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CAUSALITY RELATIONSHIPS BETWEEN LITHUANIAN DAY-AHEAD ELECTRICITY PRICE AND ITS FACTORS

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Abstract. The aim of this paper is – after the review of scientific literature on the issue of factors forming day-ahead electricity price worldwide, to assess causality relationships between electricity price and the selected price elements. Literature analysis and Granger causality test are employed to implement the aim. The results of the analysis told that Estonian, Finish, Nord Pool prices and trade volumes, as well electricity consumption and production volume in Lithuania, net electricity import volume from Russia, Belarus and Latvia and electricity trade volume in Lithuanian power exchange Granger caused day-ahead electricity price in Lithuania. The impact of air temperature and exchange rate, as well the impact of prices of resources used in electricity production indirectly Granger caused Lithuanian day-ahead electricity price.

Keywords: day-ahead market, electricity price, Granger causality, price factors.

Jel classification: C59, L94, Q40, E39.

1. Introduction

Actuality of the paper. In 1 January 2010 power exchange started functioning in Lithuania. It provides market participants a pathway to perform business activities in a competitive environment. Under the last electricity trade rules, day-ahead market participants can trade electricity in accordance to a unified price, which is influenced by many factors that still are not well know by electricity trades, but are very important to them seeking to profitably sell or cheaply buy electricity.

Novelty of the paper. There were published a great variety of papers (Wolak 1998; Serletis, Herbert 1999; Catalão *et al.* 2007; Karakatsani, Bunn 2008; Ferkingstad *et al*. 2010; Mierra *et al*. 2008; Rio 2010, *etc*.) on issue of electricity price. However, there was not found any paper that could deal with issue of price formation factors in Lithuanian day-ahead electricity market. This paper fulfills the gap.

***The object of the paper* –** a day-ahead electricity price from 1 January 2010 to 30 September 2011.

The aim of the paper is – after the review of scientific literature on the issue of factors forming day-ahead electricity price worldwide, to assess causality relationships between electricity price and the selected price elements in Lithuania.

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

1. to discuss day-ahead electricity price factors;
2. to describe the methodology applied in investigation of causality testing;
3. to set the causality interrelationships between a day-ahead electricity price in Lithuania and various factors.

In order to exercise these tasks the following ***methods*** are applied: analysis of scientific literature, the augmented Dickey-Fuller test, and Granger causality test.

2. Electricity price formation factors: review of literature

There are found a great variety of papers on the issue of electricity price formation process and attempts to explain to what factors do electricity price respond?

F. Wolak (1998) finds that market structure and market rules cause significant differences in the behavior of spot prices. As he noticed, a major determinant of prices in hydro-electric capacity dominated markets is the amount of water available. Besides, the behavior of prices is the result of market power.

A. Serletis and J. Herbert (1999) try to explain electricity price formation after the assessment of relationships between natural gas, oil and electricity prices in USA. Scientists find that there exists a long-run relationship between spot natural gas and oil prices. Long-run relationships between spot electricity price and prices of fuels are not investigated.

J. P. S. Catalão *et al.* (2007) mention that electricity price is influenced by many factors, including historical prices, demand, bidding strategies, operating reserves, imports, temperature, predicted power shortfall, and generation outages.

N. V. Karakatsani and D. W. Bunn (2008) set that spot electricity price is influenced by a mixture of factors including economic fundamentals, plant constraints, strategic behavior, perceived risk, trading inefficiencies, learning, and market design implications. The intensity of these effects across markets is expected to depend on the specific market configuration.

E. Ferkingstad *et al*. (2010) determine that electricity price is directly influenced by exchange rate EUR/USD, coal and natural gas prices, electricity prices in neighboring countries. Indirectly electricity price is impacted by oil price that itself has an influence on electricity price in neighboring countries. Several relationships contradict the results that are received by other scientists. For example, R. A. Amano and S. van Norden (1998), Sh. Sh. Chen and H. C. Chen (2007), P. K. Narayan *et al.* (2008), R. A. Lizardo and A. V. Mollick (2010) find arguments that fluctuations in oil prices have an impact on exchange rate. Meanwhile the results of analysis performed by Y. J. Zhang *et al*. (2008) show that changes in exchange rate generate fluctuations of oil prices. Model prepared by E. Ferkingstad *et al*. (2010) shows that there are no causal relationships between exchange rate and oil prices.

