ENERGETIKA. 2006. Nr. 3. P. 102–109

A new nuclear power plant in Lithuania in the light of power system development in the Baltic region

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The paper deals with the application of the MESSAGE model for analysis of the energy sector development in three Baltic countries – Estonia, Latvia and Lithuania. The main issue for the Baltic countries is an efficient, secure and environmentally benign manner of power system development after the predetermined closure of the Ignalina NPP, the biggest power plant in the region. The paper focuses on the methodology of analysis, describes in detail the structure of the multi-regional model, presents options analysed for the future power system development, gives characteristics of the scenarios analyzed. The paper focuses on highlighting the circumstances under which a new nuclear power plant can be economically justified in the region.

Key words: power system, development, mathematical modelling, nuclear power plant, Baltic states, scenario

1. OBJECTIVES OF THE ANALYSES

The paper is based on the results of the study "Analyses of energy supply options and security of energy supply in the Baltic States" [1], prepared within the framework of TC project RER/0/019: "Sustainable Energy Options for Eastern Europe".

Meeting the future energy service requirements of the Baltic countries in an efficient, secure and environmentally benign manner lies at the heart of this analysis. Taking into account the availability of domestic energy reserves and resources, the vintage of existing energy infrastructures (including regional and inter-regional interconnections), future technology options and future energy trade links, the study aims to identify robust energy development strategies for the region. Robust encapsulates the potentially conflicting dimensions of energy security, economic efficiency and environmental protection. For example, supply security is likely to incur an 'insurance premium or environmental protection may well raise the costs of energy-service supplies.

Specifically, the study intends:

• To identify cost-optimal energy system development trajectories for each of the Baltic countries, each based on the maximum national energy self-sufficiency while complying with EU-wide obligations (e.g., environmental protection, renewables directive, etc.).

• To determine and quantify the benefits and costs of the regional integration of the energy systems of the three Baltic countries (sharing of infrastructures and generating capacities, access to resources and storage facilities and utilizing interconnections, etc.) for different levels of energy import dependence. Benefits and costs include the economics of energy supply, changes in emissions, differences in energy import dependence, etc.

• To formulate policy recommendations for actions targeted at the improvement of energy security in the Baltic region.

This paper mainly focuses on the modeling of power system development in Baltic countries and on the analysis of circumstances at which a new nuclear power plant (NPP) can be economically justified in the region.

2. METHODOLOGY

Analysis is based on the scenario approach. Scenarios are internally consistent images of how the future energy sector might unfold depending on the underlying assumptions about future socioeconomic, technological and environmental developments. Analysis was performed in four major steps.

First, a comprehensive review of each country's situation was carried out. This analysis has identified policies relevant to the future development of the national energy systems, including environmental protection measures, policies to promote the use of renewable energy, policies that targeted the improvement of energy efficiency and those that increased the independence of the energy supply, etc. This review served as a basis for developing informed scenario assumptions about the plausible future development paths. In parallel, projections of future electricity demand were derived from previous demand analyses.

Second, performance data and information on current and future technology and resource options were collected.

The third step was the harmonization of all the scenario characteristics used by the country teams. This harmonization dealt inclusively with scenarios assumptions, compliance with the EU-related obligations and all conceivable technical options for the future expansion of the energy systems in the Baltic countries.

The fourth step involved the modeling and optimization of the national energy systems as well as the integrated Baltic energy sector for each of the predefined scenarios.

3. STRUCTURE AND MAIN FEATURES OF THE MATHEMATICAL MODEL OF ENERGY SYSTEMS IN THE BALTIC COUNTRIES

The mathematical model prepared to analyse the development of the energy systems of a country represents the whole energy sector of that particular country, including all the processes from primary energy extraction or import to the supply of final energy to different end-use sectors along the energy conversion chain. The principal structure of the Lithuanian energy sector model is presented in Fig. 1. The structure of the Latvian and Estonian models is similar to the Lithuanian one.

