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COMPETETIVENESS OF NUCLEAR POWER PLANT IN ELECTRICITY MARKETS OF THE BALTIC SEA REGION

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Aspects of continuing nuclear power plant operation in Lithuania are discussed in the paper. The major factors influencing the development of energy sector over a long-time period are analysed: growth of electricity demand, future scenarios of fuel price development, expected changes in electricity production cost in electricity markets of neighbouring countries, construction of new generating capacities using fossil fuels and nuclear energy, energy security. The method of the performed analysis is based on application of an econometric model including uncertainty analysis (for electricity demand forecasting) and the MESSAGE model (for optimization of the development of energy supply systems, including options of utilisation of energy resources, modernization of existing energy technologies and construction of new power plants, implementation of environment protection measures, etc). The most probable path of electricity demand growth, including its feasible fluctuation in a range of ±10%, within the period 2000–2025 is presented. It is shown in the paper that in the case of construction of comparatively small power plants, Lithuania will have enough capacities to meet the growing demand until 2014. Factors influencing competitiveness of new nuclear power are analyzed, principles of energy security are discussed.

Introduction

The term of the final decommissioning of Ignalina Nuclear Power Plant (NPP) is approaching, and the necessity to make a decision and real steps which would allow implementing the aspiration for continuity of the use of nuclear energy is becoming more and more urgent. To implement this

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aspiration, the construction of a new modern nuclear power plant, which complies with international nuclear safety objectives, is required. The decision about construction of a powerful power plant should be based on the analysis of its competitiveness in the internal electricity market as well as in electricity markets of Estonia, Latvia and other neighbouring countries.

Economical attractiveness of the construction of a new nuclear power plant and terms when this plant should appear in the market have been analysed in various studies. The detailed analysis was performed in recent studies [1–4]. Recommendations presented in these studies are different, especially in regard to terms of its commissioning. Uncertainty of conclusions is stipulated by different assumptions and diversity of factors influencing the appearance of significant changes in new technologies. Construction of a new nuclear power plant should be justified taking into consideration many factors: investment cost, discount rate, technical and economic indicators of alternative technologies, fuel prices, size of nuclear unit, regimes of power system operation, environmental requirements, country's international obligations, pace of electricity demand growth, decisions related to the problem of storage and final disposal of spent fuel and radioactive waste, policy and ways of modernisation of district heating sector, necessity to increase usage of renewable energy sources, etc.

In Vilnius, on October 25, 2006, the Steering Committee consisting of the managements of three Baltic energy companies approved the results of the feasibility study for construction of a new nuclear power plant in Lithuania. The main conclusion of the study which has examined current and expected economic, technological, financial as well as legal issues: it is feasible to build a new nuclear power plant in Lithuania. Nevertheless the analysis of factors which will influence its economical effectiveness in the electricity market is still urgent.

The aim of this paper is to set up some findings from the analysis of various factors influencing the necessity of construction of new capacities, competitiveness of the new nuclear power plant in the internal market, as well as possibilities to export electricity into markets of neighbouring countries. The paper presents the method of electricity demand forecasting and optimisation of various paths of future energy development, forecasts of electricity demand and balance of generating capacities, and discusses the main assumptions and results of the performed analysis.

Forecast of electricity demand and balance of capacities

Forecasts of energy demand and its structure by energy forms (electricity, district heat, oil products, natural gas, etc.) play a crucial role in decision-making on further development of energy systems. Analysis of real trends in energy consumption by applying mathematical modeling, mathematical statistics and economics is rather complicated for countries in transition. In many countries with sudden steep changes in energy consumption, description of its trends by the use of various time-series methods is not possible, and extrapolation of existing energy consumption trends cannot be applied. Taking into consideration this specific feature of countries with transition economies, forecasting is based on the application of simulation or econometric models. Their application requires determination of the most important factors influencing energy consumption in the base period and the mutual relationships between these factors and consumption over the long-term period.

Electricity demand forecasts are often based on the application of econometric models. Experience gained using this approach has shown that energy demand could be determined by changes in the main macroeconomic indicators, characteristics of the development of various branches of the national economy, and by changes in fuel and energy prices. In general, energy demand at any time could be described as a function of the preceding amount demanded, relative changes in income (or development of economic activity in a certain sector of economy) and in energy prices, and the behavioural reactions of consumers to changes in income and prices, as well as of additional energy saving [5]:

$$E_{ij}(t) = E_{ij}(t-1)[V_i(t)/V_i(t-1)]^{\alpha(ijl)} \times [P_{ij}(t)/P_{ij}(t-1)]^{\beta(ijl)} \times C_{ijl}. \qquad (1)$$

where

i – index of the sector of the national economy; $i = 1, \ldots, m$;
j – index of the energy form; $j = 1, \ldots, n$);
l – index of the end-use appliance, $l = 1, \ldots, L$;
t – time index, $t = 2005, 2010, 2015, 2020, \ldots$;
E_{ij} – demand of energy form j in the sector i;
V_i – economic activity of the sector i;
P_{ij} – price of energy form j in sector i;
$\alpha(ijl)$ – income elasticity in sector i for fuel j and end use l;
$\beta(ijl)$ – price elasticity in sector i for fuel j and end use l;
C_{ijl} – factor of additional energy saving in sector i for fuel j and end use l.