Electricity price model prepared my E. Ferkingstad *et al*. (2010) differs from one that is prepared by M. P. Muñoz and D. A. Dickey (2009). The latter scientists set that electricity price in Spain is co-integrated with exchange rate USD/EUR and oil price. This allows concluding that there exist long-run relationships between the selected variables. Scientists identified short-run relationships:

– change in oil price influences on change of exchange rate USD/EUR;

– change in oil price impacts on spot electricity price; and

– a relationship between exchange rate USD/EUR and spot electricity price is not significant.

One of the first works, where additional to natural gas, coal, and crude oil prices, the uranium prices are analyzed, is prepared by J. W. Mjelde and D. A. Bessler (2009). The results of the analysis tell that peak and off-peak electricity prices in USA respond to shocks that appear in natural resource markets.

A structured attitude towards factors influencing on spot electricity price is expressed by A. K. Aggarwal *et al*. (2009). These scientists segregated lot of spot electricity price factors and prescribed them to one of the following group:

– *market features* – historical load, system load rate, imports / exports, capacity excess / shortfall, historical reserves, generation capacity, system's binding constraints, line limits;

– *nonstrategic uncertainties* – temperature, weather, oil and gas prices;

– *other stochastic uncertainties* – generation outages, line status, line contingency information, congestion index, historical prices; and

– *temporal effects* – demand elasticity, bidding strategies, spike existence index, settlement period, day type, month, holiday code, season.

P. Rio Gonzalez and F. Hernandez (2007) at theoretical level analyzed various alternatives of the effects of energy efficiency measures and support to renewable energy on electricity price. The results of the analysis suggest that the effect of measures on electricity price highly depend on the level of electricity market integration and implementation level of measures.

M. Rathmann (2007) analyzed the effect of feed-in tariff on CO_2 price and electricity price. He argues that support to renewable electricity allows increasing the amount of renewable electricity, which lead to a substitution of fossil fuel electricity to renewable electricity. Because of substitution the amount of CO_2 reduces; demand for emission allowances and CO_2 price decreases. As a result spot electricity price decreases.

G. Mierra *et al*. (2008) identified relationships that link volume of renewable electricity, which increases because of support to renewables, wholesale and retail electricity prices. They set that relationships between variables are:

– *absolute negative correlation* – because of the increased volume of renewable electricity, there is a reduction in the wholesale electricity price. The reduction is lager then the costs related to renewable electricity support. This leads to a reduction in the retail electricity price;

– *relative negative correlation* – because of the increased volume of renewable electricity the reduction in the wholesale price of electricity does not compensate the increase in costs related to renewable electricity support. This leads to an increase in the retail electricity price;

– *positive correlation* – renewable electricity deployment does not lead to a reduction in the wholesale electricity price; therefore retail electricity price increases by the increase of renewable electricity support.

The analysis of scientific literature revealed that electricity price depends on various factors. It is valuable to group these factors under the supply and demand criteria.

3. Research methodology

3.1. Methodology for time series stationary testing

First of all stationarities of time series of a day-ahead electricity price and various factors are tested. Scientific literature proposes various types of tests for stationarity testing. In S. H. Yoo and S. J. Ku (2009) and N. Odhiambo (2010) the Phillip-Perron test is applied. In J. Chontanawat *et al*. (2008) and L. Jinke *et al*. (2008) the augmented Dickey-Fuller (ADF) test is used. In the papers of J. H. Yuan *et al*. (2008), U. Soytas and S. Sari (2009) five different unit root tests are applied. The tests produce contradictory results. In this paper it is decided to apply the ADF test, which refers to the hypotheses that the selected time series is:

H_0: Non-stationary;

H_A: Stationary.

