Nuclear power – Additions to wholesale electricity prices and margin of safety

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Abstract: After the Fukushima Daichii Accident, nuclear phase-out policy (so-called "Energiewende") of Germany and the increasing use of renewable energy sources for electricity generation led to new challenges in energy balancing and security of supply, and induced the reduction of wholesale electricity prices especially in Eastern-European Countries to the detriment of German households creating a financially risky environment for the operators of conventional large-scale power plants. Due to their front-loaded cost-structure and the relatively high share of fixed versus variable costs in its costs structure, nuclear energy plants were extremely exposed to wholesale price fluctuations. The goal of this study is to highlight the impact of diminishing German wholesale electricity prices on the margin of safety of two Eastern-European nuclear power plants.

Key-Words: nuclear power plants, CVP analysis, margin of safety, wholesale electricity prices

1 Introduction

In competitive and liberalized energy markets investment risks and financial challenges are dominant and these markets are characterized by new types of risk (van der Zwaan 2008; Virág et al., 2012, WEC, 2013; IEA-NEA, 2005). According to the IEA-NEA (2005: 177-178), the most important business risks affecting energy generation technologies are:

- factors that affect the demand for electricity and impact the supply of capital and labor;
- factors under the control of the policy-makers, such as regulatory (economic and non-economic) and political risks, with possible implications for costs, financing conditions and on earnings

- price and volume risks in the electricity market;
- fuel price and availability risks;
- risks arising from the financing of investment.

Between 2011 and 2016, the decline of the average selling price of electricity in the European Union represented one of these major risk sources. The impacts of supporting schemes and the merit-order effects of renewable-based power generation and cogeneration on wholesale electricity prices are well-studied in the relevant literature (Dillig et al., 2016; da Silva & Cerqueira, 2017; Hirth, 2018) as well as the interrelatedness of national wholesale markets of the EU member states (see e.g. de Menezes & Houllier, 2015, 2016; Keppler et al. 2017), and most of the studies (von Roon and Huck, 2010, BMWI, 2012, Cludius et al. 2014; Hirth, 2018) emphasize the spillover effects of German wholesale electricity price reductions on neighboring national markets influencing the operational performance and profitability of conventional fossil fuel and nuclear power plants.

In order to illustrate this impact of wholesale price reduction on nuclear power generation this paper demonstrates a cost – volume – profit analysis of two Eastern-European nuclear power plant.

2 Economics of Nuclear Power Generation

2.1. Investment and O&M costs of nuclear power generation

Nuclear power is seen as an important source of low-carbon electricity, supporting energy security goals, and contribute to competitive base-load electricity supply, since nuclear power plants have generally high availability and load factors, and a dispatchable nature, and compared to fossil-fuel based energy generation technologies, nuclear power at the point of electricity generation does not produce any GHG emissions that damage local air quality (WEC 2007a; 2007b; Andoura et al. 2011, Poncelet 2013, Fisher 2013, NEA 2013, OECD-NEA 2012, ENEF 2013, Euroconfluences 2011). Nuclear energy is also said to be one of the most competitive energy generation technology due to its cost structure and limited impacts of fuel price volatility.

Financial requirements of nuclear power plants include the initial investment, operation and maintenance, fuel procurement, waste treatment and disposal and end of life decommissioning cost. According to IEA-NEA (2010, 2015) the levelized cost of electricity (LCOE) of new nuclear plants in 2030 will be competitive with other generating options, however the more investment intensive the option, the more sensitive the LCOE to the value of the discount rate (see Table 1).

Table 1: Levelized costs of electricity of European nuclear plants (USD/MWh)

Country	LCOE with 50% capacity factor			LCOE with 85% capacity factor			LCOE (2010)	
	3%	7%	10%	3%	7%	10%	5%	10%
BELGIUM	70.67	126.19	181.78	51.45	84.17	116.81	61.06	109.14
FINLAND	64.65	118.21	171.70	43.13	77.64	109.10		
FRANCE	69.09	124.63	179.98	49.98	82.64	115.21	58.42	92.38
HUNGARY	81.68	142.97	202.47	53.90	89.94	124.95	81.85	121.82
SLOVAKIA	82.28	133.36	188.66	53.90	83.95	116.48	82.69	97.92

Source: IEA-NEA (2010, 2015)

Based on a relevant literature review, Kessides (2010: 3852) summarises the most important types of cost categories and determinants of nuclear economics, which are

- Construction or capital costs for reactors, including:
  - overnight costs
  - shares of overnight capital costs in total levelized cost of electricity of nuclear plants
  - reactor designs and capital cost scenarios
  - construction time
- Alternative fuel costs
- Operations and maintenance charges
- Insurance and liability
- 'Back-end'' costs for waste and decommissioning

Investment costs of nuclear power plants represent by far the largest share (around 60% on average) of LCOE. Depending on plant size, multiple unit sites, design improvement, standardization, and performance improvement, investment costs are ranging from €2-3.5 billion (for 1000MWe to 1600MWe) and the construction costs of nuclear energy generation are significantly higher in comparison to fossil fuel technologies (EC 2007, IEA 2011, WEC 2007/a, van der Zwaan 2008). After the Fukushima Daiichi Accident EU Member States retain their sovereignty over the use of nuclear power, some of the countries are still expanding their nuclear capacities, building or planning to build new nuclear reactors, or investing in nuclear fleet's life-extension, upgrade or uprate activities, while some countries agreed to phase out nuclear generation by about 2022 or 2025. This 'front-loaded' cost structure of nuclear plants suggests that existing operating nuclear power plants continue to be a generally competitive profitable source of electricity, but for new construction, the economic competitiveness of nuclear power depends on several factors, such as cost overruns, project delays, higher cost of capital, long-term payback times, uncertainties related to planning and construction period including supply chain constraints, changing regulation, and their sensitivity related to safety standards and market conditions, and to public acceptance (WEC 2007b:5; Kiyar & Wittneben, 2012, ENEF, 2010). Thus in order to be able to refinance the high capital costs, new nuclear power plants need a guaranteed long operating life and a guaranteed high full-load operation.

Operations and maintenance costs of nuclear plants show a relative stability compared with competing technologies and in 2016 nuclear production costs in the European Union were around 1c€/kWh, which is much lower than for coal and gas plants (IEA-NEA, 2010, WNA 2017).

The range of generating costs depend on the age of the given nuclear plant, and the regulatory requirements concerning safety inspections and security measures, however operation and maintenance costs of nuclear power plants are seemed to be around 24% of total LCOE costs and fuel costs represent only 10-15% of total generation costs (IEA-NEA, 2010, WNA 2017). The IEA-NEA (2015) also estimates that decommissioning and disposal costs make up 10% and 15% of the capital costs of a plant.