Future values of these parameters, in particular pace of country‘s economic development, could be defined with some uncertainty. Seeking to encompass the large range of possible long-term development paths, the scenario method is most often applied. As shown in [6], the solution of this problem could be based of application of the method of uncertainty analysis. This method could be applied also for sensitivity analysis of the most probable energy demand scenario [3].

Forecast of electricity demand was based on application of the model (1) assuming that five factors are the most important: GDP growth rate, income elasticity, pace of increase of electricity price, price elasticity, and additional electricity saving. Sensitivity of the forecast was established with different combinations of the main factors mentioned above. These combinations were prepared by application of the SUSA programming code [7]. Combinations generated by this code are formed using as input data values of the main parameters with their feasible minimal and maximal bounds and assumptions about their probability distribution within this range. It was assumed that: 1) GDP growth rates (range from 3 to 6%), annual increase of electricity prices (range from 2 to 3.5%) and annual reduction of electricity consumption due to saving by end-users (range from –1.5 to –0.5%) could be characterized by normal distribution; 2) income elasticity (range from 0.8 to 0.95) and price elasticity (range from –0.25 to –0.05) by even distribution.

When applying the method of uncertainty, minimal number of necessary calculations, which are required to determine minimal and maximal values of electricity demand forecast with desirable accuracy, is established by Wilk's formula [8]. Based on this criterion it was established that 93 combinations of selected factors are necessary seeking to determine minimal and maximal values of forecast and to define a range where 95% of all results of calculations are present with the probability of 0.95. These 93 different combinations of modelling parameters were formed by applying the SUSA programming tool and generated accidentally taking into account probability distribution of each parameter as well as its minimal and maximal values. Based on combinations of modelling parameters, electricity demand forecasts were established in Lithuania for the period 2000–2025. Taking into consideration uncertainty of economic development, it was assumed that the range of this uncertainty could be described by including into analysis all forecasts that are by 10% bigger and by 10% smaller than median of the basic scenario, which corresponds to probable average values of all analysed indicators.

Analysis of forecasts shows that the final electricity demand in branches of economy for the most probable (basic) scenario will increase on average by 3.7% per year, and in 2025, requirements of final consumers will be 2.5 times higher than in 2000.

The share of final electricity consumption in the Lithuanian balance of electricity supplied to network is increasing, but in 2005 it was equal to 75.1%, and the share of the energy sector needs and losses in network was still rather high – 24.9%. In countries of the EU-15, the share of final consumption in 2004 was 88.3%. It is natural to expect that in 20 years the share of electricity supplied to final consumers in Lithuania will increase to about 83%, and the share of the energy sector and losses in electricity network will decrease correspondingly. Therefore in the case of basic scenario, growth rates of the net electricity generation over the period 2000–2025 will be lower than design growth rates of final electricity demand and will amount on average to 3.2% per year.

This scenario was assumed to be the main scenario for the analysis of necessary changes in the structure of generating capacities in the Lithuanian power system. Based on the method presented above, minimal and maximal bounds of net electricity generation would be characterised in this case by average annual growth rates of 2.8 and 3.6%, respectively (Fig. 1).

Figure 2 presents the maximal load in the Lithuanian power system, which corresponds to the design net electricity production for the basic scenario, including its probable fluctuation within the uncertainty zone, and power balance (system reserve, necessary capacity of system services and a rest of capacities) in the case of rational development of combined power and heat generation power plants but without construction of new nuclear units at Ignalina NPP site and without usage of capacities at Kruonis HPSP.