Seeking to reject the H_0 it is necessary to compare t-statistics of the ADF test to critical values at 1% or 5% level of significance. In the case H_0 is accepted, the selected time series is non-stationary. Thus, it is necessary to difference it. Differencing usually converts the selected time series from non-stationarity to stationarity. The ADF test takes several forms:

$$\Delta y_t = \beta y_{t-1} + \delta_1 \Delta y_{t-1} + \delta_2 \Delta y_{t-2} + \ldots + \delta_p \Delta y_{t-p} + \varepsilon_t \quad (1)$$

$$\Delta y_t = \alpha_0 + \beta y_{t-1} + \delta_1 \Delta y_{t-1} + \delta_2 \Delta y_{t-2} + \ldots + \delta_p \Delta y_{t-p} + \varepsilon_t \quad (2)$$

$$\Delta y_t = \alpha_0 + \beta y_{t-1} + \gamma t + \delta_1 \Delta y_{t-1} + \delta_2 \Delta y_{t-2} + \ldots + \delta_p \Delta y_{t-p} + \varepsilon_t \quad (3)$$

here: Δy_t – 1st differenced value of y; α_0 – intercept; y_{t-1} – the 1st lagged value of y; *y* – variable to be tested; *p* – augmenting lags; ε_t – error term; *t* – time trend; β, δ_p – the parameters to be estimated.

The (1) equation shows that time series is flat and potentially slow-turning around zero. The (2) equation represents time series that is flat and slow-turning around a non zero value. This equation has an intercept term, but no time trend. The (3) equation describes time series that has a trend (down or up) and is potentially slow-turning around a trend line.

3.2. Granger causality test

After the stationarity of time series is tested, secondly, Granger causality test is performed. Granger causality test is based on the equations (4) and (5):

$$y_t = \mu_0 + \sum_{i=1}^{p} \alpha_i y_{t-i} + \sum_{j=1}^{q} \beta_j x_{t-j} + \varepsilon_t, \quad (4)$$

$$x_t = \mu_0 + \sum_{i=1}^{p} \alpha_i x_{t-i} + \sum_{j=1}^{q} \beta_j y_{t-j} + \kappa_t; \quad (5)$$

here: y_t – electricity price at time t; y_{t-i} – electricity price at time t–i; y_{t-j} – electricity price at time t–j; x_t – electricity price factor at time t; x_{t-i} – electricity price factor at time t–i; x_{t-j} – electricity price factor at time t–j; α_i, β_j – coefficients that are needed to be estimated; ε_t, κ_t – "white noise".

The H_0 hypothesis of coefficients b_j statistical significance is tested (see equation (4)). H_0 states that b_j is statistically not significant ($\beta_1 = \beta_2 = ...\beta_j = 0$), therefore „x does not Granger cause y". If b_j is statistically significant, then „x Granger cause y". Seeking to test H_0, 5% significance level is chosen.

4. The main results of the research performed

4.1. Results of time series stationarity testing

Based on the methodology described above, stationarity of a day-ahead electricity price and various factors are tested. The results are presented in Table 1.

Table 1. Results of stationarity testing at level: p-value (Source: compiled by authors)

Number of lags	Without constant	With constant	With constant and trend
Day-ahead electricity price, $P_{Exchange}$			
5	0,0011	8,06·10–52	7,82·10–89
25	0,4081	5,69·10–12	2,58·10–11