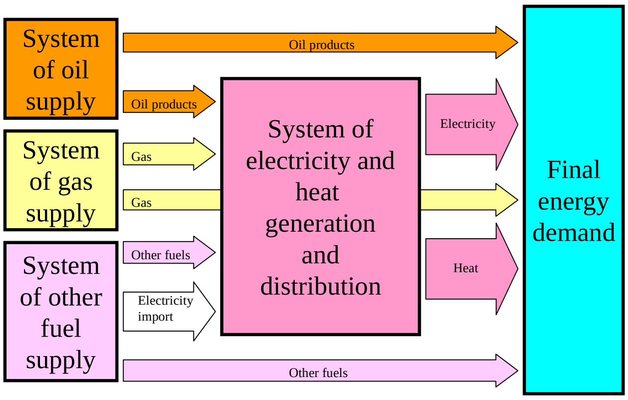

Fig. 1. The model of the Lithuanian energy sector

A few important factors have been taken into account during preparation of country models:

- Similar complexity of the energy sector models in all countries.
- Emphasis on the electricity and district heating systems.
- Highlighting of main components.
- Intentions of country experts to reflect specific issues.
- Availability of primary information.
- Possible future application of the model.

A similar complexity of the country models is necessary in order to avoid artificial differences for competitiveness of similar technologies in different countries. For example, the same technology will have a better economic competitiveness if less direct or indirect constrains would be applied, and vice versa. Different indirect constrains can be created if the same technological environment will be represented with a different resolution.

Electricity and district heating systems form the core of the country models, because major changes after the closure of the nuclear power plant are expected in the electricity sector. A district heating system is closely linked with the electricity sector due to a significant share of combined heat and power plants (CHP) in the structure of the generating capacities of the Baltic States. CHP capacities can be further extended in the future and may take considerable part in electricity and heat production.

Highlighting the main components was mainly linked to those that are important for energy supply reliability and security.

- Resources of oil shale in Estonia, their extraction and conversion into other energy forms, as well as two large power plants that run on local fuel.
- Cascade of hydro power plants (HPPS) in Latvia, underground gas storage and a large terminal for oil products.
- Two large terminals for oil and oil products in Lithuania, a refinery, a nuclear power plant (NPP) and the possibility of building a new one, a hydro pumped storage power plant (HPSPP) and the Lithuanian thermal power plant (TPP) which can use three types of fuel.

The intention of country experts to reflect specific issues such as various options for modernization of existing power plants, a bottleneck in the electricity transmission network (between the western and eastern parts of Latvia), national energy policy objectives, international obligations, and others were also taken into account during preparation of energy sector models in each country.

Availability of initial information and the possible application of the model also made some modeling corrections. Unavailable information required to use a lower resolution in modeling various processes, while the possible application of the model was linked with additional aspects (technologies) that temporary were left inactive or without necessary information.

The energy sector models of individual countries are linked to each other to give a multi-regional model, also taking into account existing and possible new links with third countries. Linking of models is done by modelling the exchange of various fuel and energy forms among the Baltic countries and between the Baltics and third countries. The principal structure of the multi-regional model is presented in Fig. 2, while fuel and energy exchanges that bind Baltic countries together and that bind the Baltic countries with third countries are shown in Fig. 3 and Fig. 4, respectively.

In order to have the possibility of running either the regional or the country energy models, all energy imports or exports have been organized directly to or from each country. Therefore a country's interaction with the main region (see Fig. 2) has been used only due to regional constrains such as the requirement to keep a certain amount of regional annual gas consumption in the storage, to fulfil regional obligations regarding the use of renewable energy resources instead of country obligations, etc.