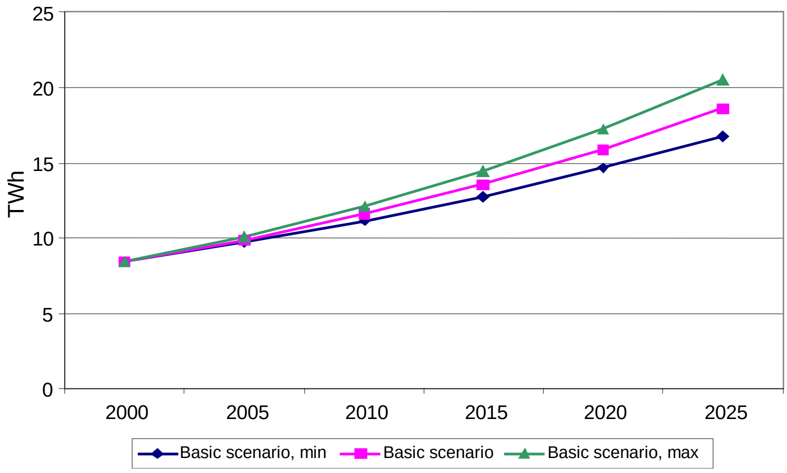

Fig. 1. Forecast of net electricity production in Lithuania.

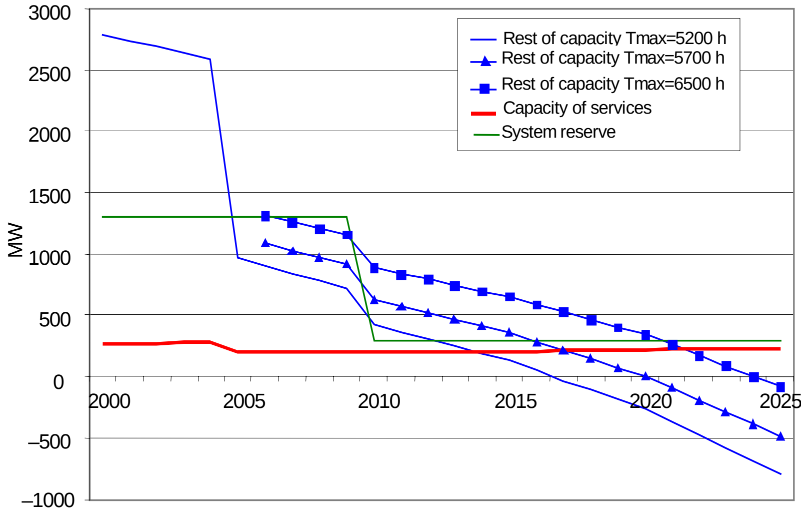

Fig. 2. Balance of capacities without construction of new nuclear units at Ignalina NPP site and different time of maximal load in the power system.

After decommissioning of both units at Ignalina NPP in 2009 and in the case of moderate development of thermal power plants, which could be based on construction of combined power and heat generation power plants at district heating utilities and industrial enterprises, the existing available capacities in the Lithuanian power system will be sufficient to meet the national demand for the period by the year 2014 even without the usage of capacities at Kruonis HPSP and without taking into account contribution from wind power plants. If some contribution of wind power plants is taken into account, the existing capacities will be sufficient until 2016. In the case when a deficit in power cannot be supplied by Kruonis HPSP in maximal load (peak) hours, new generating capacities (new combined cycle gas turbine condensing power plant or additional CHP plants) should be commissioned by 2015.

Requirement for commissioning of new generating capacities could be reduced by implementation of advanced technologies, by improvement of energy efficiency in all branches of economy and by further structural changes in manufacturing, construction and agriculture. Surplus of existing capacities would be also guaranteed for a longer period in the case of continuing operation of Unit 2 at Ignalina NPP. The tendency to spread electricity demand more evenly throughout the day and the year has arisen during the last five years. If this tendency remains and T_{max} reaches average in the EU-15 countries (about 6500 hours), a deficit of generating capacities will appear in 2021 even without construction of a new nuclear power plant. However, in the case of low T_{max} (about 5200 hours), the necessity to commission new power plants will appear in 2014.

Forecast of fuel prices

Electricity generation costs and development trends of power systems will depend on prices of oil, natural gas and other fuel. Changes in production of oil and natural gas and in electricity price in Russia as well as import possibilities will also greatly influence the Lithuanian economy and energy systems. The analysis of the data provided by the Energy Information Administration (EIA) of the US Department of Energy [9] shows that prices of oil and natural gas depend very much on political and economical processes in energy-exporting countries, terroristic acts and natural disasters. Oil price started to grow because of nationalization of oil mines in the Near East in 1973–1974. This growth was followed by a jump of oil price during Iran and Iraq war in 1977–1980 reaching the margin of 67 USD2004/bbl. After the agreement of new OPEC countries on oil quotas, oil price started to decrease and after 5–6 years reached the level of 20 USD2004/bbl. Later on, almost for two decades, the average oil price was 22 USD2004/bbl and exceeded the price before the first oil price jump by 10 USD/bbl. The events of September 11th in 2003 in USA and in 2004 in Iraq as well as hurricanes in Mexican bay have caused the fourth jump of oil price. Oil price reached the margin of 56 USD2004/bbl, grew further, and at the end of 2005 reached the level of 65 USD2004/bbl. In the summer of 2006, the oil spot price reached even 78 USD2004/bbl, but at the end of the year it decreased below 60 USD2004/bbl. The growth of oil price is partly linked with fast economic development of Asian countries (China, India and etc.). However, such a wide range of oil price variation is stipulated mostly by political and natural processes but not by economical reasons.