Continuation of Table 1

Number of lags	Without constant	With constant	With constant and trend
Volume of electricity traded in a day-ahead electricity market, $Q_{Exchange}$			
5	0,0469	2,53·10–40	1,83·10–60
25	0,5581	9,61·10–7	1,83·10–7
Volume of electricity consumption in Lithuania, Q_C			
5	1,110·10–5	6,83·10–50	6,21·10–119
25	0,5428	1,41·10–5	9,30·10–7
Volume of electricity production in Lithuania, Q_P			
5	6,33·10–8	2,33·10–39	1,31·10–57
25	0,1046	5,84·10–6	3,17·10–6
Volume of net electricity import to Lithuania, Q_I			
5	0,0074	9,47·10–46	7,79·10–65
25	0,4716	5,47·10–7	5,25·10–6
Electricity flow with Russia, $Flow_{RU}$			
5	6,37·10–6	1,31·10–13	2,37·10–22
25	0,0945	0,0102	0,0011
Electricity flow with Belarus, $Flow_{BY}$			
5	2,05·10–14	6,56·10–23	4,96·10–25
25	0,0203	0,0146	0,0554
Electricity flow with Latvia, $Flow_{LV}$			
5	5,40·10–5	4,72·10–9	1,14·10–12
25	0,0871	0,1291	0,0612
Electricity system price in Nord Pool, $P_{Nord\ Pool}$			
5	0,0368	4,26·10–9	1,55·10–41
25	0,1403	0,2913	5,44·10–5
Electricity system price in Estonia, $P_{Estonia}$			
5	6,12·10–5	5,14·10–52	6,5·10–91
25	0,2912	1,87·10–12	5,76·10–12
Electricity system price in Finland, $P_{Finland}$			
5	0,0376	2,61·10–27	1,34·10–63
25	0,1810	0,0004	5,88·10–10
Electricity trade volume in Nord Pool's day-ahead electricity market, $Q_{Nord\ Pool}$			
5	0,0536	6,44·10–18	2,13·10–39
25	0,3229	0,0010	1,5·10–7
Natural gas price in Nord Pool, P_{Gas}			
5	0,0858	3,57·10–7	1,97·10–5
25	0,0857	7,51·10–9	3,92·10–7
Average air temperature in Lithuania, $T_{Temperature}$			
5	0,1436	0,2027	0,0463
25	0,1673	0,2021	0,7629
Exchange rate LTL/USD, $E_{LTL/USD}$			
5	0,5878	2,01·10–7	1,33·10–7
25	0,5984	0,0022	0,0084

End of Table 1

Number of lags	Without constant	With constant	With constant and trend
CO_2 emission price in EEX exchange, P_{CO2}			
5	0,3541	0,9448	0,7910
Number of lags	Without constant	With constant	With constant and trend
25	0,3349	0,9402	0,8158

Remark: numbers written in **black colour** show that time series is stationary at 5% level of significance; in **purple colour** – stationary at 10% level of significance; in **red colour** – time series is non-stationary.

As it is presented in Table 1, time series of a day-ahead electricity price and selected price factors are stationary at level, when 5% or 10% level of significance is taken into account, except time series of CO_2 emission price. Usually time series becomes stationary in the cases when constant or constant and trend is included in testing the stationarity. Besides, when the number of lags included in testing increases, the probability that time series is stationary decreases. Time series of CO_2 emission price becomes stationary after the first differencing (Table 2).

Table 2. Results of time series stationarity testing at the first differencing: p-value (Source: compiled by authors)

Number of lags	Without constant	With constant	With constant and trend
CO_2 emission price in EEX exchange, P_{CO2}			
5-25	$3{,}61 \cdot 10^{-28}$	$5{,}42 \cdot 10^{-30}$	$3{,}33 \cdot 10^{-35}$
Day-ahead electricity price, $P_{Exchange}$			
5	$7{,}51 \cdot 10^{-31}$	$5{,}08 \cdot 10^{-45}$	$6{,}50 \cdot 10^{-123}$
25	$2{,}38 \cdot 10^{-40}$	$1{,}65 \cdot 10^{-47}$	$9{,}76 \cdot 10^{-70}$

Thus, by summarizing what was said the conclusion can be drawn that time series of a day-ahead electricity price and its factors are stationary at level (except CO_2 emission price).

4.2. Results of Granger causality test

Granger test is used to set the causality relationships between a day-ahead electricity price and various factors. Seeking to determine the relationships there was decided to choose from 5 to 30 number of lags. Summarized results of the Granger causality test are presented in Table 3.

Table 3. Results of Granger causality test (Source: compiled by authors)

Factor	$P_{Exchange}$					
	Number of lags					
	5	10	15	20	25	30
Volume of electricity traded in a day-ahead electricity market	↕	↕	↕	↕	↕	↕
Volume of electricity consumption	↕	↕	↕	↕	↕	↕
Factor	5	10	15	20	25	30
Volume of electricity production	↕	↕	↕	↕	↕	↕
Volume of net electricity import to Lithuania	↕	↕	↕	↕	↕	↕
Electricity flow with Russia	↕	↕	↕	↕	↕	↕
Electricity flow with Belarus	↕	↕	↕	↕	↕	↕
Electricity flow with Latvia	↕	↕	↕	↕	↕	↕
Electricity system price in Nord Pool	↕	↕	↕	↕	↕	↕
Electricity trade volume in Nord Pool's day-ahead electricity market	↕	↕	↕	↕	↕	↕
Electricity system price in Estonia	↕	↕	↕	↕	↕	↕
Electricity system price in Finland	↕	↕	↕	↕	↕	↕
Natural gas price in Nord Pool	–	–	–	–	–	–
Average air temperature in Lithuania	↑	↑	–	–	–	–
Exchange rate LTL/USD	–	–	–	–	–	–
CO_2 emission price in EEX exchange	–	↑	↑	↑	↑	↑