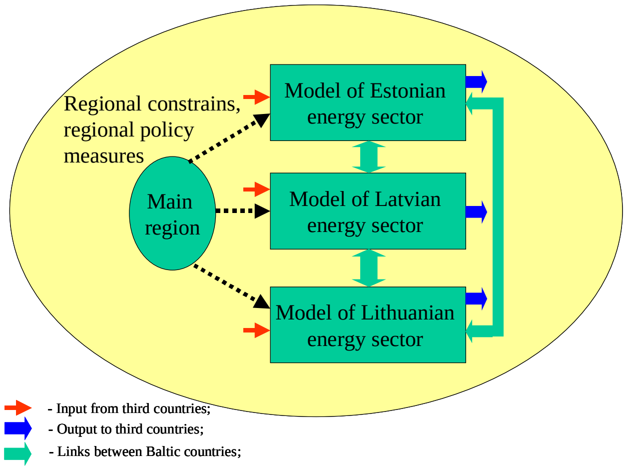

Fig. 2. The structure of the multi-regional model

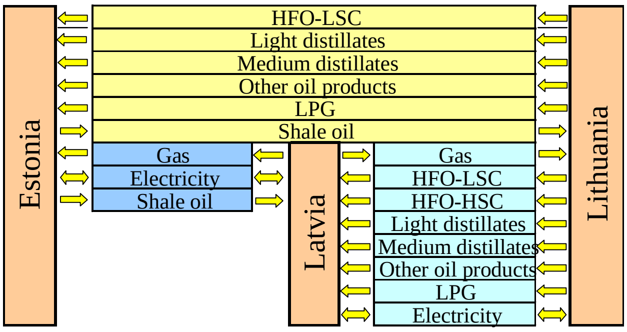

Fig. 3. Interlinks between Baltic countries in the multi-regional model. HFO-HSC – heavy fuel oil – high sulphur content; HFO-LSC – heavy fuel oil – low sulphur content, LPG – liquid petroleum gas. Arrows represent possible direction of the energy flow

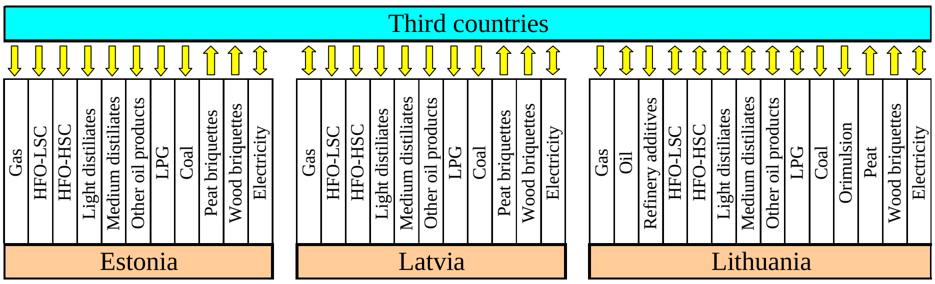

Fig. 4. Interlinks between the Baltic States and third countries in the multi-regional model. Abbreviations the same as for Fig. 3

Figures 3 and 4 show not only energy exchange among the countries, but also indicate the particularity of energy carriers in the energy model of the Baltic countries. A full energy chain for each shown energy carrier is presented in a country energy model taking into account the availability of resources, potential conversion capacities, transportation and distribution infrastructures, storages and other factors.

The electricity, heat and gas flows in the model of each country were represented with their daily and seasonal variations, while only annual energy flows were used for other energy carriers.

As it was already mentioned, the electricity and district heating sectors form the major part of the energy sector model in each Baltic country. The electricity sector has no regionalism in Estonia and Lithuania. This means that the electricity transmission network has no bottlenecks and the geographical location of power plant has no impact on its competitiveness. The high voltage 330–110 kV electricity transmission network in the model is represented by one technology. Both the middle voltage electricity network (35–10 kV), as well as the distribution network (0.4 kV) are also represented as covering the whole country without regionalisation. The main attempt in this modeling was oriented to correct representation of losses and electricity transmission and distribution cost for different groups of final consumers connected to different voltage levels.

The electricity sector in Latvia was divided into two parts, western and eastern, because there is a weak transmission line of the west-east orientation. An optional enhancement of throughput capacity between the western and eastern parts was represented, too. Therefore the economic competitiveness of power plants in the western and eastern parts was evaluated simultaneously with optional liquidation of technical constrains of throughput capacities in the lines connecting those parts of Latvia. In this relation, middle voltage and low voltage electricity networks in the model were represented separately for the eastern and western parts of Latvia.

The district heating sector was regionalized in each country in order to prevent heat transfer from one geographical location to another. Regionalisation was done taking into account the actual location of the main heat generators (mainly combined heat and power plants), country peculiarities and availability of reliable information. In this relation, the district heating sector in Estonia was represented by the Tallinn and Narva-Viru district heating regions, as well as the district heating region of the other part of Estonia. The district heating sector was similarly regionalized in Latvia. It consists of the Riga district heating region located on the right bank of the Daugava river, the district heating region of big cities and the district heating region of small cities. The district heating sector in Lithuania was divided into six regions: five regions represented the district heating systems of the Vilnius, Kaunas, Klaipėda, Mažeikiai and Elektrėnai cities having local CHPs, and one district heating region covering the remaining part of Lithuania. The above mentioned regionalisation means that individual heat demand together with existing and optional heat generation technologies are represented in the model separately for each region. Such representation of district heating sectors also allows reflecting the peculiarities of each region such as demand variation and applicability of technologies, including decentralized ones. Introduction of decentralized heat generators enables avoiding the district heat distribution network, however, requiring development of the gas distribution network in order to supply gas to each small heat generator. Decentralized heat supply is more economically attractive in areas of lower demand density. Therefore, an additional subdivision of district heating regions according to demand densities and conditions of existing distribution networks is necessary. Due to the lack of reliable information this option was modeled in a simplified manner.