In the summer of 2006, EIA of the US has provided the forecast [9] that future development of oil prices could be described by three scenarios (Fig. 3). In the high price case, prices are designed to reach 100 USD2004/bbl in 2030. In the reference price case, prices would decrease to 47 USD2004/bbl in 2010, and later on would gradually grow, not exceeding 60 USD2004/bbl in 2030. In the low-price case, oil price would decrease to 34 USD2004/bbl in 2015 and later on would be stable.

Analysis of oil price forecasts shows that the probability of high price scenario is comparatively low. Taking into consideration the duration of previous jumps and falls of oil price and the average settled price, one can expect that in 4–5 years oil price could be close to the forecasted in the reference case, and over next two decades it could vary in the range from 40 to 50 USD/bbl.

Natural gas prices are also influenced by changes of oil prices. Future trends of gas prices could be based on the EIA of the US forecast (Fig. 4). Based on the experience of forecasting, usually the reference or the base case proves right or wrong in the real life. Therefore one can assume that natural gas price for electricity generation will decrease from 293 USD/1000 m^3 in 2005 to 183 USD/1000 m^3 in 2016, and later on will increase gradually reaching the margin of 226 USD/1000 m^3 in 2030.

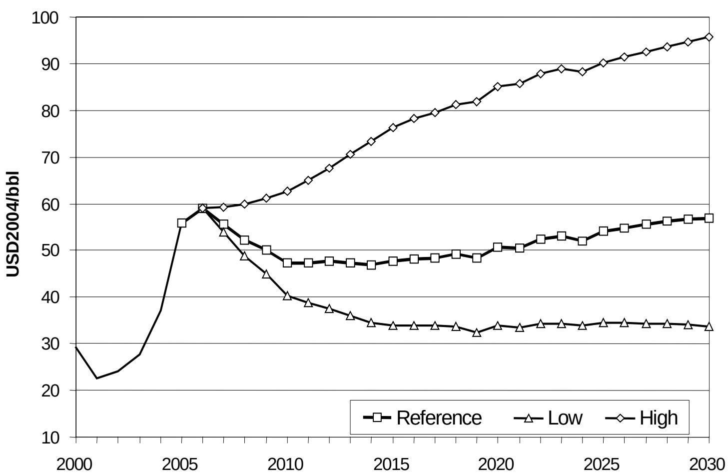

Fig. 3. Oil price forecast.

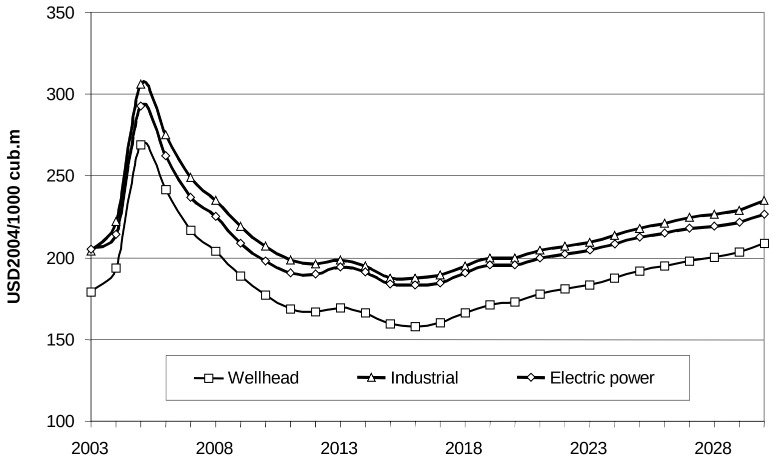

Fig. 4. Natural gas price forecast.

There is an opinion that with increasing prices of fossil fuels the only alternative is nuclear fuel. However, it should be noted that profitable reservoirs of uranium for nuclear reactors are limited and could substantially decrease even in the first half of this century. Therefore uranium price should increase with increasing prices of oil and other primary energy resources. The performed analysis shows [10] that uranium price is very sensitive to changes in oil price. The average UxU_3O_8 price in 1985–2003 was about 24 USD/kg, and increased to 106 USD/kg in 2006 (in November 2006, uranium spot price was 136 USD/kg), i.e. increased 4 times. Based on this analysis one can assume that uranium price will grow further. The provided uranium price constitutes up to about 30% of total costs of nuclear-fuel cycle. It should be taken into account that cost of enrichment (about 30% in the structure of total cost) and fuel conversion (about 20%) would also increase. Thus, nuclear fuel price can increase significantly.

