Lithuanian energy security level assessment based on indicator dependence

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Abstract

The issue of energy security has recently become especially important and problematic in Lithuania. Prior to 2010, Lithuania was a nuclear power energy producing country; however the second (last) unit of Ignalina NPP was shutdown at the end of 2009. Thus, Lithuania is currently producing a part of electricity in its thermal power plants and imports the other part. The purpose of this paper is to assess Lithuanian energy security level taking into account various security indicators whose values were obtained from statistical data. The indicator system was divided into three blocks, namely: technical, economical and socio-political, and each block was divided into groups. As the indicators, ascribed to groups, are interdependent, these dependencies were invoked for the calculation of the weights of indicators. Additionally, the paper presents pilot calculations and the comparison of energy security level in Lithuania in 2007, 2010 and after the construction of a liquefied natural gas terminal.
Keywords: energy security level assessment, security level, energy security indicators.

1 Introduction

Although security of energy supply has always been an important field of national security in every country, it has recently gained even greater attention in the policy agenda due to the growing dependence of industrialized economies on energy consumption and the increased frequency of supply disruption. Energy security is a vast field encompassing such areas as mining, conversion and transportation of primary energy sources, generation, distribution and supply of

energy, functioning of infrastructure, secure life of society in technical, economical, socio-political and environmental point of view.

Energy security conception is understood differently. Finding rational solutions for energy supply security requires evaluating the costs and probability of supply disruptions, comparing the present energy supply security level with the forecasts, and deciding on the strategies for its improvement. Different approaches are used for assessing security of energy supply, such as: geopolitical assessment of scenarios, economical modelling, expert risk assessment, analysis of primary energy sources, and development of security indicators system. The presented research is based on the latter indicator system for the assessment of Lithuanian energy security level.

Sufficient security level of energy supply is vital to the functioning of modern economy since reliable supply is necessary to ensure industrial activities and satisfy population needs. A secure energy supply is one of the priorities of country's energy sectors because it is an integral part of national security [1]. This issue receives a great deal of attention from the European Union (EU); and is a strategic task of the North Atlantic Treaty Organization (NATO) aiming at a stable power supply to the members of the alliance.

The issue of energy security has recently become especially important and problematic in Lithuania. Prior to 2010, Lithuania was a nuclear power energy producing country; however, the second (last) unit of Ignalina NPP was shutdown in the end of 2009. Thus, Lithuania is currently producing a part of electricity in its thermal power plants and imports the other part. According to the Lithuanian National Energy (Energy Independence) Strategy [2], a liquefied natural gas (LNG) terminal and electricity network between Lithuania and Sweden NORDBALT are going to be built.

The main reasons for the construction of the LNG terminal are the following [2]:

- diversification of natural gas supply and freedom from the dependence on a single gas supplier;
- provision of emergency natural gas reserve enabling Lithuania to cover the emergency demand for gas independently;
- gaining access to gas spot markets;
- fulfilling the preconditions for forming a primary gas market in Lithuania.

Thus, the purpose of the paper is to assess Lithuanian energy security level taking into account various security indicators. The calculations and comparison of energy security level in Lithuania in 2007, in 2010 and after the construction of LNG terminal are also presented.

2 Energy security indicators system

The calculation of energy security level is based on security indicators which are special indexes giving numerical values to important issues in energy sector security.

Material for indicator systems can be received from statistical data, economical modelling, reliability modelling, experts' judgment and social/political assessment, which is often based on hypothetical probabilities received from lognormal distribution.

Assessing the energy security level of Lithuania, at first the indicator blocks and groups were constructed and their weights determined. Three indicator blocks were created, namely: technical block, economic block and socio-political block. Equal weights were attributed to all three blocks: $s_i = 1/3$, $i = 1,2,3$, assuming that they have equal impact on the level of energy security.