2.2. Fixed and variable costs of nuclear power generation

Based on the different research studies (OECD-NEA 2012, Rothwell 2016; Srinivasan & Rethinaraj 2013, Gilbert et al. 2017) dealing with the economics of power generation technologies it can be concluded that nuclear power plants have relatively high fixed and relatively low variable costs. However, in the relevant literature, there is no consensus on the general composition of fixed and variable costs of nuclear power plants. In most of the cases, fixed costs of nuclear power plants cover the overnight costs, the costs of decommissioning and waste management, and the fixed parts of operation and maintenance costs, i.e. labor costs, planned and unplanned maintenance costs, and payments for O&M service agreements. Sometimes the category of fixed costs also includes other types of costs, such as property taxes, insurance fees, duties, and network & system charges (Fazekas 2006, Energinet 2012, GIF 2007). By contrast, variable costs usually include nuclear fuel costs, costs of consumption of auxiliary materials and spare parts, and the output related part of repair and maintenance costs, while in some cases, costs associated with the treatment and disposal of residuals are classified as fuel costs as well (Konstantin 2007).

Differences in the categorization of fixed and variable costs presented above have a significant impact on the rate of fixed and variable costs in total costs structure of nuclear power plants. Biermayer and Haas (2008) highlight that in the case of nuclear power plants there is a rule of thumb that fixed costs make up nearly two-thirds of electricity production costs. Similarly, WNA (2017) states that for nuclear power plants fixed costs represent nearly 75% of the total costs, while the rate of variable costs is estimated to be 25%. According to the calculations of Areva NP, construction costs of nuclear power plants represent nearly 70% of the total cost per kWh, while the share of fixed and variable O&M costs in total unit cost is estimated to be 20% and 10% respectively (CEC 2010). It is important to mention that this classification of Areva NP does not take into account the costs associated with decommissioning and waste management of nuclear power plants.

Research studies of nuclear power plants' economics (see e.g. Rothwell 2016; Srinivasan & Rethinaraj 2013, Gilbert et al. 2017) suggest that while fixed costs represent about 90-95% of the total O&M costs associated with electricity generation, variable costs are in the range of 5-10%. The share of fixed and variable unit costs in total unit costs depends also on the timeframe being followed. Despite of the fact that certain types of fuel and non-fuel O&M costs, such as water usage charges nuclear fuel costs, etc. are not completely fixed since in times of permanently shut-down these costs are not incurred and can be treated as variable costs in the long run, during plant operation they are relatively fixed due to their long-term procurement contracts with fixed prices (Thomas 2010:50). According to Thomas (2010:4904) if the wholesale price of electricity falls below the level needed to repay the high fixed costs of nuclear power plants for more than a short time, and there is no scope for nuclear plant owners to reduce their costs, losses of the plant will quickly accumulate.

The rate of fixed and variable unit costs indicates that companies operating nuclear power plants have a high degree of operating leverage which means that a small increase or decrease in the sales revenues can have a high magnifying effect over EBIT (Pintér & Bélyácz 2005, Bozsik et al. 2013). High degree of operating leverage represents higher operating risk and increases the overall risk of the firm (Pintér & Bélyácz 2005). After deregulation and liberalization processes, energy companies being active in the competitive market are exposed to price risk. In a liberalized electricity market price is influenced by a wide range of factors such as consumption patterns on the local and on the regional markets, the structure of the electricity market, the competition capacity of the main manufacturers, the use of renewable energy resources and its supporting mechanisms, and the state of interconnection capacities. Taking into account the cost structure of nuclear power companies and the dominance of fixed costs in total generation costs, declining electricity prices enhance price risks and have a significant impact on the operational performance of these firms.

Based on these statements in the following Chapter, sensitivity of the margin of safety of two Eastern-European nuclear power plants operating in Hungary and Romania (hereafter referred to as HNPP and RNPP respectively) will be analyzed as case studies in order to highlight the main impacts of wholesale price volatility on the operational performance of the nuclear power plants. In order to perform the prudent and comprehensive analysis of the margin of safety of these nuclear power plants, in the first step, main trends and tendencies of their national markets will be investigated. In the next step, wholesale and retail electricity prices of the national markets will be presented, and the impact of the reduction of wholesale prices of base-load products traded in the German Power Exchange will be analyzed by using correlation and linear regression approaches. In the next sub-chapter, technical and economic analysis of the NPPs will be performed. In the last chapter results of CVP-analysis and the main conclusions will be summarized.

For investigating the relationships among sales volume, expenses, revenue, and profit cost-volume-profit (CVP) analysis is used. While CVP analysis usually helps managers to define the effects of output volume on revenue, expenses and net income, it also supports the examination of the effects of price and cost changes on profit (Horngren et al. 2000, Illés, 2008).

Data used in this paper are taken from the publicly available financial statements of the companies exclusively, the wholesale prices are provided by EEX, PXE, HUPX, and Bloomberg databases, nuclear statistics are provided by EC (2017), EUROSTAT and PRIS databases of International Atomic Energy Agency. MS Excel was used for the calculations and for the creation of figures. All monetary values are expressed in EUR.

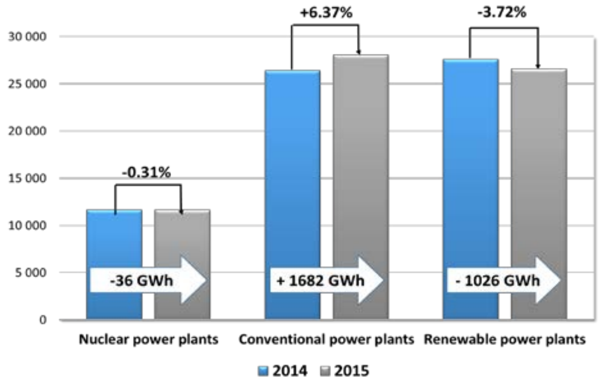
3 Costs and margin of safety of nuclear power plants

3.1 Main trends in the electricity markets of Hungary and Romania

According to the latest available data on electricity supply in Hungary cumulative installed electricity capacity was 8 579 MW in 2015, which decreased by 8.73% from 2012 due to the decommissioning of thermal power plants. At the same time, in Romania, total installed electricity capacity amounted to 23 830 MW in 2015 which represents a 9.48% growth from 2012. The country's electricity generation is based on fossil fuel thermal power plants (47.14%) with a significant support from hydro and wind power plants (28.24% and 13.13% respectively), followed by nuclear (5.92%) and solar power (5.56%) (EC, 2017).