Forecast of electricity prices

Electricity price in power systems is forecasted taking into consideration changes of fuel prices, the structure of electricity production and electricity production costs in a certain power plant. Due to lack of information about forecasted electricity prices c_E of the analyzed power system, these prices could be defined using the data about electricity generation costs at various types of generation sources [11], influence of fuel price changes on generation costs and data about expected changes in the electricity generation structure according to the fuel type:

$$c_E = \frac{\sum_k (W_{k,t} \cdot K_{k,t})}{\sum_k W_{k,t}}; \tag{2}$$

where:

$W_{k,t}$ – produced electricity using fuel k in the year t;

$K_{k,t}$ – electricity production cost at the power plants using fuel k in the year t;

k – fuel type; t – year.

Applying the principle of weighted average, electricity prices in a certain power system can be calculated basing on demand, fuel price scenario, electricity generation costs and structure by fuel type.

To solve the problem of the possibility of electricity export and import for Lithuania and other Baltic countries, it is important to construct interconnections necessary for integration into the markets of neighboring countries as well as to determine competitiveness new power plants based on the analysis of electricity prices in these markets.

In the energy strategy of Russia [12] electricity prices forecasted until 2020 (Fig. 5) are provided. Their growth is determined by increasing fuel prices in the internal Russian market.

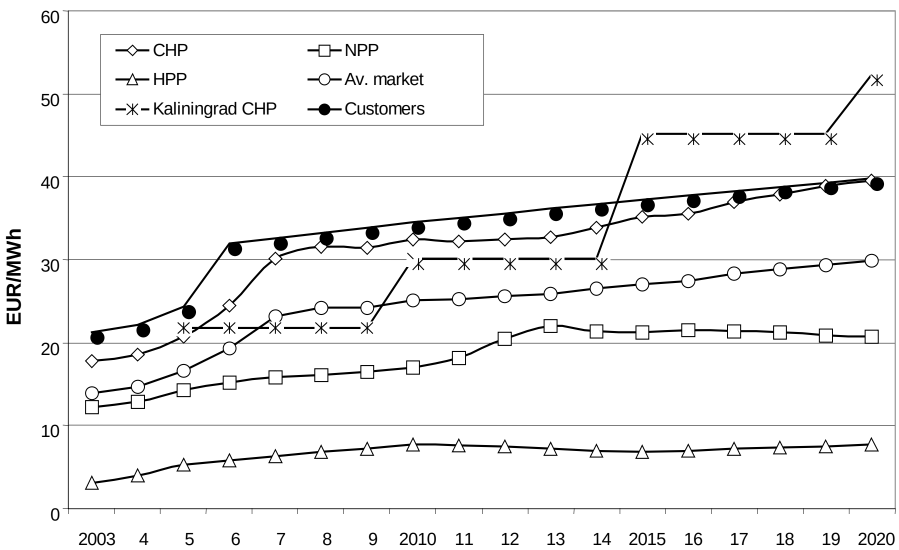

Fig. 5. Forecast of wholesale electricity prices in Russia.

The analysis of electricity production cost at various power plants in Russia shows that the average prices at wholesale market and for electricity supplied to the customers are growing. In 2010 these prices could reach 25 and 34.5 EUR/MWh, respectively and in 2020 – 30 and 40 EUR/MWh. Changes of electricity prices in the Kaliningrad region and in the rest of Russia are similar, and faster growth is stipulated by a more precise assessment of growing fuel prices because calculations were performed later. It is forecasted that in 2010 electricity price could reach 30 EUR/MWh, in 2015 – 45 EUR/MWh and in 2020 – 52 EUR/MWh.

The electricity market of Nordic countries is open for all electricity producers, suppliers and most of consumers. The main players in this market are Nordic countries, but there are also contracts with other countries, and construction of interconnections from Estonia to Finland and from Lithuania to Sweden will allow Baltic countries to take part in the NordPool electricity market.

Forecasts of electricity market price in Scandinavian countries (Fig. 6) are based on several sources [13–15].

Electricity prices foreseen in various studies related to electricity sector development over the period 2005–2025 are in the range 26–35 EUR/MWh. With fast expansion of gas-fired and wind power plants, electricity price could reach 41–43 EUR/MWh.

After construction of interconnections with Poland, Lithuania and other Baltic countries will have a possibility to trade electricity with neighboring countries in Central Europe. The dynamics of hourly and monthly electricity prices in Poland shows that there is no big price volatility in the Polish electricity market, because during winter and summer electricity is generated by the same type of power plants. Electricity price varies from 25 EUR/MWh during summer night time to 39 EUR/MWh during winter peak load period. Forecasted electricity market price of peak load [16] in Poland can vary from 30 EUR/MWh during weekends to 50 EUR/MWh over evenings of working days.