The groups of technical and economic blocks were distinguished according to the kind of fuel used in the energy system. Electricity and heat were additionally included in the composition of these indicator blocks as separate groups of indicators. The technical and economic blocks, the weights of indicator groups s_{ij}, $i=1, 2$, $j=1,\dots, m$ were identified considering each kind of fuel and electricity, as well as heat consumption and calculating the part of relative oil fuel equivalents by thousands of tons in the total energy consumption. These group weights change depending on the modelling scenario, whereas the weights of groups in the socio-political block were determined as equal: $s_{31} = s_{32} = 1/2$.

When presenting the indicators of the technical block, technical and reliability parameters were taken into account, emphasizing the capacity of fuel supply to Lithuania, annual or maximum demands, energy generators lifetime and accumulated fuel reserves.

During the formation of the indicators of economic block, most attention was paid to the annual demand for appropriate kind of fuel, a possibility to choose fuel suppliers freely, diversification of fuel suppliers, and the ratio of the imported fuel to annual consumption.

The socio-political block was divided into two groups: geopolitical indicators and socio-political indicators. The aim of the former is to assess the internationally announced political ratings of the state and foreign countries, the energy resources are supplied from and through by transit. The values of these indicators were taken from International Country Risk Guide [3]. The aim of socio-political indicators is to present the implementation of the assumed international obligations and EU directives in Lithuania and to describe the ratio of energy consumption to gross domestic product.

All indicators are presented in table 1 by giving their titles and factual values X_{ijk}, where $i=1,\dots,$ n – block number, $j=1,\dots,$ m – group number in the block, $k=1,\dots,$ l – indicator number in the group, threshold pre-critical ($pctv_{ijk}$) and critical (ctv_{ijk}) state values [4]. All indicators are given in percents.

3   The algorithm of energy security level assessment

In order to identify the level of security of energy supply, the state of each indicator should be evaluated. For this purpose, the pre-critical $pctv_{ijk}$ and critical ctv_{ijk} threshold values of indicators were determined by experts. Then, the indicators were evaluated in points using an evaluation scale constructed for each indicator (see fig. 1). The direction of indicator values was considered in creation

Table 1:   Indicators for energy security level assessment.

Nr	Name of the indicator	Notation	Direction of the scale
1	Technical block		
1.1	Electricity		
1.1.1	Ratio of total installed power capacity of generators and connection lines to the maximal power demand	X_{111}	max
1.1.2	Ratio of the largest power plant capacity to installed capacity of the whole system	X_{112}	min
1.1.3	The maximal share of a single installed technology in the total production of electricity	X_{113}	min
1.1.4	Average ratio of power units lifetime to their technical resource time	X_{114}	max
1.2	Gas		
1.2.1	Ratio of total pipeline capacity to maximum gas consumption	X_{121}	max
1.2.2	Ratio of gas amount possible to store in gas storages to average annual consumption	X_{122}	max
1.2.3	Ratio of the capacity of the largest gas supply facility to average consumption	X_{123}	min
1.3	Oil		
1.3.1	Ratio of the potential supply of oil and its products to Lithuania to average annual consumption	X_{131}	max
1.3.2	Ratio of the capacity of the largest supplier of oil and its products to annual consumption	X_{132}	min
1.3.3	Ratio of accumulated reserves of oil products to average annual consumption	X_{133}	max
1.4	Coal		
1.4.1	Ratio of technical capacities of coal supply to annual demand	X_{141}	max
1.4.2	Ratio of the capacity of the largest coal supplier to annual coal demand	X_{142}	min
1.4.3	Ratio of accumulated reserve of coal to average annual consumption	X_{143}	max
1.5	Nuclear fuel		
1.5.1	Ratio of technical possibilities of nuclear fuel supply to annual demand	X_{151}	max
1.5.2	Ratio of spent nuclear fuel repository capacity to demand (during assessment)	X_{152}	max
1.5.3	Ratio of the accumulated nuclear fuel amount to average annual consumption	X_{153}	max
1.6	Biofuel		
1.6.1	Ratio of biofuel production capacity to annual consumption of biofuel	X_{161}	max

Table 1:   Continued.