Gross electricity production in Hungary has reduced by 12.39% to 30 342 TWh from 2012 and 2015, while in Romania a continuous growth (3.07%/year) can be observed in the same period, and in 2015 gross electricity production of the country reached 66 296 TWh. In 2015 national electricity production by fuel type illustrates (see Fig.1) that in Romania electricity production was primarily supported by conventional power plants (42.35%) while the share of nuclear energy and renewable-based power plants were 17.6% and 40.1% (EC, 2017).

Fig. 1: Electricity production by fuel type in Romania



Source: EC (2017)

Although, electricity production of nuclear and renewable power plants reduced by 0.31% and

3.72%, in 2015 conventional power plants produced 6.72% more electricity than in the previous year. Renewable energy generation was supported by the green certificate trading mechanism combined with a mandatory green certificates acquisition quota, introduced in 2015. Price of green certificates should be in the range of 27-55 EUR which limits were determined by ANRE, the Romanian Energy Regulatory Authority. Currently, the price of green certificates is relatively high exceeding 50 EUR (ANRE, 2017).

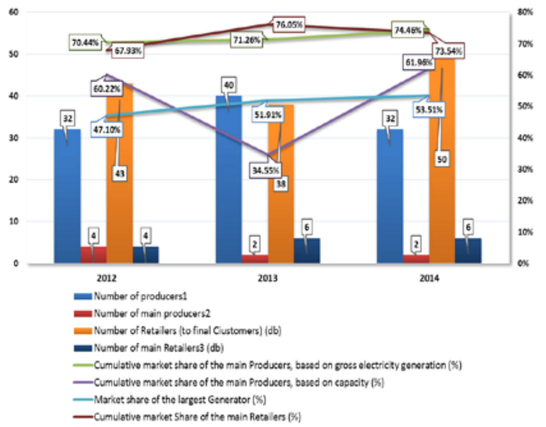
Regarding domestic electricity supply, both in terms of capacity and gross production in Hungary was dominated by nuclear power followed by lignite and hydrocarbon during the period under review. At the same time, the contribution of nuclear-based electricity generation to the total domestic production in Hungary increased from 45.59% in 2012 to 52.18% in 2015. The share of renewable energy based electricity generation grew by 21.35% from 2.65% in 2012 to 3.21 in 2015. Renewable based electricity production was supported with a feed-in tariff obligation system and guaranteed price. The share of large and small electricity generation units in total electricity generation in Hungary was not changed significantly in the period with a contribution rate of 80-20% (EC, 2017).

Domestic electricity demand in Hungary increased to 43 749 TWh from 38 920 TWh from 2012 to 2015, which indicates that the major part of Hungary's domestic demand was supplied from import. From 2012 to 2015, electricity import increased from 16 969 TWh to 19 936 TWh, although, after a remarkable drop in between 2012 and 2013, the volume of electricity export increased by 31.62%. From the neighbor countries, the main export partner was Croatia and the key import partners were Slovakia and Ukraine (MAVIR, 2016).

It is worth to note, that Romania has the highest average network losses in the region which is related to the high rate of illegal network connection making it difficult to define the real rate of domestic consumption. According to the EC (2017) database, net electricity demand in Romania exceeded 40 000 GWh between 2011 and 2015. Domestic electricity consumption increased by an average 1.1% per year, in sum from 2011 to 2015 net electricity demand grew by 9%. From 2014 to 2015 electricity consumption increased by around 6% mainly due to the 3.7% improvement of network losses. Unlike Hungary, Romania can also be seen as a net electricity exporter country since in 2015 net electricity export achieved 6 725 GWh. In 2016 the import-export balance was negative (-5.02 TWh) and the export decreased approximately by 18%, and the import by 5% compared to 2015 (ANRE, 2017). Main import countries were Hungary and Ukraine, while Bulgaria and Serbia were the most important electricity export markets of Romania.

In spite of the fact that market liberalization and deregulation in Hungary was completed in 2008, as Fig. 2 illustrates, electricity markets – production and retail - in Hungary continues to be characterized by high market concentration.

Fig.2: Main market indicators of Hungary between 2012 and 2014



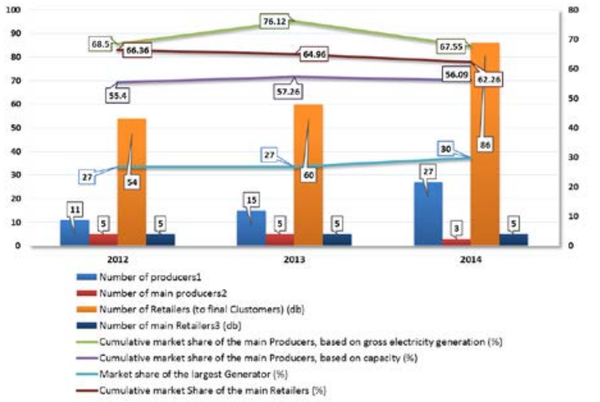
Source: CEER Country Report (2016)

In 2015 with its 53.51% share, the largest producer in the country was responsible for nearly 75% of the sales in the wholesale market and has a dominant share in the electricity purchases of universal service providers (79.66%) and retailers (27.6%). Currently, there are 109 certified suppliers and three main universal electricity suppliers operating in the country. Development and operation of the Hungarian transmission system are carried out by the Hungarian independent transmission operator company. In Hungary, the Hungarian Power Exchange Company (hereafter referred to as HUPX) is the licensed operator of the Hungarian power exchange offering three markets: an intraday market with 31, a day-ahead market with 60 and a physical futures market with 26 members.

The Romanian electricity market has been fully liberalized since 1 July 2007, however, in 2015 electricity was still supplied under two systems: the regulated market (44%), which covers households and part of the industrial sector, and the competitive market (56%), mainly represented by large industrial consumers (Tanasi, 2015:17).

As Fig. 3 shows, in 2014 the number of electricity producers was 27 from which only 3 companies had more than 5% of market share. Due to the fact that these main producers accounted for 67.55% of total gross electricity generation indicating a highly oligopolistic market. The market share of the largest producer grew by 5.58% from 2008. The electricity transmission system is operated, maintained and further developed by one natural monopoly owned by the state. The electricity distribution service is ensured by eight independent Distribution System Operators that divided the market geographically and have exclusive rights in specific regions of the country (Tanasi, 2015). The number of retailers grew significantly from 2008 to 2014 to 86 companies, only five of them had more than 5% of market share in 2014. Despite the 7.49% from 2018 in the cumulative market share of the main retailers, in 2014 the concentration of the retail market remained high (62.26%) (EC, 2017).