As it can be seen from the Table 3, there existed several types of causal relationships between the selected factors. The upward (↑) arrow showed that there existed one-way relationship between a day-ahead electricity price in Lithuania and the selected factor. Two-way (↕) relationship disclosed that mutual relationship existed between a day-ahead electricity price in Lithuania and the selected factor, i.e. electricity price had an influence on the factor and the factor itself impacted on electricity price. In some cells of the Table 3, dash (–) is written. It showed that there was not found a causality relationship between electricity price and the selected factor, when 5% level of significance was chosen.

Table 3 presents that irrespective of the number of lags chosen for performance of Granger causality test; there were set statistically significant two-way causality relationships between a day-ahead electricity price and the following factors:

– volume of electricity traded in a day-ahead electricity market in Lithuania;
– volume of electricity consumption and production in Lithuania;
– volume of net electricity import to Lithuania;

– electricity flow with Russia, Belarus and Latvia;
– electricity system price in Nord Pool, Finland and Estonia; and
– electricity trade volume in Nord Pool's day-ahead electricity market.

This disclosed that not only identified factors influenced on a day-ahead electricity price, but also electricity price impacted on these factors in a short-run. In the cases, when 5 and 10 numbers of lags were selected, then one-way relationships were set between electricity price and average air temperature. The identification of this relationship confirmed that climatic factor had an impact on a day-ahead electricity price during the analyzed time period. In the cases, when 10 and more lags were selected, then one-way relationship existed between electricity price in Lithuania and CO_2 emission price in EEX exchange. It should be noticed that there were not found direct causal relationships running from natural gas price and exchange rate LTL/USD to electricity price in Lithuania. However, this could not deny that these factors had impact on a day-ahead electricity price. This is very well can be illustrated by information provided in Fig. 1.

As it is seen from information provided in Fig. 1, natural gas price formed in Nord Pool's spot market had an impact on Nord Pool's electricity system price and electricity trade volume in Nord Pool's spot market. The latter factors are directly related to electricity price in a day-ahead electricity market in Lithuania. This proposed that electricity traders in Lithuania considered electricity prices in neighbouring countries, when were bidding Lithuanian power exchange.

Exchange rate LTL/USD Granger caused volume of electricity consumed in Lithuania. Changes in electricity consumption volumes impacted on trade volume of electricity in a day-ahead electricity market in Lithuania and then on a day-ahead electricity price in Lithuania.

Electricity production and consumption volume depended on air temperature in Lithuania. As it could be noticed changes in climatic factors had an influence on electricity consumption and production volumes in Lithuania and, of cause, on electricity price.

During the analyzed time period Lithuania had links with three countries, namely, Russia, Belarus, and Latvia. Besides, Lithuania was a net electricity importer. During three quarters of 2011 electricity import flow was 5251.2 GW and export – 222.4 GW. 41.9% of electricity import came from Latvia, 31.9% and 26.2% correspondingly from Russia and Belarus. Electricity trade in BaltPool rules requires that all electricity imported from or exported to would be traded via power exchange. This suggested that international trade in electricity had impact on electricity prices in Lithuania. Fig. 1 confirmed this.