A few options have been foreseen for technologies in each sector of the country energy model:

- Utilization of existing capacities until the end of their technical lifetime.
- Modernization of existing technologies in order to improve their performance or extend lifetime.
- Decommissioning of obsolete capacities.
- Construction of new capacities.
- Implementation of emission reduction measures.

Modernization options are individual for each technology, and this was taken into account during preparation of the country energy sector models. Different modernization options have been represented by a corresponding combination of technologies and by adequate technical and economical information. Power plant modernization options cover replacement of steam boilers, turbines, generators, control or metering devices or other elements, switching to other fuels, as well as refurbishment of power plants by installation of additional gas turbines before a steam boiler and conversion of a conventional plant into combined cycle gas turbine technology. The most serious modernization of boiler houses is their conversion to CHP.

Among the new power plants, the following options have been analyzed in the Baltic countries:

- New coal power plants.
- A new nuclear power plant.
- New gas turbine power plants.
- New gas turbine CHP.
- New CCGT CHP.
- New modular CHP.
- New middle and small hydro power plants.
- New CCGT power plants.
- New wind power plants.
- New CHP on renewable sources.

4. SCENARIOS ANALYZED

Seven main scenarios have been calculated in order to analyse technological changes, fuel and energy balances, security of energy supply, environmental consequences and other issues of the Baltic energy sector in the middle-term perspective.

Scenario 1N: *National self-sufficiency scenario (for each country).* This scenario incorporates:

- All the relevant existing requirements of laws and obligations included into the national models as constraints.
- Shutdown of the Ignalina NPP in accordance with the agreement with the EU.
- Most probable modernisation of Estonian oil shale power plants, Riga combined heat and power plants and the Lithuanian thermal power plant (modernization process is already in progress).
- National power plants cover 100% of the national electricity demand starting from 2010.
- Electricity imports and/or exports, when allowed, are in a base regime.
- Storage requirement for oil products to be ensured for 90 days (taken into account after optimisation calculations).

Scenario 1R: *Regional self-sufficiency scenario.* The first three and the last assumption for Scenario 1N are applied for regional calculations, but the remaining assumptions are changed as follows:

- Regional power plants supply 100% of the regional electricity demand for the whole planning period starting from 2010.
- Power exports and/or imports from/to the Baltic region to third countries are not allowed from 2010, but power exchanges among the Baltic countries are possible.
- Power import and/or exports from/to the region before 2010 are allowed in a base regime.

Scenario 2R: *Regional scenario with cross-boarder power exchanges — interlinks.* Assumptions for Scenario 1R are applied, plus:

- Existing cross-boarder power transmission infrastructure with Russia and the Commonwealth of Independent States is taken into account.
- New power interconnection with the Union for the Coordination of Transmission of Electricity (UCTE) (Link "LIT-POL" connecting Lithuania and Poland, 1000 MW) and NORDEL (Link "Estlink", connecting Estonia and Finland, 350 MW).
- Import and export of electricity to/from the region is allowed during the whole study period. Import and/or export is foreseen in the base regime.

Scenario 3R: *Regional scenario with enhanced security of gas supply – gas storage.* Assumptions for Scenario 1R are applied, plus:

- Gas storage within the region from 2010 is foreseen for 120 days.

Scenario 4R: *Regional scenario with gas supply limitation*. Assumptions for Scenario 1R are applied, plus:

- The upper limit on gas supply to the region — 25% of gas share in the fuel balance for power and heat production in the Baltic region from 2010 (its share of 20% is foreseen for scenario 4Ra and 30% for scenario 4Rc).

Scenario 5R: *Regional scenario with prolonged operation of the Ignalina NPP Unit 2*. Assumptions for Scenario 1R are applied, but:

• Operation of the Ignalina NPP Unit 2 is foreseen until 2017.