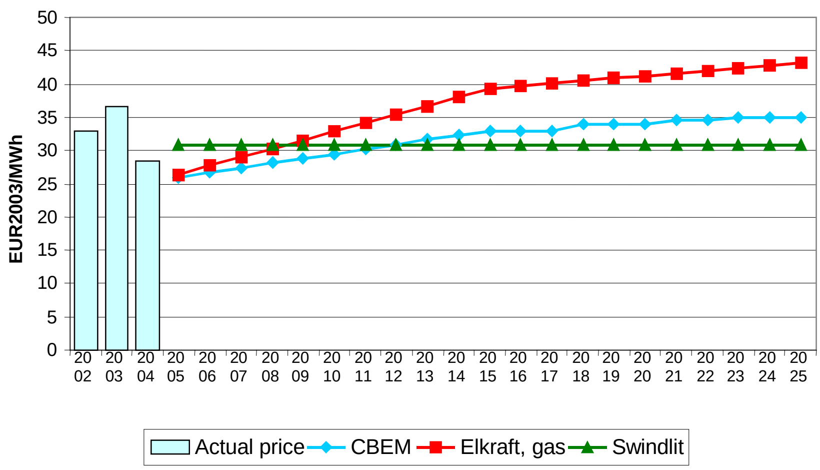

Fig. 6. Comparison of price forecasts in the Scandinavian electricity market.

Using the above method and data about electricity generation costs and structure of electricity generation by fuel type, average electricity price variation for Poland was calculated. Calculation results show that in the case of low fuel price scenario electricity price could reach 31 EUR/MWh. If coal price would rise 1.5 times (extra high fuel prices), electricity price will increase up to 36 EUR/MWh.

Scenarios of power sector development in Lithuania

Evaluation of economic effectiveness of new generating capacities in the electricity market is a complex problem. To determine correctly justified decisions, a mathematical model was developed and applied at the Lithuanian Energy Institute. This modelling tool is based on the MESSAGE model [17] and allows to perform comprehensive analysis of the energy sector development during a comparatively long-time period (about 30 years) taking into consideration options of utilisation of energy resources, construction of new energy generating capacities, modernization of existing technologies, implementation of environment protection measures, etc.

The energy demand forecast is used as the driving input for optimization of the energy supply systems using the MESSAGE model. Other inputs to the optimization process include:

- Description of the existing systems supplying oil and oil products, natural gas, other fuels, electricity and district heat.
- Techno-economic and environmental characteristics of all technologies and processes constituting the supply system now and the candidates for the future system.
- Consideration about availability of natural gas and electricity import.
- Environmental protection requirements established in the EU Directives.

Optimisation of the Lithuanian energy sector has shown that from the economical point of view three different development paths can be identified:

- A development when future electricity generation is based on fossil fuel.
- A development when the decommissioned Ignalina NPP is immediately replaced by the new NPP.
- A development when the decommissioned Ignalina NPP is replaced by the postponed commissioning of the new NPP.

In order to model diversification of energy supply in the study [2], a regional scenario of power sector development in the Baltic States with forced commissioning of new nuclear power plant in Lithuania was analyzed. In the reference fuel price case and low fuel price case, this scenario is more expensive than the regional one based on fossil fuel. Construction of a new nuclear plant would practically remove Lithuanian TPP from electricity generation (Fig. 7). This power plant would serve as reserve capacity only. The new nuclear plant would also reduce electricity output from new combined heat and power plants.

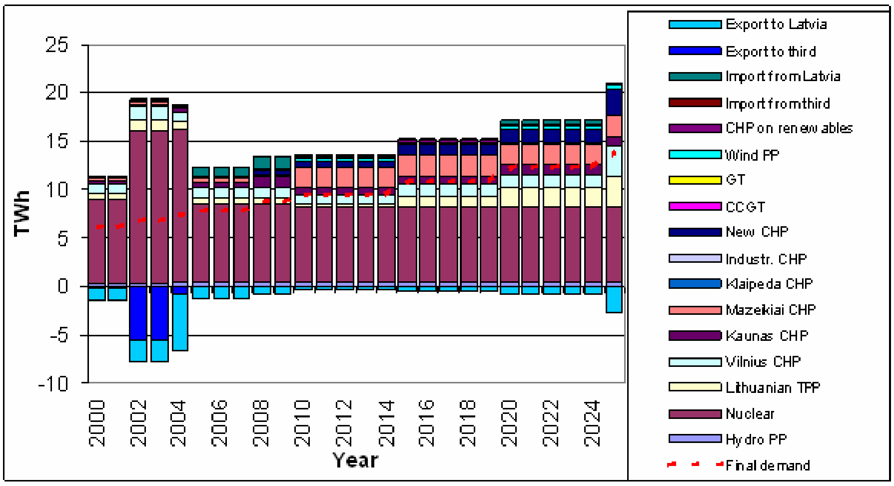

Fig. 7. Nuclear scenario of electricity generation in Lithuania.