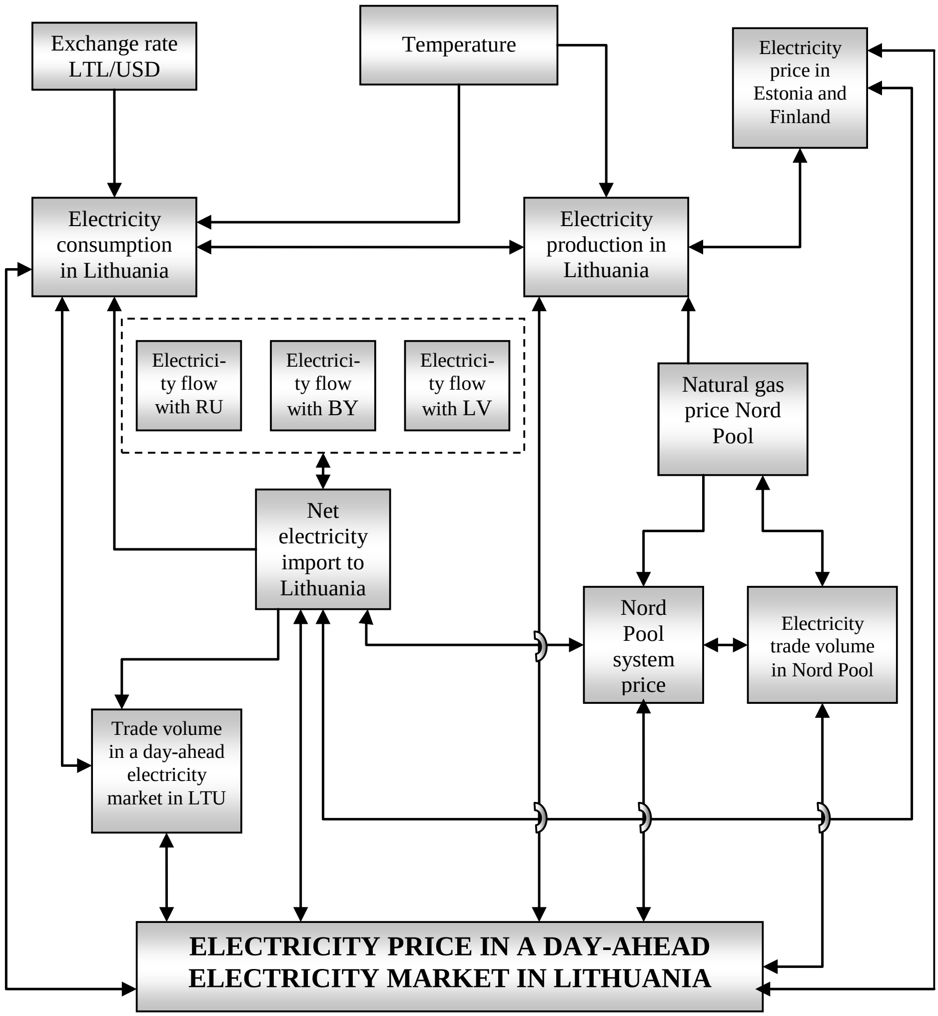

Fig. 1. System of factors of a day-ahead electricity price in Lithuania (in the case, when 25 lags are chosen) (Source: compiled by authors)

5. Conclusions

Based on the results of the analysis performed the following conclusions might be drawn:

1. There are a great variety of factors influencing on a day-ahead electricity price. They can be segregated under the two criteria, i.e. under the factor's relationship with demand and supply:
   – *factors having influence on electricity supply* are electricity production structure and water resource level, electricity import and export volumes, prices of fuels used for electricity production, prices of emission allow-

ances, and technical parameters of electricity distribution and transmission.
– *factors having influence on electricity demand* are outside air temperature, economic activity, price level, prices of electricity substitutes, behaviour of electricity consumers during weekends and on workdays, electricity demand seasonality, and exchange rates.

2. Granger causality test can be applied in disclosing relationships between a day-ahead electricity price and selected variables. However, interpretation of results should be performed carefully, since method allows discovering mathematical relationships. In practice it has to be found reality reflecting facts (economic, technical and other reasoning) that could substantiate mathematical reasoning.
3. Electricity price in a day-ahead electricity market in Lithuania is influenced by electricity trade, production, consumption and import volumes, situation in prices and trade volumes in neighbouring electricity markets, macroeconomic (exchange rate) and climatic factors (temperature). The results of Granger causality test reveal that electricity price formation in a day-ahead electricity market in Lithuania is continuous and permanently developing process depending on the changes of various factors.

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