Scenario 6R: *Regional scenario with fuel diversification.* Assumptions for Scenario 1R are applied, plus:

• Imposed construction of a new nuclear unit at the Ignalina NPP and a coal-fired plant in Latvia after 2010. (Only a new nuclear unit at the Ignalina NPP is foreseen for scenario 6Ra and only a coal fired plant for scenario 6Rb).

Scenario 7R: *Regional scenario with different environmental taxes.* Assumptions for Scenario 1R are applied, plus:

• High environmental taxes for CO_2 emissions from 2008 (20 €/t), lower taxes (5 €/t) for scenario 7Ra and 10 €/t for scenario 7Rb).

The mentioned scenarios have been calculated for various conditions which are summarized in Table 1. The full set of the cases analysed is presented in Table 2.

Table 1. **Conditions for scenario calculations**

Aa	Unconstrained gas supply to Estonia and Lithuania, to Latvia only in summer. Low fuel prices. Unconstrained gas supply means that there is no any constraint on the quantity and regime of gas supply. Gas supply to Latvia is possible only during summer, however, even in this case there is no constraint on the quantity and supply regime in summer. The limiting factor is only throughput capacities of pipelines and storage capacity which in addition can be enlarged if necessary. Investment cost will be taken into account in this case.
Aaa	Unconstrained gas supply to Estonia and Lithuania, to Latvia only in summer. Gas and orimulsion are constrained for electricity and heat supply in scenarios 4R, 4Ra, 4Rc. This means that gas and orimulsion together should not exceed the shares in total fuel consumption that have been specified for gas alone (20%, 25%, 30%). Low fuel prices.
Aab	Unconstrained gas supply to Estonia and Lithuania, to Latvia only in summer. Low fuel prices. Forced construction of gas storage in Lithuania and extension in Latvia.
Ab	Unconstrained gas supply to Estonia and Lithuania, to Latvia only in summer. Extra high fuel prices.
Ac	Unconstrained gas supply to Estonia and Lithuania, to Latvia only in summer. High fuel prices.
Ea	Unconstrained gas supply to Estonia and Lithuania, to Latvia only in summer. Low fuel prices. 3% annual growth of electricity produced from renewable energy sources from 2010.
Ba	Gas supply to the region is constant during the year, but to Latvia it is available only in summer. This means that gas is supplied (when allowed) to Baltic countries only in the so-called base load regime. Low fuel prices.
Baa	Gas supply to Estonia and Lithuania is constant during the year, to Latvia only in summer. Gas and orimulsion are constrained for electricity and heat supply in scenarios 4R, 4Ra, 4Rc. Low fuel prices.
Bb	Gas supply to Estonia and Lithuania is constant during the year, to Latvia only in summer. Extra high fuel prices.
Ca	Gas supply to Estonia and Lithuania is constant during the year, to Latvia only in summer. Low fuel prices. Orimulsion is not available. Modernisation of the Lithuanian TPP is not obligatory. This means that the process of modernisation of the Lithuanian TPP is assumed as optional but not as factual.
Da	Gas supply to Estonia and Lithuania is constant during the year, to Latvia only in summer. Low fuel prices. Limited capacity of modernised oil shale power plants. This represents a case when the modernization program of Estonian oil shale power plants will be abridged.

Table 2. **The cases analysed**

Scenario	Conditions										
	Aa	Aaa	Aab	Ab	Ac	Ea	Ba	Baa	Bb	Ca	Da
1N	+										
1R	+			+	+	+	+		+	+	+
2R	+			+	+	+	+		+	+	+
3R	+		+	+	+	+					
4R	+	+		+	+	+	+	+	+	+	+
4Ra	+	+		+			+	+	+		
4Rb	+	+		+			+	+	+		
5R	+			+		+	+		+	+	+
6R	+			+	+	+	+		+	+	+
6Ra	+			+			+		+		
6Rb	+			+			+		+		
7R	+			+	+		+		+		
7Ra	+			+			+		+		
7Rb	+			+		+	+		+	+	+

Three cases of fuel price forecasts were applied in the analysis of energy supply development scenarios. It was assumed that oil price in the case of low fuel price scenario will increase from 5.68 €/GJ in 2005 to 5.78 €/GJ in 2025. The main jump of fuel prices in the case of high and extra high fuel price scenarios was foreseen in 2005. The price of crude oil in the case of high fuel price scenario jumped to 7.24 €/GJ in 2005 and gradually increased to 8.71 €/GJ in 2025. For the extra high fuel price scenario, a sharper price increase was foreseen in 2005 when it reached 8.51 €/GJ and increased to 8.75 €/GJ in 2025. Gas import prices also jumped in 2005 to 2.68 €/GJ, 3.41 €/GJ and 4.01 €/GJ respectively for the low, high and extra high fuel price scenarios and during the study period increased 1.5 times.