Experience accumulated from safe and reliable operation of Ignalina NPP is a strong argument for continuing operation of the Unit 2 until commissioning of the new nuclear power plant. Scenario of continuing operation of the nuclear power plant in Lithuania would give significant benefit for the energy sectors and economies of all three Baltic States. However, this scenario could be implemented only with positive acceptance of this opportunity by all EU member states. Otherwise after the closure of Ignalina NPP in 2009, the major part of electricity will be generated by existing thermal power plants fired by natural gas, orimulsion and fuel oil.

In the fossil fuel scenario, beginning from 2010 the modernised Lithuanian Thermal Power Plant will become one of the most important generation sources in the Baltic region. Its reliable performance with a capacity of 1500 MW requires finishing the process of plant modernisation by this time. Supply of cheaper fuel (orimulsion or heavy fuel oil) should be guaranteed because Lithuanian TPP using expensive natural gas cannot generate electricity competitive in the market. Due to uncertainty of orimulsion import from Venezuela, increase of the efficiency of this power plant is urgent, and construction of a new combined-cycle gas-turbine unit with a capacity of 400 MW on the existing site is required by 2010.

Changes in the structure of generating capacities in Lithuania, Latvia and Estonia will influence corresponding changes of electricity prices. Until 2009, marginal electricity production cost are in a range of 17.1 21.8 EUR/MWh [3]. The lowest electricity prices are in Estonia because domestic fuel (oil shale) is cheaper, and the highest prices – in Lithuania because combined heat and power plants in condensing mode and Lithuanian TPP are fired by more expensive imported fuels – natural gas and heavy fuel oil. The level of electricity prices in Latvia is similar to that in Lithuania, because of similar CHP technologies and fuel prices (Fig. 8).

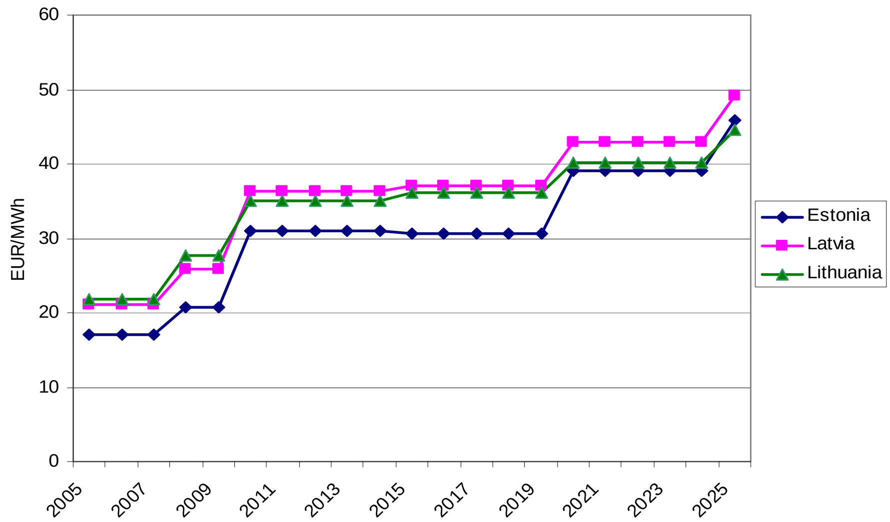

Fig. 8. Marginal electricity production prices.

Decommissioning of Ignalina NPP will stipulate increase of marginal electricity production cost up to 30.9-36.4 EUR/MWh, because new combined heat and power plants with a higher electricity cost will appear in the electricity market. This level of electricity prices will remain comparatively stable until 2020, and then it can reach the level of 39.2–42.9 EUR/MWh. This jump of production cost is linked with the necessity to construct a coal-fired condensing power plant in Latvia, new CHP units in Estonia and Lithuania.

Electricity production cost will increase more significantly in the case of high fuel prices. After the closure of Ignalina NPP, marginal cost will reach the level of 35–46 EUR/MWh, and at the end of the analysed period – 50 EUR/MWh. The largest increment of electricity price (up to 10 EUR/MWh) in the case of the fossil fuel scenario will occur in Lithuania and the smallest (up to 5 EUR/MWh) – in Estonia.