Fig.3: Main market indicators of Romania between 2012 and 2014



Source: EC (2017)

However, it is also worth to mention that currently about 190 independent suppliers and traders of electricity are active in the country (EC, 2017). Electricity generation plants must register on the electricity markets operated by the Romanian Electricity and Gas Market Operator (hereafter referred to as OPCOM). The most relevant trading platforms are the day-ahead market and the centralized market for bilateral contracts, which are both parts of the wholesale electricity market (Tnasi, 2015).

3.2 Development of wholesale and retail electricity prices of the relevant markets

A significant drop can be observed in the development of wholesale electricity prices in the period between 2012 and 2016 in both countries.

Average prices of base-load and peak-load electricity in HUPX reduced from 5.82 cents EUR/kWh and 7.48 cents EUR/kWh to 4.09 cents EUR/kWh and 5.04 cents EUR/kWh respectively from 2012 to 2015. A similar trend can be observed in the spot market of HUPX. Average prices of based load electricity reduced from 40.5 €/MWh to 31.22 €/MWh, average prices of peak load electricity decreased from 47.02 €/MWh to 35.86 €/MWh, while the average price of off-peak electricity moderated from 33.99 €/MWh to 26.59 €/MWh between 2014 and 2016.

The average minimal and maximal price on the centralised market of bilateral contracts in the Romanian market has decreased significantly from 2013 to 2015, since in 2014 the price of energy on the centralised market of bilateral contracts dropped in average with 17.8% compared to 2013 and between 2015 and 2014 the degree of decline of the energy selling price on the bilateral market achieved 4.5%, however in 2016 the average price for the contracts concluded on the OPCOM markets was nearly 0.37% higher than in 2015. While in 2014 the price on the day-ahead market was between the average value of 34.66 €/MWh for base load energy and 42.08 €/MWh for peak load energy, in 2015 the average price for base-load energy reduced to 41.66€/MWh and to 36.43 €/MWh for the energy delivered during peak hours. In 2016 the electricity price on the spot market had an average value of 33.65 €/MWh.

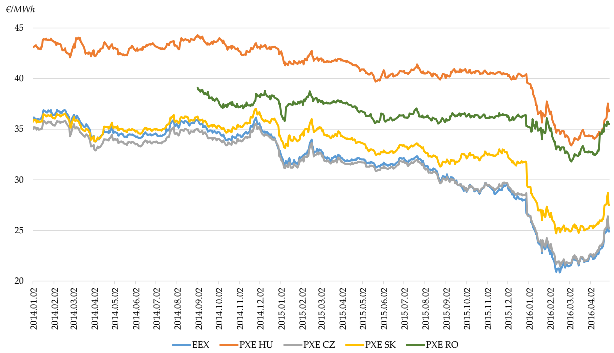
The development of wholesale electricity prices in the futures and spot markets of EEX, PXE, OTE, and OKTE – the regional power exchanges - similar tendencies can be identified. For example, in the Czech Power Exchange (PXE) market for futures average values of yearly (Y+1) base-load electricity reduced from 34.33 EUR/MWh to 23.15 EUR/MWh between 2014 and 2016. Development of the average prices of yearly (Y+1) peak-load electricity was similar, it decreased from 44.39 EZR/MWh to 39.2 MWh during the same period. The analogous trend can be observed in the development of national products' prices traded on PXE:

- The average price of Slovakian yearly base-load electricity (Y+1) decreased from 35.46 €/MWh to 26.09 €/MWh, while in the case of peak-load electricity, average price reduced to 33.99 EUR/MWh from 45.98 EUR/MWh, between 2014 and 2016.
- Average prices of Hungarian base-load products reduced by 6 EUR/MW to 35.43 EUR/MWh while average peak-load products' prices decreased by more than 10 EUR/MWh 43.53 €/MWh during the period under review.
- Romanian electricity futures can be traded on PXE markets since 1. September 2014. A

Significant drop can be observed in the average yearly prices of Romanian base-load and peak-load electricity as well: average prices of base-load electricity decreased from 37.9 €/MWh to 33.78 €/MWh, while average prices of Romanian peak-load products reduced around 3 EUR/MWh to 2016 from 44.13 €/MWh. However, it should be mentioned that wholesale prices of Romanian products did not follow the tendencies of the markets of Czech, Slovakian and Hungarian products, since in 2014 and 2015, yearly average prices of Romanian products were closer to the average prices of Slovakian products, while in 2016, Y+1 prices of Romanian products approached the average prices of Hungarian power products.

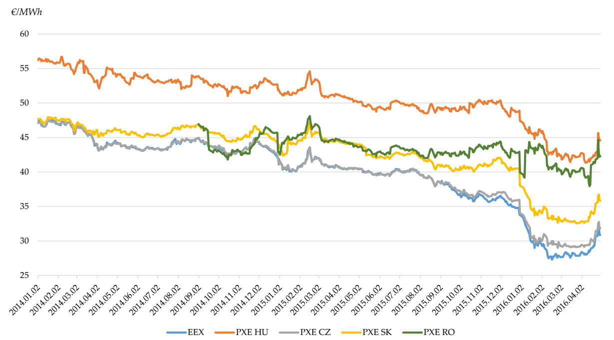
Fig. 4 and 5 confirm that the tendencies and trends of PXE's prices are similar to those of the German power exchange (EEX) market.

Fig. 4: Average yearly prices of base-load electricity products (Y+1) in EEX and PXE futures markets (2014-2016)



Source: own illustration, based on EEX and PXE database

Fig. 4: Average yearly prices of peak-load electricity products (Y+1) in EEX and PXE futures markets (2014-2016)



Source: own illustration, based on EEX and PXE database

Besides of these figures, results of correlation and linear regression analysis (see Fig. 5 and Fig. 6) of available data on base-load and peak-load power prices of national products confirm that in the period under review the prices of the electricity products traded on the Czech Power Exchange and the prices of electricity products traded on the German Power Exchange moved together, indicating that strong, positive correlation exists between them. Perfect positive correlation between German and Czech products can be observed which is represented by the value of +1.00. Results of the pairwise correlations of national electricity products traded on the power exchange of Prague also verify that Czech, Slovakian, Hungarian and Romanian power products are in strong relationships, and perfect positive correlation can be identified between the Hungarian and Romanian electricity products.

Fig.5: Correlation analysis of futures prices base-load electricity (Y+1) in EEX and PXE markets

	EEX	PXE HU	PXE CZ	PXE SK	PXE RO
EEX	1				
PXE HU	0.966	1			
PXE CZ	1	0.972	1		
PXE SK	0.980	0.980	0.987	1	
PXE RO	0.914	1	0.921	0.941	1

Source: own calculations

In spot markets, strong correlations between the average prices of national products of Central-Eastern European countries can be traced back to the market coupling mechanism (4M) of the Hungarian, Slovakian, Czech, and Romanian markets.