5. MAIN RESULTS

The most efficient path for power system development in the Baltic States from the economic and supply security points of view is continued operation of Unit 2 at the Ignalina NPP until the end of its technical lifetime in 2017 (Scenario 5R), an option that has in principle been foreclosed by the accession agreement with the European Union. The net economic benefit for the Baltic region would be in this case of the order €440 million.

The shutdown of Unit 1 in 2004 has had a less severe impact on the region, since part of the Ignalina NPP output as an excess to Baltic demands has been sold outside the Baltic region and exported to Belarus, Kaliningrad and Russia. By contrast, the impact of the shutdown of Unit 2 can be fully mitigated only by increased imports of natural gas, orimulsion and electricity or construction of a new NPP, since most alternative Baltic sources of primary energy, including renewables, will be either already utilized by 2010 or faster introduction may be hampered by cost consideration or long lead times, or both.

Prolonged operation of the Ignalina NPP beyond the agreed closure date at the end of 2009 is warranted on purely economic terms and takes the operating license issued by the national regulator VATESI at face value. In all scenarios with the closure of Unit 2 at the Ignalina NPP by 2009, the region turns from a net electricity exporting to an importing region. While import volumes vary across the scenarios, electricity imports correspond to approximately half of the Ignalina NPP Unit 2 generation before closure.

Analysis of calculation results shows that *in the case of low fuel prices* the fossil fuel development path is the most economically attractive option for Lithuania and the whole Baltic region. In this case the Lithuanian TPP, together with existing and new CHP plants, provide the greatest part of electricity generation in Lithuania. A new nuclear power plant appears only at the end of the period (Table 3). The only exception is Scenario 7R(Aa), in which high CO_2 taxes remove the Lithuanian TPP from electricity generation and create more favourable conditions for a new nuclear power plant. Scenarios 6R and 6Ra represent the forced commissioning of a new nuclear power plant. Therefore they do not represent correctly the economic competitiveness of the new nuclear power plant. Moderate CO_2 taxes, constraints on the gas share in the fuel balance, as well as the requirement to keep gas in storage for 120 days bring forward the commissioning date of the new nuclear power plant, but its operation does not start earlier than in 2025. Constraints on the common limited share of gas and orimulsion in total fuel balance (conditions Aaa) require the earlier commissioning of a new nuclear power plant — in 2020 or even in 2015. The limited availability of orimulsion significantly reduces the attractiveness of the modernised Lithuanian TPP and makes new CCGTs at existing sites a more economically attractive option. The smaller capacities of modernised oil shale power plants in Estonia increase the utilisation of the Lithuanian TPP and favour the construction of new CCGTs at existing sites in Lithuania. A constant all-year gas supply slightly reduces

Table 3. **Appearance of new nuclear power plants in the Lithuanian power system**

Scenario	Aa					Aaa					Aab					Ab				
	After2010	After2015	After2020	After2025	After2035	After2010	After2015	After2020	After2025	After2035	After2010	After2015	After2020	After2025	After2035	After2010	After2015	After2020	After2025	After2035
1N																				
1R					NPP											NPP	NPP	NPP	NPP	NPP
2R																		NPP	NPP	NPP
3R				NPP	NPP									NPP	NPP					
4R				NPP	NPP		NPP	NPP	NPP	NPP						NPP	NPP	NPP	NPP	NPP
4Ra				NPP	NPP		NPP	NPP	NPP	NPP						NPP	NPP	NPP	NPP	NPP
4Rc					NPP			NPP	NPP	NPP						NPP	NPP	NPP	NPP	NPP
5R	NPP	NPP			NPP											NPP	NPP	NPP	NPP	NPP
6R	NPP	NPP	NPP	NPP	NPP											NPP	NPP	NPP	NPP	NPP
6Ra	NPP	NPP	NPP	NPP	NPP											NPP	NPP	NPP	NPP	NPP
6Rb					NPP											NPP	NPP	NPP	NPP	NPP
7Ra					NPP											NPP	NPP	NPP	NPP	NPP
7Rb				NPP	NPP											NPP	NPP	NPP	NPP	NPP
7R	NPP	NPP	NPP	NPP	NPP											NPP	NPP	NPP	NPP	NPP