Nr	Name of the indicator	Notation	Direction of the scale
1.6.2	Ratio of the capacity of the largest biofuel producer to annual consumption	X_{162}	min
1.6.3	Ratio of accumulated biofuel reserve to average annual consumption	X_{163}	max
1.7	Heat		
1.7.1	Ratio of the total capacity of the installed heat generators to maximal heat demand	X_{171}	max
1.7.2	Average ratio of average lifetime of power units to their technical resource time	X_{172}	max
1.7.3	Share of one heat production technology generating the most heat in the total heat production	X_{173}	min
1.7.4	Percentage of heat production which can be replaced by another kind of fuel without changing technology	X_{174}	max
2	Economical block		
2.1	Electricity		
2.1.1	Ratio of the amount of electricity purchased in the electricity market to average annual demand for electricity	X_{211}	max
2.1.2	Ratio of the average cost of electricity (for 1 kWh) to open market average cost	X_{212}	min
2.1.3	Share of consumers who freely choose the producer of electricity	X_{213}	max
2.1.4	Ratio of the amount of electricity which can be produced using fuel imported only from one supplier to the total amount of produced electricity	X_{214}	min
2.1.5	Ratio of the imported electricity amount to annual demand for electricity	X_{215}	min
2.2	Gas		
2.2.1	Ratio of gas amount purchased in the gas market to average annual gas consumption	X_{221}	max
2.2.2	Ratio of the purchase cost of 1000 cubic meters of gas to the average gas purchase cost in the EU countries	X_{222}	min
2.2.3	Possibility for consumers to choose a gas supplier	X_{223}	max
2.2.4	Share of the imported gas from a single possible supplier	X_{224}	min
2.2.5	Ratio of the amount of imported gas to average annual gas consumption	X_{225}	min
2.3	Oil		
2.3.1	Ratio of the amount of oil purchased in the oil market to average annual oil consumption	X_{231}	max
2.3.2	Possibility for consumers to choose an oil supplier	X_{232}	max

Table 1:   Continued.

Nr	Name of the indicator	Notation	Direction of the scale
2.3.3	Ratio of the purchase cost of oil and its products to average open market cost	X_{233}	min
2.3.4	Share of the imported oil from a single supplier	X_{234}	min
2.3.5	Ratio of the amount of imported oil to average annual oil consumption	X_{235}	min
2.4	Coal		
2.4.1	Ratio of the amount of coal purchased on coal market to average annual consumption	X_{241}	max
2.4.2	Possibility for consumers to choose a coal supplier	X_{242}	max
2.4.3	Ratio of the purchase cost of coal to average open market cost	X_{243}	min
2.4.4	Share of the imported coal from a single possible supplier	X_{244}	min
2.4.5	Ratio of the amount of imported coal to average annual coal consumption	X_{245}	min
2.5	Nuclear fuel		
2.5.1	Ratio of the amount of nuclear fuel purchased in the nuclear fuel market to average annual nuclear fuel consumption	X_{251}	max
2.5.2	Possibility for electricity producers to choose a nuclear fuel supplier	X_{252}	max
2.5.3	Ratio of the purchase cost of nuclear fuel to average open market cost	X_{253}	min
2.5.4	Share of the imported nuclear fuel from a single possible supplier	X_{254}	min
2.5.5	Ratio of the imported nuclear fuel to average annual nuclear fuel consumption	X_{255}	min
2.6	Biofuel		
2.6.1	Ratio of the amount of biofuel purchased in the biofuel market to average annual biofuel consumption	X_{261}	max
2.6.2	Possibility for consumers to choose a biofuel supplier	X_{262}	max
2.6.3	Ratio of biofuel production cost to average open market cost	X_{263}	min
2.6.4	Share of the imported biofuel from a single possible supplier	X_{264}	min
2.6.5	Ratio of the amount of the imported biofuel to the total amount of consumed biofuel	X_{265}	min
2.7	Heat		
2.7.1	Possibility for consumers to choose a heat supplier	X_{271}	max
2.7.2	Ratio of the production cost of heat (for 1 kWh) to average production cost in the EU countries	X_{272}	min

Table 1:   Continued.