In order to further examine the relationship between the prices of products traded on the German and Czech power exchanges, four linear regression analysis was performed. Due to the fact that linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data, the explanatory variable was the average yearly prices of German base-load electricity and average yearly prices of national electricity products traded on PXE were defined as dependent variables.

Fig. 6: Regression analysis of futures prices of base-load electricity (Y+1) in EEX and PXE markets

Dependent variable: PXE CZ Independent variable: EEX		Dependent variable: PXE SK Independent variable: EEX	
r value	0.998371169	r value	0.97980905
R^2	0.996744991	R^2	0.960025774
Adjusted R^2	0.996739474	Adjusted R^2	0.959958021
Standard error	0.217788614	Standard error	0.637090251
Sample size	592	Sample size	592
Dependent variable: PXE HU Independent variable: EEX		**Dependent variable: PXE RO Independent variable: EEX**	
r value	0.965818546	r value	0.913887081
R^2	0.932805465	R^2	0.835189597
Adjusted R^2	0.932691576	Adjusted R^2	0.834797191
Standard error	0.685884114	Standard error	0.641460148
Sample size	592	Sample size	422

Source: own calculation

Fig. 6 shows that in the case of Czech and Slovakian products, values of adjusted R^2 exceed 0.95, indicating that 99.67% and 95.99% of the variation of Czech and Slovakian prices are explained by the independent variable, i.e. the average prices of German yearly based-load products. Regarding the prices of Hungarian products, the value of adjusted R^2 achieved 93.27%, which suggests a precise fit between the independent and the dependent variables. The lowest explanatory power of the linear regression model can be identified in the case of Romanian and German wholesale power prices, where the value of adjusted R^2 reached 83.48%.

All these results confirm that wholesale electricity prices of EEX have a dominant and determinant role in the regional electricity market since changes in the prices of EEX market almost immediately reflect in the prices of other national markets due to the interrelated nature of European national power systems.

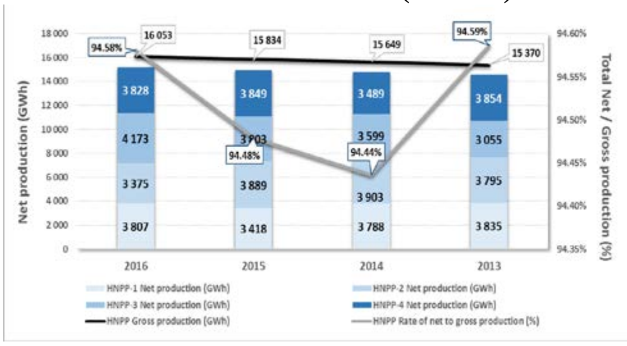
It is also worth to mention that due to the energy price reduction policy of the Hungarian government, retail market prices of universal services in Hungary also reduced significantly between 2011 and 2015 (Bartha, 2016). While in 2011 electricity retail prices of universal service providers were in the range of the 20.60-22.64 cents EUR/kWh, in 2015 average price of universal services reached only 4.91 cents EUR/kWh.

As it was mentioned before, in Romania regulated tariffs and non-regulated tariffs for final customers are still in practice. Between 2013 and 2016 regulated tariff reduced by 5.14% to 8.49 cents EUR/kWh. Based on the analysis of the development of the values of the average prices paid for the electricity consumed by the final customers, it can be stated that for non-household customers, average electricity price (without taxes) reduced from 8.24 cents EUR/kWh to 6.27 cents EUR kWh. However, for households, the average retail price of electricity increased from 9.05 cents EUR/kWh to 9.24 cents EUR/kWh between 2013 and 2016. From 2015 to 2016 a significant decrease can be observed in the average retail prices, since in 2016 households and non-households had to pay 0.175 cents and 0.882 cents EUR less for 1 kWh of electricity than in the previous year (ANRE, 2014, 2017).

3.3. Electricity production of NPPs

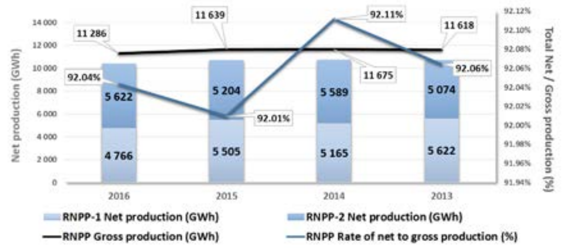
Currently, at the Hungarian site, four pressurized water type of nuclear reactors are in operation with a reference unit power of 470MW, 473MW, 473MW, and 473MW, respectively. In Romania, two Candu-type nuclear reactors are in operation both with a rated net capacity of 650 MW. Annual gross and net electricity generation of the units of HNPP and RNPP between 2013 and 2016 are illustrated in Fig. 7 and Fig. 8, respectively.

Fig. 7: Gross and net electricity generation of HNPP between 2013 and 2016 (in GWh)



Source: own edition, based on the Annual reports of the company

Fig. 8: Gross and net electricity generation of RNPP between 2013 and 2016 (in GWh)



Source: own edition, based on the Annual reports of the company

According to the figures, from 2013 to 2016 both gross and net electricity production of HNPP increased by 0.044% and the company reached its historical record production in 2016 covering the 51.3% of the gross domestic energy production of the country. On the contrary, at the same period, gross and net electricity production of RNPP decreased from 11 618 GWh to 11 286 GWh and 10 696 GWh to 10 388 GWh respectively. While the average value of the rate of the net to gross electricity production of HNPP was in the range of 94.44-94.59%, in the same period, with its 92.01-92.11% average values for the rate of the net to gross electricity production, RNPP reached lower efficiency.

The performance of the reactor units was influenced by their load and unit capability factors. Load factor is the ratio of the energy that the power unit has produced over a given period, to the energy it would have produced at its reference power capacity over that period (IAEA 2017:6). High load factor means greater total output indicating that fixed costs are spread over more kWh of output.

According to the data of IAEA (2017), the development of the load factors of reactor units of HNPP and RNPP can be summarized as follows:

- Between 2013 and 2015, the average load factor of HNPP increased from 87.88% to 91.48%. Regarding reactor units, it is worth highlighting that during the period under review the load factor of Unit 3 gradually increased and in 2016 it reached 100% due to the changeover to a 15-month fuel campaign
- During the same period, the average load factor of RNPP decreased by 2.90 percentage points caused by the significant decrease of the load factor of Unit 1 from 98.70% in 2013 to 83.50% in 2016, and the moderate increase (+9.40 percentage points) of the load factor of Unit-2. In 2016, the load factor of Unit-2 reached 98.50%.