Scenario	Ac					Ea					Ba					Baa				
	After2010	After2015	After2020	After2025	After2035	After2010	After2015	After2020	After2025	After2035	After2010	After2015	After2020	After2025	After2035	After2010	After2015	After2020	After2025	After2035
1N																				
1R			NPP	NPP	NPP					NPP										
2R				NPP	NPP															
3R			NPP	NPP	NPP				NPP	NPP										
4R	NPP	NPP	NPP	NPP	NPP		NPP	NPP	NPP	NPP				X	X		X	NPP	NPP	NPP
4Ra														NPP	NPP		X	NPP	NPP	NPP
4Rc																		X	NPP	NPP
5R						NPP	NPP			NPP	NPP	NPP								
6R	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP					
6Ra											NPP	NPP	NPP	NPP	NPP					
6Rb																				
7Ra														X	X					
7Rb													X	X	NPP					
7R	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP					

Scenario	Bb					Ca					Da				
	After2010	After2015	After2020	After2025	After2035	After2010	After2015	After2020	After2025	After2035	After2010	After2015	After2020	After2025	After2035
1N															
1R	X	X	NPP	NPP	NPP				X	X					
2R	NPP	NPP	NPP	NPP	NPP										
3R															
4R	X	X	NPP	NPP	NPP			X	NPP	NPP		NPP	NPP	NPP	NPP
4Ra	NPP	NPP	NPP	NPP	NPP										
4Rc	NPP	NPP	NPP	NPP	NPP										
5R	NPP	NPP	NPP	NPP	NPP	NPP	NPP		X	X					
6R	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
6Ra	NPP	NPP	NPP	NPP	NPP										
6Rb		X	NPP	NPP	NPP										
7Ra	NPP	NPP	NPP	NPP	NPP										
7Rb	NPP	NPP	NPP	NPP	NPP										
7R	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP

NPP X Low utilisation

the attractiveness of a new nuclear power plant, because it as a base-load plant would require gas-fired plants to cover the peak demand; however, the regime of gas supply does not match with its demand at the power plants covering the peak demand.

In the case of *extra high fuel prices*, the new nuclear power plant becomes a more economically attractive option compared to the Lithuanian TPP and construction of new CCGTs, even at existing sites. In these circumstances, immediate commissioning of a new nuclear power plant after closure of the second unit of the Ignalina NPP is economically justified nearly in all analysed circumstances. Exception can be only the case when gas to the Baltic region is supplied in the base regime (constantly during the year) or import of cheep electricity from Russia is available. Commissioning of a new nuclear power plant in these circumstances can be postponed until 2020. Construction of new CCGT in Lithuania in the case of extra high fuel prices is not economically justified. The Lithuanian TPP operates practically as a reserve capacity only. However, if gas supply to the Baltic region is constant during the year, the Lithuanian TPP, running on other types of fuel, is used to cover the peak or semi-peak demand.

In the case of *high fuel prices*, commissioning of a new nuclear power plant in Lithuania can be economically justified in 2020.

It should be noted that many factors describing the future situation in the energy sector are uncertain. There is a risk that a company may take a decision assuming one set of conditions, but in reality another set of conditions may occur. In such a case energy companies will incur financial losses. In this study it was calculated that an early (in 2010) commissioning of a new nuclear power plant in the case of low fuel prices would increase the total discounted cost of the energy sector operation and development in the Baltic region by € 407 million. However, if fuel prices will be extra high but the new nuclear power plant will be not built in Lithuania, the total discounted cost of the energy sector operation and development in the Baltic region would be higher by € 120 million. These losses are lower than those previously mentioned. This is to illustrate that construction of investment-intensive objects such as a new nuclear power plant in an uncertain situation can be more risky than switching to other less investment-intensive options.

Analysis shows that Latvia relies mostly on new CHP plants, electricity imports and the Liepaja coal power plant. New CHP plants and electricity imports are common in all the cases analysed, while the Liepaja power plant is a less uncertain source. Its attractiveness decreases with increasing taxes on CO_2, and at 20 €/t it hardly comes on-line during the period under analysis.