Nr	Name of the indicator	Notation	Direction of the scale
2.7.3	Ratio of the amount of heat produced using fuel which is possible to import from a single supplier to the total amount of heat	X_{273}	min
2.7.4	Ratio of the amount of national fuel used for production of heat to the total consumed amount of fuel	X_{274}	max
3	Socio-political block		
3.1	Geopolitics		
3.1.1	The biggest share of the amount of energy resources imported from a single country in the general energy consumption balance	X_{311}	min
3.1.2	Weighted mean (according to the size of import) of political risk factors of the countries, the energy resources are imported from	X_{312}	max
3.1.3	Weighted mean (according to the size of transit) of political risk factors of transit countries, the energy resources are imported through	X_{313}	max
3.1.4	Weighted mean (according to the size of invested capital) of political risk factors of foreign states that have invested into national energy no less than 10% of the energy system capital	X_{314}	max
3.1.5	Political risk factor of the country	X_{315}	max
3.2	Socio-politics		
3.2.1	Average expenses for energy per inhabitant in comparison with average annual income	X_{321}	min
3.2.2	Degree of undertaking the commitment regarding the share of renewable energy in the total final consumption	X_{322}	max
3.2.3	Degree of following the requirements of Kyoto Protocol regarding the reduction of greenhouse gas emission	X_{323}	max
3.2.4	Degree of undertaking the commitment regarding energy saving	X_{324}	max
3.2.5	Positive social assessment of the development of nuclear power in the country	X_{325}	max

of the evaluation scale; thus, the values increase when $pctv_{ijk}>ctv_{ijk}$ (e.g. the indicator X_{111} "Ratio of total installed power capacity of generators and connections lines to the maximal power demand") and decrease when $pctv_{ijk}<ctv_{ijk}$ (e.g. the indicator X_{112} "Ratio of the largest power plant capacity to installed capacity of the whole system"). In the first case, the higher value of the

indicator corresponds to the higher level of security, whereas in the second case to the lower. Pre-critical and critical threshold values were employed for dividing the increasing and decreasing scales of factual values of the indicators into three following parts: normal, pre-critical and critical states which were further subdivided into five equal parts accordingly. After that, each state was evaluated by points from 1 to 15: normal state – 11–15 points; pre-critical state – 6–10 points; critical state – 1–5 points. In our previous works [4, 5] or in the works of other scientists [6, 7], an 8-point indicator evaluation scale (8 points – normal state, 7-5 points – pre-critical state and 4-1 points – critical state) is used, but we noticed that this scale lacks sensitivity.
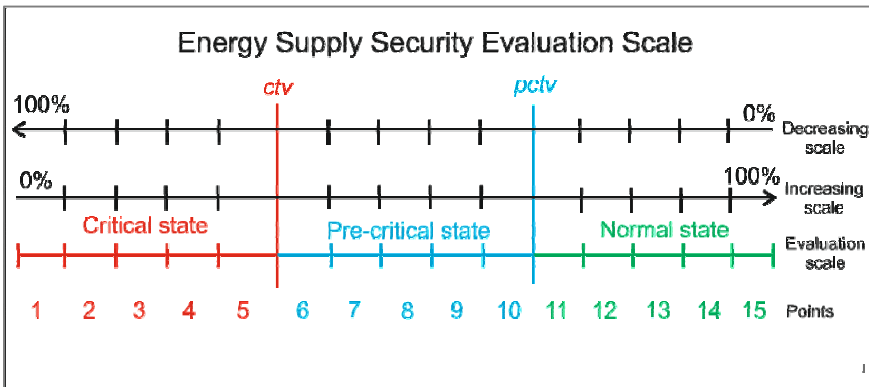

Figure 1:   Scale of energy supply security state assessment.