Unit capability factor is the ratio of the energy that the unit was capable of generating over a given time period considering the only limitation under the plant management control, to the reference energy generation over the same time period (IAEA 2017:6). Based on the IAEA (2017) database it can be concluded, that

- Since nuclear power plants are usually at the high end of the range of capacity factors, average unit capability factor of HNPP in 2016 reached 90.90% representing a 3.60% increase from 2013 similarly to load factor values, the highest improvement of unit capability factor can be observed at Unit 3 and the unit capability factor of Unit 2 dropped sharply by 2016 after a continuous growth trend.
- Average unit capability factor of RNPP reduced by around 1.6% from 2013 to 2016. As in the case of load factor, unit capability factor of Unit 1 reduced by 13.47 percentage points in the period under review, while the unit capability factor Unit-2 was constantly improving from 2013 and achieved 99.66% in 2016.

Values of load and unit capability factors of the reactor units were determined by the planned and unplanned outages. Regarding the development of planned and non-planned outages of HNPP and RNPP, it can be stated that:

- From 2013 to 2016 planned outage of HNPP decreased from 145.88 days 116.17 days, and unplanned outage declined from 44.46 days to 9.33 days. due to a planned maintenance work caused by the failure of a mechanical equipment, the duration of planned outage of Unit 2 reached 60.96 days while in the case of Unit 3 the planned and unplanned outages equaled to zero in 2016 (IAEA 2017).
- While in 2013 the total planned outage of RNPP was only 24 days, in 2016 total planned outage reached 50.45 days. Duration of unplanned outage reduced from 14.85 days to 3.47 days in the period under review. In 2016, planned and unplanned outage of Unit-2 was 0 and the duration of unplanned outages of Unit 1 was caused by a breakdown of evacuation line of 400KV in the National Energetic System (IAEA 2017).

3.4 Electricity sales tendencies and financial performance of NPPs

Regarding electricity sales, it should be noted that HNPP and RNPP operate only on their national markets being the only nuclear power producers of their country. Due to their technological attributes, these NPPs sell mainly base-load electricity and is an active participant in the market for system services as well.

Table 2: Energy sales revenues and operating revenues (2013-2016) of HNPP

(in thousand EUR)	2016	2015	2014	2013
Sales revenues, out of which:	**561 078**	**554 977**	**560 079**	**624 947**
Electricity sales revenues	**554 348**	**548 471**	**553 578**	**618 203**
Thermal power sales revenues	*889*	*861*	*800*	*852*
Other sales revenues	*5 841*	*5 645*	*5 701*	*5 891*
Other operating revenues	**10 988**	**11 823**	**14 719**	**13 417**
Total operating revenues	**572 065**	**566 800**	**574 798**	**638 364**

Source: own edition, based on the Annual reports of the company

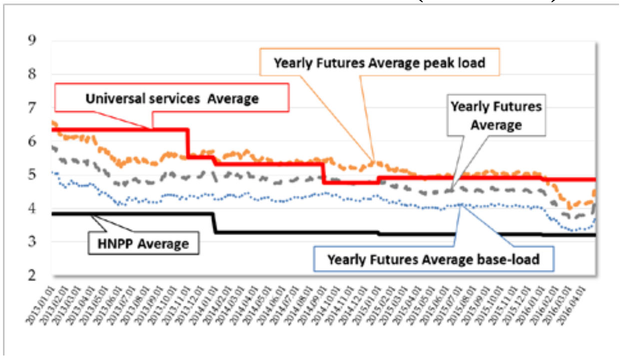
Table 3: Energy sales revenues and operating revenues (2013-2016) of RNPP

(in thousand EUR)	2016	2015	2014	2013
Electricity sales revenues	363 763	372 233	378 746	412 778
Energy sold on the regulated market	53 185	79 579	126 435	170 574
Competitive market	310 578	292 644	252 311	242 406
CMBC contracts	*216 716*	*258 637*	*220 516*	*220 285*
DAM contracts	*93 455*	*33 867*	*31 595*	*21 919*
Balancing market	*407*	*141*	*200*	*202*
Other operating revenues	7 323	7 646	4 417	28 631
Total operating revenues	377 577	397 104	408 275	465 947

Source: own edition, based on the Annual reports of the company

As Table 2 and 3 illustrate, during this period, net sales revenues of HNPP declined by nearly 1.45% annually. According to the sale-purchase contract, electricity produced and supplied by HNPP was offered and sold to its parent company. Although electricity sales increased in volume and the share of electricity sales revenues in total sales revenues remained in the range of 96.31%-96.90% during the period under review, electricity sales revenues reduced from 618.203 million EUR in 2013 to 554.348 million EUR in 2016, which means that the reduction of electricity sales revenues can be traced back to the decline of the average selling price. From 2013 to 2016, HNPP's average selling price of 1 kWh electricity declined by 10% to 3.65 cents EUR/kWh, which tendency reflects the reduction in the average prices of HUPX and universal services experienced in the period under review (see Fig.9).

Fig. 9: Changes in the average prices of HUPX, universal services and HNPP (2013-2016)



Source: own edition

Sales revenues and operating revenues of RNPP in the period between 2013 and 2016 decreased from 437 317 tEUR to 363 760 tEUR and from 465 947 tEUR to 377 577 tEUR respectively. Despite the fact that the share of electricity sales revenues in total sales revenues increased continuously (by annually) during the period under review, the company's electricity sales revenues reduced by 7.7% between 2014 and 2013, by 2.6% between 2014 and 2015, and by 2.3% between 2015 and 2016. The reduction in electricity sales revenues was based on the significant drop in the company's average electricity sales price (from 38.6 €/MWh in 2013 to 33.5 €/MWh in 2016) and the sales volumes could not compensate for the price effect since the amount of electricity produced and sold by the company declined either by 5.04%.

Based on the distribution of the company's electricity sales quantities and revenues, it can be stated, that the share of electricity sales on the regulated market in the company's electricity portfolio has been constantly decreasing. The regulated market represents a specific category of sales because the buyers, contracted quantities and selling price are annually established by ANRE. While in 2013 the electricity quantity sold by regulated contracts represented approximately 48.2% of the total electricity sales, the company's dependency on this market segment is declining, since in 2016 sales volumes in the regulated market barely reached the 13.91% of the total sales quantities.

