolute and relative changes of the electricity market price. Volatility of the electricity market price was

determined using the following indicators: dispersion, standard error, oscillation coefficient, variation coefficient, and price velocity indicators. In order to evaluate price spikes, the critical value of electricity market price was calculated.

4. The results of the Polish data analysis have shown that electricity market price volatility is moderate in Poland. Volatility has a tendency to increase in the autumn and winter in Poland. Price spikes have been an observable phenomenon in the Polish day-ahead market. Price spikes were present for 3.15% of the time period analysed.
5. The dominant determinants of electricity market prices in this part of Europe are climate conditions and fluctuations of primary energy sources.

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Table 1. Indicators for identification of price spikes

Author	Indicator	Formula of indicator	Valuation
Lu *et al*., 2005 [18]	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 to the 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.
Lucia & Schwartz, 2002 [19]	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.

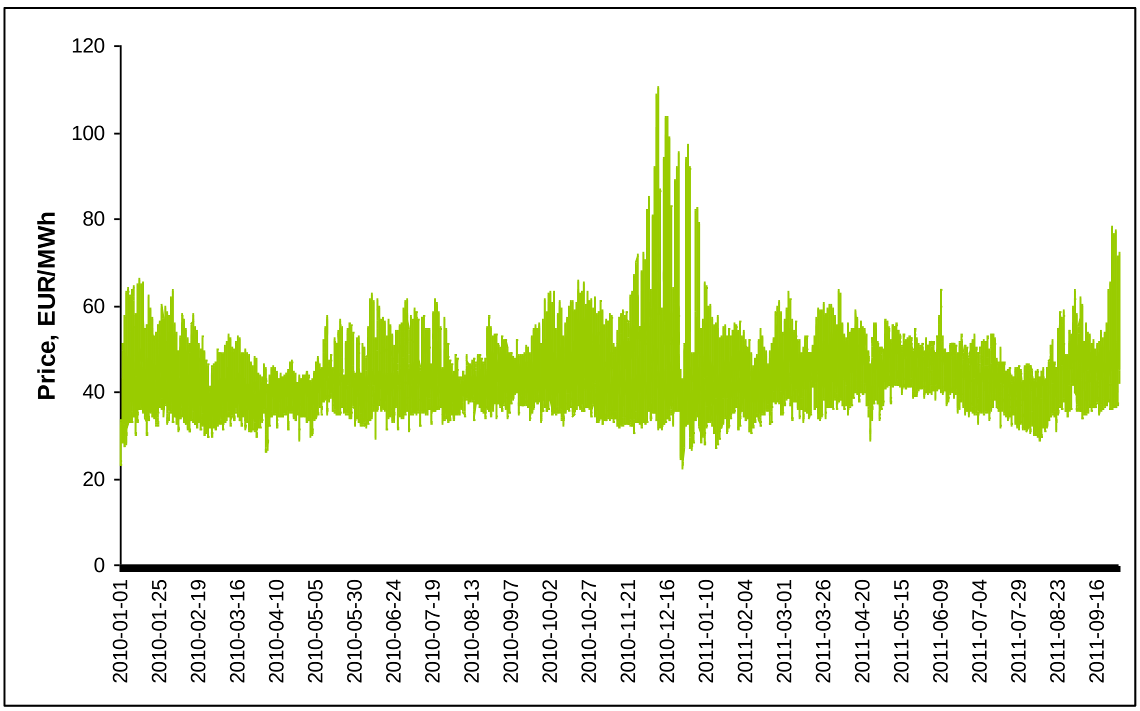

Fig. 1. Development of electricity market prices in Poland in 2010-2011 [24]

Table 2. Volatility and other indicators of Polish electricity price in 2010-2011 (authors' calculations)

Time period		Average price, EUR/MWh	Minimum price, EUR/MWh	Maximum price, EUR/MWh	Variation gap, EUR/MWh	Oscillation coefficient, %	Standard deviation, EUR/MWh	Variation coefficient, %
2010 m.	January-February	41.91	23.27	66.22	42.94	102.46	7.85	18.73
	March-May	40.03	26.08	57.59	31.50	78.69	4.83	12.07
	June-August	42.81	29.19	62.98	33.79	78.95	5.81	13.56

	September-November	43.43	30.61	72.28	41.67	95.94	6.85	15.77
2011 m.	December-February	44.55	22.43	110.43	88.00	197.54	11.94	26.79
	March-May	45.69	28.67	63.62	34.95	76.50	5.51	12.06
	June-August	43.15	28.96	63.75	34.78	80.61	5.43	12.59
	September	45.12	34.05	78.07	44.01	97.53	6.44	14.27