Each indicator of the research year was evaluated by points from 1 to 15 and defined as X_{ijk}^p taking into consideration the factual value of each indicator. When the direction of the indicator scale is decreasing, the state of the indicator is considered as:

- normal when indicator value is $X_{ijk} < pctv_{ijk}$;
- pre-critical when $pctv_{ijk} \leq X_{ijk} \leq ctv_{ijk}$;
- critical when $X_{ijk} > ctv_{ijk}$.

When the direction of the indicator scale is increasing the state is:

- normal when the indicator's value is $X_{ijk} > pctv_{ijk}$;
- pre-critical when $ctv_{ijk} \leq X_{ijk} \leq pctv_{ijk}$;
- critical when $X_{ijk} < ctv_{ijk}$.

It is necessary to establish the weights of indicators in each group on purpose to assess the level of security of energy supply. In our previous papers we used equal indicator weights or weights evaluated by expert assessment method [4, 5]. As the indicators are interdependent in each group, between groups and blocks, it is advisable to calculate indicator weights considering the correlation coefficients between the indicators. Correlation coefficients were calculated using statistical data, i.e. evoking factual values of indicators. In this paper, we made an assumption that indicators are interdependent only inside the group. Considering

the correlation coefficients, dependencies between the indicators can be described by the following equation (1):

$$X_{ijk} = 1 + \sum_{\substack{t=1 \\ t \neq k}}^{l} r_{kt} X_{ijt}, \qquad i = 1, \dots, n, j = 1, \dots, m, k = 1, \dots, l, \tag{1}$$

here r_{kt} - correlation coefficient between indicators t and k. Using equation (1) a symmetric correlation matrix can be written as follows:

$$\mathrm{R}_{ij} = \begin{pmatrix} 1 & r_{12} & \dots & r_{1l} \\ r_{21} & 1 & \dots & r_{2l} \\ \dots & \dots & \dots & \dots \\ r_{l1} & r_{l2} & \dots & 1 \end{pmatrix}, i = 1, \dots, n, j = 1, \dots, m. \tag{2}$$

The indicators which are independent from other indicators in the group have the biggest weight. The dependent indicators have less weight as they influence the level of security of energy supply through their correlations. Using the correlation matrix (2) auxiliary coefficients were calculated in such manner:

$$\alpha_k = \sum_{t=1}^{l} (1 - |r_{kt}|), \qquad k = 1, \dots, l, \tag{3}$$

and vector $\alpha = (\alpha_1, \alpha_2, \dots, \alpha_l)$ was constructed. Next, each indicator weight in the group can be calculated according to the following formula:

$$s_{ijk} = \frac{\alpha_k}{\|\alpha\|_\Sigma}, i = 1, \dots, n, j = 1, \dots, m, k = 1, \dots, l, \tag{4}$$

here $\|\alpha\|_\Sigma = \sum_{i=1}^{n} |\alpha_i|$. Coefficients s_{ijk} obtain values in the interval

$$\frac{1}{\|\alpha\|_\Sigma} \leq s_{ijk} \leq \frac{l}{\|\alpha\|_\Sigma}, \tag{5}$$

i.e. the maximum weight of indicator in the group is 0.5.

The state of security of energy supply was evaluated taking into account the weights of blocks s_i, groups s_{ij} and indicators s_{ijk} according to the formula:

$$B = \sum_{i=1}^{n} \left(s_i \sum_{j=1}^{m} \left(s_{ij} \sum_{k=1}^{l} s_{ijk} X_{ijk}^{p} \right) \right). \tag{6}$$

4 Assessment of level of security of energy supply in Lithuania

Taking into consideration the assessment of indicators in points, their weights in groups, and weights of groups and blocks, the security of energy supply in Lithuania of separate indicator blocks was determined (on 15-point scale) at first. The results are presented in table 2.

The integral characteristics of security of energy supply in Lithuania in the years 2007, 2010 and after building the LNG terminal are presented in fig. 2. The level of security of energy supply is in pre-critical state, but building the LNG terminal would increase energy security level by 1.3 points.

Table 2:   Assessment of technical, economic and socio-political blocks in points.