The sales revenues on the regulated market in 2016 represented approximately 14.62% of the total electricity revenues of RNPP, while in 2015 21.4%, in 2014 33.4% and in 2013 41.32% of the total net electricity sales revenues derived from the regulated market. At the same time, RNPP's sales revenues from the competitive market have growth constantly. RNPP is active on the competitive market through sale-purchase contracts on the bilateral market, on the day-ahead and intraday spot market as well as on the balancing market. The bilateral contracts are concluded as a result of bidding organized on the OPCOM platforms, namely on CMBC, CMBC-LE, CMBC-CN, and CMUS. In 2013, RNPP concluded 84 selling contracts with 26 buyers and the number of contracts increased to 133 (27 buyers) by 2014, and to 174 (35 buyers) by 2015. Due to the convention concluded on June 16, 2008, with the market operator OPCOM, RNPP can sell energy on the Centralised Market for the Day-Ahead. It is worth to mention that between 2013 and 2016 energy quantity sold on this competitive market grew steadily from 730GWh to 3 001GWh in 2016. Sales revenues from the spot market were quadrupled during this period, while in 2016, 25% of the total electricity sales revenues derived from the spot market. In this segment, RNPP sells baseload energy. According to the convention concluded on 28th November 2005 with the Romanian system and transport operator, RNPP participates in the Romanian Balancing market. Although sales volumes in the market are negligible, from 2013 to 2015 electricity sales quantities increased by 76% to

44 GWh, in 2016 the company sold only 27 GWh in this segment. In sum, the average selling price of RNPP reduced from 3.86 EUR/MWh in 2013 to 3.50 EUR/MWh in 2016.

Table 3 and 4 summarize the main financial indicators associated with the electricity activities of the companies. In the case of HNPP, operating expenses grew by an average 0.053% annually from 2013 to 2016. Although, between 2013 and 2015 electricity related net profit reduced by an average 15.88% annually, in 2016 net profit increased again by 14.41%. This tendency is reflected in the development of ROA and ROE as well. Financial indicators of RNPP suggest that electricity sales revenues of RNPP decreased by 11.87%, and despite the reduction of the operating expenses of RPNN, net profit of RPNN reduced 16.42% annually from 2013 to 2016. It is worth to mention that in the ROE and ROA indicators of RPNN significant decline can be observed during the period under review (72.73% and 66.67% respectively).

Table 4: Financial indicators of electricity activities of HNPP (2013-2016)

	2016	2015	2014	2013
Electricity sales revenues (t EUR)	554 348	548 471	553 578	618 207
Operating expenses (t EUR)	502 196	490 774	494 487	489 854
Net profit (t EUR)	27 694	22 163	26 653	77 003
EBIT (t EUR)	58 881	64 203	65 592	135 093
DOL (% EBIT/% Electricity sales revenues)	-7.74	2.30	4.92	
ROE (%)	6.24%	5.30 %	6.35 %	17.64 %
ROA (%)	4.50%	3.61 %	4.26 %	11.00 %

Source: own calculations based on the Annual reports of the company

Table 5: Financial indicators of electricity activities of RNPP (2013-2016)

	2016	2015	2014	2013
Electricity sales revenues (t EUR)	363 763	372 233	378 746	412 778
Operating expenses (t EUR)	341 764	361 438	368 846	361 604
Net profit (t EUR)	25 270	33 217	29 945	95 811
EBIT (t EUR)	35 813	35 666	39 429	104 344
DOL (% EBIT/% Electricity sales revenues)	-0.18	5.55	7.55	
ROE (%)	1.50%	2.00%	1.80%	5.50%
ROA (%)	1.20%	1.60%	1.40%	3.60%

Source: own calculations based on the Annual reports of the company

The formula used for determining the Degree of Operating Leverage (DOL) was the follows:

$$DOL = \frac{Change\ in\ EBIT\ (\%)}{Change\ in\ Sales\ (\%)} \quad (1)$$

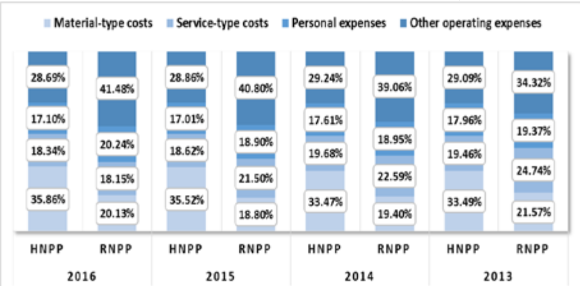
The annual values of the degree of operating leverage (DOL) indicate, between 2015 and 2016 1% increase in electricity sales revenues reduced the gross operating profit of HNPP by 7.74% and diminished the gross operating profit of RNPP by 0.18%. These results illustrate that both companies became riskier since their DOL had risen. It can be also concluded that from these two nuclear power plants, HNPP seems to be more sensitive to the changes in the selling price and volume, as a company with a higher DOL has more extreme fluctuations in operating income than a company with a lower DOL when a change in sales revenue occurs. Higher DOL also indicates that HNPP operated with higher fixed costs than RNPP did. In the next Chapter, detailed analysis of flat cost and the development of the breakeven output is performed.

3.5 Structure of flat cost of NPPs

In order to calculate the annual electricity-related flat cost of the given companies, the general calculation methodology defined by the relevant literature was followed, i.e. flat cost was measured by the operating expenses per one unit of electricity sold. Main advantages of this methodology lie in its flexibility and reliability and the transparency and traceability of the results.

Based on the publicly available annual statements of the companies, between 2013 and 2016 total flat cost of electricity-related activities of HNPP and RNPP decreased by around 2%. Fig. 10 illustrates the development of the structure of flat cost by main categories – material-type costs, personal expenses, service-type costs and other costs – of both companies.

Fig. 10: Share of cost categories in total flat cost between 2013 and 2016 (in %)



Source: own calculations based on the Annual reports of the companies

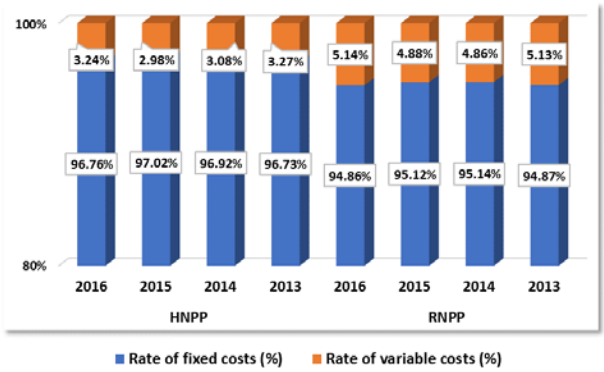
Main conclusions are the follows:

- The share of electricity-related material-type unit costs in total flat costs of HNPP increased by 0.07 percentage point. The value of material-type unit costs including the nuclear fuel costs, water usage fees, and other material related to cost per one unit of electricity sold, grew steadily from 2013, and in 2016 it reached 1.49 cents EUR/kWh due to the 15% increase of nuclear fuel costs. By contrast, the share of material-type unit costs in total flat costs of RNPP did not change significantly and stabilized around 20% in the given period. This result can be traced back to the 27% increase in nuclear fuel cost and to the relatively unchanged rate of water usage fee.