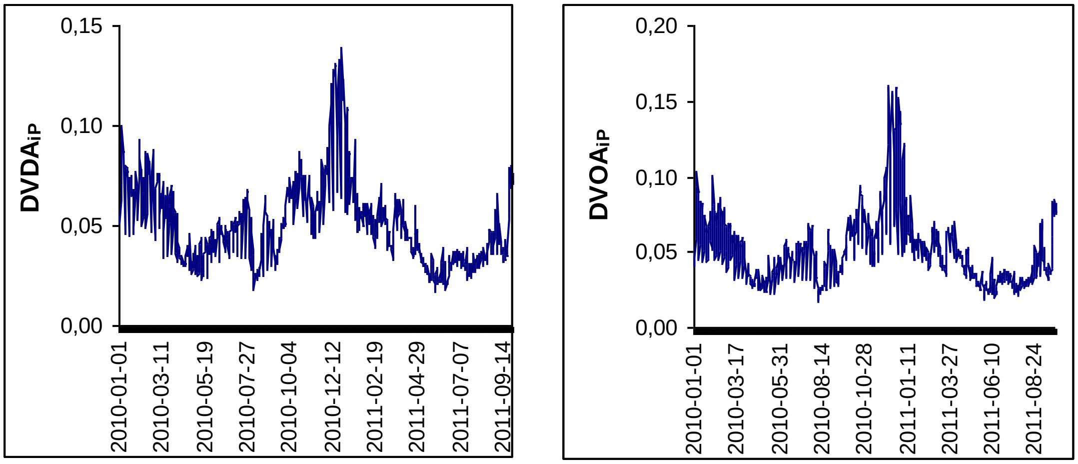

Fig. 2. Development of Polish electricity price volatility based on $DVDA_{iP}$ and $DVOA_{IP}$ indicators (authors' calculations)

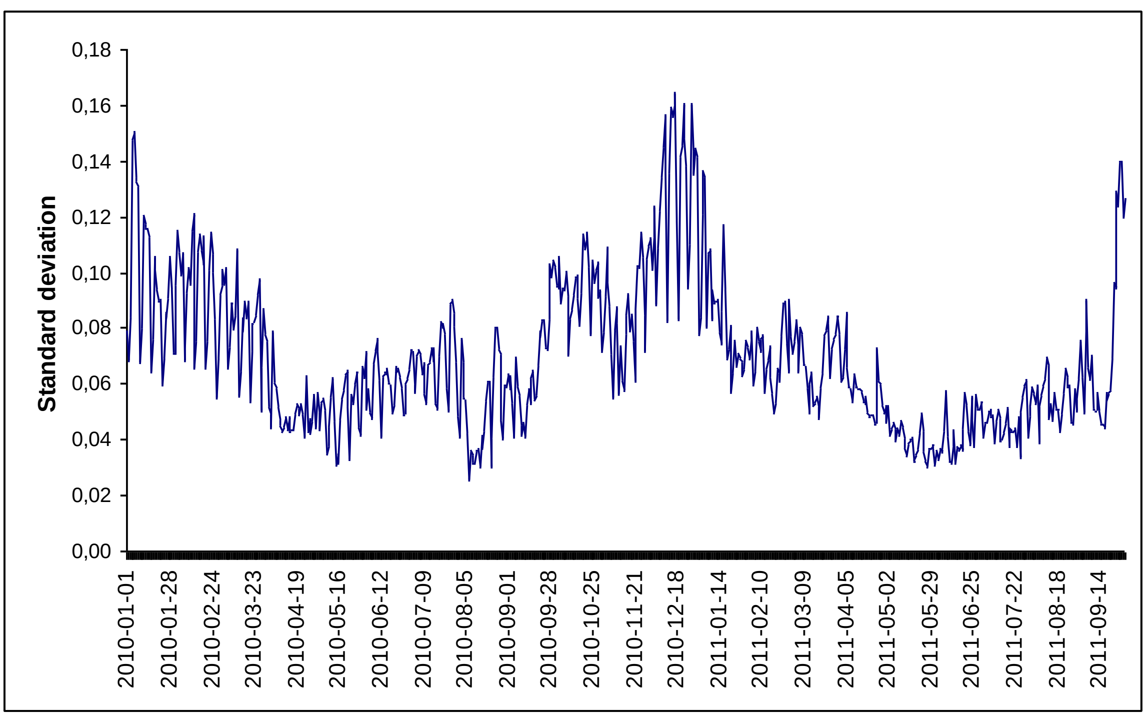

Fig. 3. Development of Polish electricity price volatility based on standard deviation indicator (authors' calculations)

Table 3. The results of disclosure of Polish electricity price spikes (authors' calculations)

Time period		$P_K = \bar{x} \pm 2 \cdot \sigma$		Price spikes at rule of $2 \cdot \sigma$, %	$P_K = \bar{x} \pm 3 \cdot \sigma$		Price spikes at rule of $3 \cdot \sigma$, %
		Lower bound	Upper bound		Lower bound	Upper bound	
2010-2011 September		28.50	57.96	3.15	21.14	65.33	0.99
	spring			2.01			0.86
	summer			0.16			0.00
	autumn			0.29			0.00
	winter			0.68			0.13
2010	January-February	26.21	57.61	4.45	18.36	65.46	3.95
	March-May	30.37	49.69	0.05	25.54	54.52	0.00
	June-August	31.19	54.42	1.77	25.39	60.23	1.77
	September-November	29.73	57.13	3.80	22.88	63.98	3.80
2011	December-February	20.68	68.42	10.69	8.74	80.35	10.05
	March-May	34.67	56.70	1.00	29.16	62.21	1.00
	June-August	32.29	54.02	0.59	26.85	59.45	0.59
	September	32.25	58.00	4.03	25.81	64.44	4.03

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