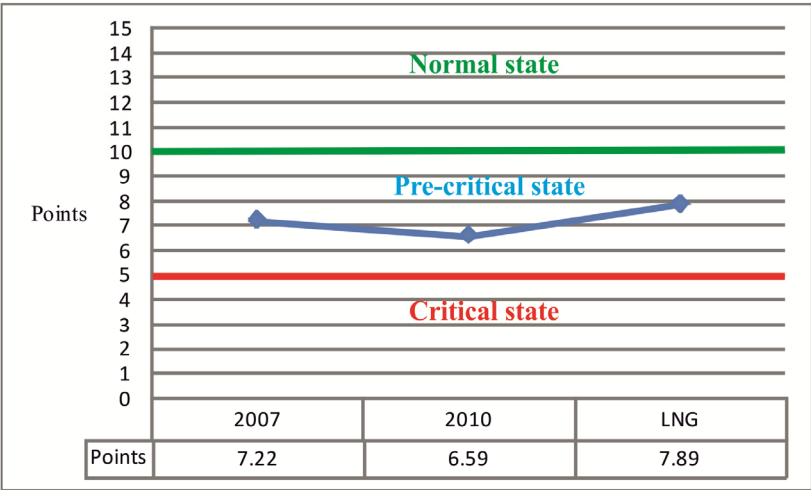| Year Block	2007	2010	LNG terminal
Technical	8.82	7.61	9.21
Economic	6.26	5.51	7.70
Socio-political	6.59	6.64	6.75

	2007	2010	LNG
Points	7.22	6.59	7.89

Figure 2:   State of security of energy supply in Lithuania in 2007, 2010 and after building the LNG terminal.

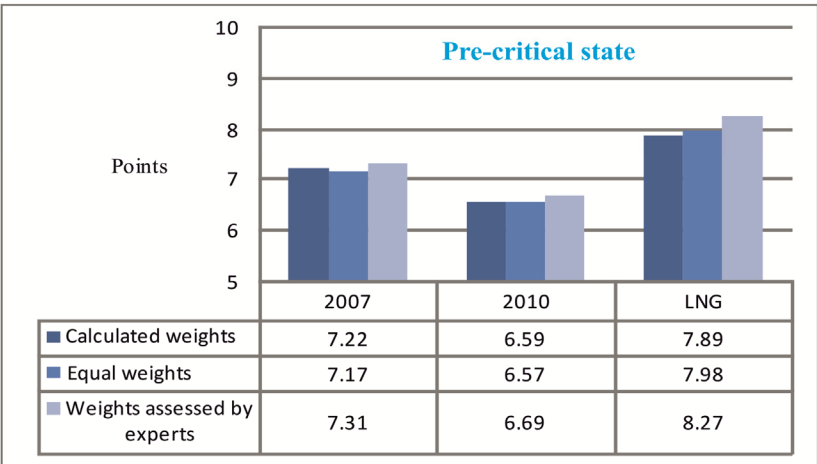|	2007	2010	LNG
Calculated weights	7.22	6.59	7.89
Equal weights	7.17	6.57	7.98
Weights assessed by experts	7.31	6.69	8.27

Figure 3:   State of Lithuanian energy supply security estimated different weights of indicators in groups.

For the sake of comparison we calculated the level of security of Lithuanian energy supply using two different types of indicator weights, i.e. equal weights and weights determined by experts. The results are presented in fig. 3.

5 Conclusions

1. Each intended object in the energy development programme (such as LNG terminal, electricity network between Lithuania and Sweden NORDBALT, etc.) influence the changes of certain values of indicators in all three blocks: the values of some indicators increase and some values decrease.
2. The state of security of energy supply in Lithuania will increase up to 7.89 and 7.98 points (calculated or equal weights of indicators in groups) or up to 8.27 points (weights of indicators assessed by experts) after building the LNG terminal.
3. When the weights of indicators in groups are calculated on the basis of correlations, then the level of security of energy supply in Lithuania is pre-critical.

Acknowledgement

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