- Personal expenses per one unit of electricity sold by HNPP contain per unit costs of wages and salaries, social security and assimilated costs, and other staff benefits. The share of unit costs of personal expenses related to electricity activities in total flat cost decreased by 4.76% from 17.96% in 2013 to 17.10% in 2016. The rate of personal expenses of the total flat cost of RNPP was higher throughout the whole period and reached 20.24% in 2016.
- Main categories of service-type unit costs in the case of HNPP cover the unit costs associated with repair and maintenance, engineering and other services. Between 2013 and 2016 the company was able to reduce the value of service-type unit costs by 7.78% and the share of service-related unit cost in total flat cost of electricity activities also decreased 5.77% during the period under review. The share of service-type unit costs of RNPP - including repairs and maintenance and service-related expenses – had been successfully reduced by 6.59 percentage points from 2013 to 2016.
- The share of other operating expenses including other costs, provisions, waste and decommissioning charges, taxes, and fees, depreciation in total flat cost of electricity-related activities of HNPP reduced by 1.39 percentage points and the value of other operating expenses per one unit of electricity sold by HNPP still decreased by 2.13% during the period under review. The share of other operating expenses of total unit costs, which grew continuously from 2013, was around twice as high for RNPP than for HNPP reaching 41.48% in 2016.

As it was presented in Chapter 2, examination of the impacts of decreasing wholesale prices on flat costs necessitates the calculation of fixed and variable costs.

Fig. 11: Rate of fixed and variable costs in total flat cost (2013-2016)



Source: own calculations based on the Annual reports of the companies

Following the calculation methodology introduced in Chapter 2.2 variable unit costs of electricity production include only specific water usage fees, while specific nuclear fuel costs and all other sub-categories of material-type, service-type, personal-type and other operating expenses associated with net electricity production of the company are regarded as variable unit costs. Fig. 11 shows the development of electricity-related fixed and variable costs in total flat costs.

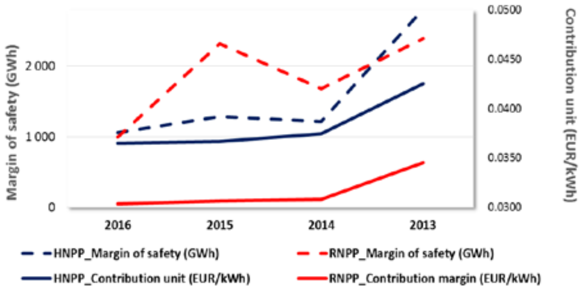
According to Fig. 11. the share of fixed and variable unit costs in total flat costs was in the range defined by the relevant literature sources presented in Chapter 2.2. The amount of total variable costs per unit of production was not changed significantly and reached 0.011 cents EUR/kWh for HNPP and 0.0164 cents EUR/kWh for RNPP, while the average share of variable costs per unit of production in total unit costs were 96.86% for HNPP and 95.0% for RNPP between 2013 and 2016.

Comparing the structures of the flat cost of these NPPs it can be stated that during the period under review, HNPP was operating with higher fixed costs than RNPP mainly due to the lower share of water usage fees and the higher share of nuclear fuel costs.

3.6 CVP analysis and the impact of wholesale price reduction

Considering the relatively high rates of fixed unit cost of both companies, it is worth to analyze the development of break-even output in the given period. The results of break-even analysis (see Fig. 8) illustrate that between 2013 and 2016 contribution per unit of HNPP decreased by 14.47% and the amount of break-even output grew by 20.46%, while in the case of RNPP, contribution per unit decreased by 12.11% and the amount of break-even output increased by 13.08%.

Fig. 12: Results of break-even analysis (2013-2016)



Source: own calculations based on the Annual reports of the companies

This means that due to the sharp decrease in the average selling price the margin of safety, i.e. the extent by which actual sales exceed the break-even sales of the companies, also reduced, indicating that while in 2013 a 19.35% reduction in electricity sales of HNPP and a 22.34% reduction in power sales of RNPP would result in just breaking even, this value of sales reduction decreased to 6.96% and 9.58% respectively in 2016. In sum, the margin of safety of HNPP reduced by 51.92% from 2013 to 2016, while the extent of the reduction of the margin of safety of RNPP was 58.33%, confirming the negative impacts of wholesale price reductions on the financial and operational performance of nuclear power plant being analyzed.

Thus, these changes in the margin of safety flag a warning to the management of the companies indicating the increasing vulnerability of current operation to price reductions despite their active efficiency improvements.

4 Conclusion

4.1. Main conclusions of the study

The main purpose of this research was to investigate the impact of the fluctuation of wholesale electricity price on the operational performance of nuclear power plants based on the case of two Eastern-European nuclear power plant.

Correlation and regression analysis of average wholesale prices of base-load electricity traded in the German and Czech Power Exchanges confirm the results and consequences of previous studies emphasizing that German wholesale prices had a dominant and determinant influence on the regional electricity market of other European power markets.

Results on the share of fixed and variable unit costs associated with electricity-related activities of the company being analyzed correspond to the findings in the relevant literature on nuclear power plants' economics.

Changes in the margin of safety of the company in recent years confirm that the observed reduction in the average selling price represents a considerable risk for the Hungarian and the Romanian power plants. Since the improvement of the load factor of the power plants is limited, to avoid the reduction of the margin of safety and to maintain a profitable operation, Companies should supervise their cost-structure and identify options for further cost reduction.

4.2. Limitations and further challenges

Examination of the impact of wholesale price reduction on operational performance of nuclear power plants by CVP analysis presented in this paper has serious limitations on the applicability of the results for decision making. Main limitations of the results relate to the assumptions of the composition of fixed and variable unit costs of nuclear power plants and to the assumptions of constant unit variable cost and constant unit prices for all levels of volume. Calculation methodology used in this paper is based exclusively on the guidelines of the relevant literature, which means that our results and findings do not reflect the official calculations of the companies. It is also important to note that the analysis presented in this paper is based on the publicly available annual reports of the companies which means that availability of detailed subdivision of electricity-related costs could rise further the level of sophistication of the results and conclusions.

Finally, two case studies do not guarantee generalization of results, for this a more detailed and comparative analysis of nuclear power plants' cost structure is needed.

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