In the case of high fuel price, significant changes in the structure of generating capacities are stipulated by the appearance of a new nuclear power plant. Its economic effectiveness is very much dependent on various factors – investment cost, discount rate, utilization of capacity factor, cost of final disposal of spent nuclear fuel, changes in nuclear fuel price, unit size, etc. Nevertheless, construction of the new nuclear power plant has one important priority – nuclear fuel will significantly reduce utilization of natural gas for electricity production and will increase energy security in Lithuania and other Baltic States.

Construction of a new nuclear power plant in Lithuania as early as possible can be economically justified also in the case of high (20 EUR/t and more) taxes on CO_2 emissions. Thus, commissioning of the new nuclear power plant in Lithuania could be justified by the necessity to reduce the dependence on import of expensive fossil fuels and to reduce harmful impact of emissions.

Basing on the analysis preformed in [3], cost of electricity produced by this new nuclear power plant can vary in the range of 37–48 EUR/MWh. Similar cost of electricity generation (42 EUR/MWh) is presented in the feasibility study for construction of the new nuclear power plant in Lithuania, and it is based on the analysis performed by German experts. Such indicators will guarantee competitiveness of the new nuclear power plant in the electricity market of the Baltic States.

Analysis of changes in electricity market of the Baltic Sea region has shown that the lowest prices after 2015 are expected in Russia, Poland and possibly Ukraine (Fig. 9). Electricity prices in Scandinavian countries are dependent on future changes of generating capacities but could be similar as in the Baltic States. Thus, inauguration of an undersea cable Estonia-Finland and future construction of interconnection Lithuania-Sweden will create favourable conditions for export of electricity, in particular that generated by the new nuclear power plant, from the Baltic States to the Nordic countries. Therefore power systems of the Baltic States should be ready to compete with producers of neighbouring countries and to comply with requirements of reliability and quality of electricity supply.

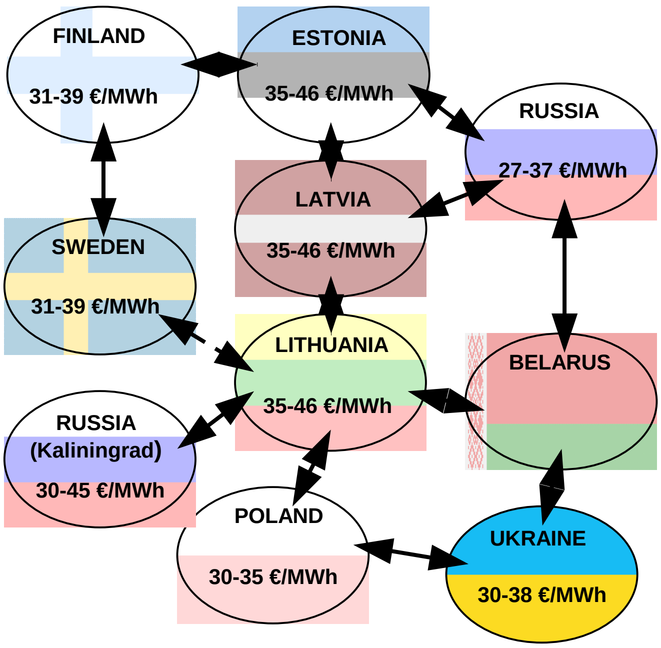

Fig. 9. Acceptable electricity market in Baltic region.

Security of energy systems

Experience of Western European countries shows that development of power systems as such is based on the principle of self-sufficiency seeking to meet requirements of not only long-term security (taking into consideration of primary energy supply), but also short-term security (resistance to major disturbances). Resistance of a power system to major disturbances or black-outs is of higher priority than electricity market. UCTE technical platform for electricity market is based on independent control areas and blocks. Thus, to ensure country's security, establishment of independently controlled power system (control area) is required. Control areas of several systems could form separate control block.

To ensure short-term security as the highest priority of power system development, it is necessary to increase the control potential of power systems in Baltic countries and to approach their reliability and independent operation set by UCTE requirements [18]:

- To ensure reliable electricity supply and high-quality energy for internal customers.
- To develop distributed generation.
- To unbundle generation and transmission.
- To implement automatic control of generation and participate in control of frequency and load flow.
- To ensure fast internal emergency power reserve, which could replace immediately the largest switched-off unit.
- To have the possibility to separate the subsystems of the power system for autonomous operation ensuring at least electricity supply for own customers.
- To restore the power system fast and effectively after a major black-out.

Decommissioning of Ignalina NPP at the end of 2009 is a forced measure for Lithuania, but at the same time it allows for power systems of Baltic countries to approach the requirements and conditions of UCTE seeking in the future to integrate into power systems of Western Europe for synchronous operation.

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