The most economically attractive year to commission the Liepaja power plant is 2020. This is so in most of the cases analysed. Earlier commissioning is reasonable with extra high fuel prices when the consumption of gas and orimulsion is constrained, or with a lower modernised capacity of the Estonian oil shale power plants. New hydropower plants are attractive in Latvia, a country with the self-sufficiency scenario, with growing requirements for green electricity, extra high fuel prices or high taxes for CO_2. The most likely date to commission these power plants is 2025, but in high emission tax scenarios the commissioning date can move to 2015.

Construction of new CHP plants is an attractive option in Estonia too, and it happens in all the cases analysed. Any lack of capacity (if the capacity of the modernised oil shale power plants is not sufficient) in Estonia is covered by new CCGTs and electricity imports.

6. CONCLUSIONS

1. In the case of low fuel prices, commissioning of a new nuclear power plant in Lithuania is economically justified in 2025 or later.

2. Strong constraints (25% or less) on the *common share* of natural gas and orimulsion in total fuel consumption for electricity and heat production would put forward the commissioning date of a new nuclear power plant. The economically justified date can be 2015–2020. Constraints on the share of gas only have practically no impact on the commissioning date of the new nuclear power plant, because orimulsion can substitute gas for electricity generation.

3. In the case of *high* or *extra high fuel prices but with gas supply in the base-load regime,* the commissioning of a new nuclear power plant in Lithuania is economically justified in about 2020.

4. Immediate or as early as possible commissioning of a new nuclear power plant in Lithuania can be economically justified in the case of *high (20 €/t or more) taxes on* CO_2 and in the case of *extra high fuel prices without limitations on gas supply regime*.

5. The available cheep electricity import from Russia will postpone the commissioning date of a new nuclear power plant by 5 years approximately.

Received 14 September 2006
Accepted 28 September 2006

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NAUJA ATOMINĖ ELEKTRINĖ LIETUVOJE BALTIJOS ŠALIŲ ELEKTROS ENERGETIKOS SISTEMŲ PLĖTROS POŽIŪRIU

Santrauka

Straipsnyje nagrinėjami klausimai, susiję su MESSAGE matematinio modelio taikymu energetikos sektoriaus raidos analizei trijose Baltijos valstybėse – Estijoje, Latvijoje ir Lietuvoje. Pagrindinė problema po pirmalaikio Ignalinos AE, stambiausios elektrinės regione, uždarymo yra efektyvus, saugus ir supančią aplinką tausojantis energijos tiekimas. Straipsnyje pateikiama tyrimo metodika, detaliai aprašoma daugiasektorinio matematinio modelio struktūra, analizuojamos galimos energetikos sektoriaus raidos alternatyvos, apibūdinami nagrinėti scenarijai. Apžvelgiant tyrimų rezultatus siekiama išryškinti aplinkybes, kurioms esant naujos AE statyba regione yra ekonomiškai patraukli.

Raktažodžiai: elektros energetikos sistema, plėtra, matematinis modeliavimas, atominė elektrinė, Baltijos šalys, scenarijai

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НОВАЯ АТОМНАЯ ЭЛЕКТРОСТАНЦИЯ В ЛИТВЕ В ПЕРСПЕКТИВЕ РАЗВИТИЯ ЭЛЕКТРОЭНЕРГЕТИЧЕСКОЙ СИСТЕМЫ В БАЛТИЙСКОМ РЕГИОНЕ

Резюме

В статье рассматриваются вопросы, связанные с применением математической модели MESSAGE для анализа развития энергосистемы в трех странах Балтии – Эстонии, Латвии и Литве. Основной проблемой в балтийских странах после преднамеренного закрытия Игналинской АЭС, наиболее мощной станции в регионе, является эффективное, надежное и для окружающей среды приемлемое энергоснабжение. В статье рассматривается методика анализа, детально представляется структура многорегиональной математической модели, анализируются возможные альтернативы развития энергосистемы, приводится характеристика рассматриваемых сценариев. При представлении результатов анализа на первый план выдвигается характеристика обстоятельств, в которых строительство новой АЭС в Литве является экономически оправданным мероприятием.

Ключевые слова: электроэнергетическая система, развитие, математическое моделирование, ядерная электростанция, балтийские страны, сценарии