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Analysis of energy security level in the Baltic States based on indicator approach

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ABSTRACT

Energy security for small countries like Estonia, Latvia and Lithuania, which are called the Baltic States, is vital for ensuring energy independence and is a driving force for the development of a strong economy. The aim of the study presented in this paper is an analysis of the Baltic States regarding the performance of energy security level based on indicators. The analysis covers 2008–2016, in which the Baltic States faced essential changes in the energy sector. The methodology, based on indexes, is adopted for an integral measure of energy security level. The system of indicators is proposed, which considers technical, economic, geopolitical and sociopolitical aspects of energy security. The indicator system using statistical data is applied to each Baltic State, which enables evaluation of energy security level. The application of the developed model demonstrates which measures strengthen energy security. The results demonstrate that the energy security level of Estonia and Latvia is higher in comparison to Lithuania. The main factors for these differences are that Estonia and Latvia have strong own energy resources, such as oil shale and hydropower respectively, while Lithuania is characterized by high level of electricity import.

1. Introduction

A secure supply of reliable energy services at affordable prices is essential to promote economic growth. This directly refers to the energy security concept, which still does not have an acceptable and agreed definition within the existing literature in the field. Many studies concentrate on defining, conceptualizing and measuring energy security. Ang et al. [1] surveyed 104 studies from 2001 to June 2014, reporting the findings of energy security definitions, dimensions and indexes as well as methodological issues during the development of these indexes. Azzuni and Breyer [2] agree that current research literature lacks a commonly accepted, precisely defined definition of energy security and provide an advanced review of definitions and dimensions of energy security. However, most of the reviewed studies agree with the definition provided by the International Energy Agency, which states that energy security has many aspects and should cover the uninterrupted availability of energy sources at an affordable price [3].

Ensuring energy security is particularly challenging for small countries, such as Estonia, Latvia and Lithuania. In recent years, Baltic States have undergone major changes in the energy sector, which have a great impact on strengthening energy security in the Baltic region. Nevertheless, energy security topic in the research field considering these States does not receive so much attention, specifically when measuring energy security. However, energy security for the Baltic States has been analysed in some of the studies, which briefly are reviewed in Section 2.

The goal of the study presented in the paper is twofold. Firstly, using best practises it proposes a composite energy security measure by integrating various indexes into a single characteristic called the energy security level (ESL). It allows to estimate past and future status of energy security of the analysed system and demonstrates which measures strengthen energy security. Secondly, using the latest available statistical data it evaluates the energy security level for the Baltic States in 2008–2016 and complements similar studies with the comprehensive analysis of energy security performance for these States. Additionally, the study is supplemented with uncertainty and sensitivity analysis that contributes

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Abbreviations

EAPI	Energy Architecture Performance Index
ESI	Energy Security Index
ESL	Energy Security Level
EU	European Union
GESRI	Geopolitical Energy Supply Risk Index
GHG	Greenhouse Gas
NPP	Nuclear Power Plant
LNG	Liquefied Natural Gas
NEIS	National Energy Independence Strategy
REES	Risky External Energy Supply
RES	Renewable Energy Sources
SWI	Shannon–Wiener index
WEC	World Energy Council
WEF	World Economic Forum
WETI	World Energy Trilemma Index

to a better understanding of energy security level of the Baltic region, as well as provides additional information to the decision-makers at the European Union (EU) level.

The remaining part of the paper is structured as follows: Section 2 contains a brief literature review on energy security for the Baltic States; Section 3 briefly presents energy country profiles; the proposed methodological approach is described in Section 4; the results of analysis of energy security level during 2008–2016 of the Baltic States are discussed in Section 5; Section 6 of conclusions summarizes main findings of the conducted study.

2. Literature review

The World Energy Council (WEC) annually prepares so-called the World Energy Trilemma Index (WETI), which is based on three core dimensions (energy security, energy equity and environmental sustainability) and ranks energy systems of 125 countries worldwide [4]. In the latest report of 2018 in terms of energy security dimension, Latvia is ranked as 11th, Estonia as 19th and Lithuania as 46th. The main disadvantage of this index is that it does not provide values of the index dimensions, but demonstrates only country ranking.

The global Energy Architecture Performance Index (EAPI) also ranks worldwide countries, particularly on their ability to deliver secure, affordable and sustainable energy [5]. The EAPI provides index values on a scale of 0–1. Results of the latest report in 2017 demonstrate the energy system performance of 127 countries using the EAPI scores [5]. According to sub-index “energy access and security”, Latvia among the Baltic States has the highest score of 0.80 in 2017, while Lithuania and Estonia observed 0.78 and 0.75 respectively.

Global national energy security was evaluated by Wang and Zhou [6] using Energy Security Index (ESI). Evaluated 162 countries were categorized into 9 sub-groups in terms of energy security performance in different regions. The Baltic States were clustered into Eurasia and among these countries, Latvia and Lithuania were in the Good (I) group or second best out of nine, while Estonia was classified as Limited (II) or fifth out of nine.

Chalvatzis and Ioannidis [7] studied energy supply security in the EU countries considering diversity and dependence metrics, such as import dependence, Shannon–Wiener index (SWI) and Herfindahl–Hirschman index. It is observed that Latvia and Estonia have reduced their import dependence due to renewable energy growth. However, Estonia is determined as one of the countries with the least diverse fuel mix.

Matsumoto et al. [8] evaluated energy security in the EU countries concentrating on diversity, import dependence and supply risk. However, the analysis ends in 2014, which means that Lithuania and Latvia were still non-OECD countries at that time moment. For such countries, only diversity indicator was applied, which does not demonstrate the entire picture.

The energy security index, which covers environmental and social aspects, was proposed by Radovanović et al. [9] and applied to the EU countries from 1990 to 2012. Estonia and Lithuania in 2012 were grouped into the first category, meanwhile, Latvia fall in the fourth category. Since the index does not provide any threshold values, the results are difficult to interpret. Also, it is surprisingly low energy security index for Sweden and Latvia and high index for Lithuania in 2012, which does not properly address the reality. Thus, this index is not an informative measure in terms of energy security.

Other energy security index, constructed using the five most common dimensions of energy security (availability, affordability, accessibility, acceptability and efficiency), was developed by Erahman et al. [10] and applied for 71 countries. In 2013, observed values of this index for Estonia, Latvia and Lithuania were 0.641, 0.610 and 0.598 (on a scale of 0–1) respectively, while the average index value of all analysed countries was 0.593. Although the analysis covers many countries, however, the last year of the analysis is 2013, which does not reveal an energy security performance in recent years.

The security of external energy supply in the EU was analysed by Le Coq et al. [11] for oil, natural gas and coal. Risky External Energy Supply (REES) index was considered for the assessment, which demonstrated one of the highest risks in terms of natural gas supply in Latvia and Lithuania in 2006. Furthermore, in terms of crude oil, Lithuania was reported as having one of the highest supply risks as well.

Socioeconomic Energy Risk Index was presented by Delgado [12] for the EU-25 countries. The highest risk in 2009 was determined in Latvia (40.9), Lithuania (40.8) and Estonia (38.1), while the average value for the EU-25 was 28.9. Similarly, Geopolitical Energy Supply Risk Index (GESRI) was proposed by Muñoz et al. [13] that aims to quantitatively estimate the geopolitical risk of energy supply. The index was applied for 122 countries and aggregated over the period 2000–2010. As a result, Estonia is ranked as 28th, Lithuania is 30th and Latvia is ranked as 33rd.

Composite indicators for the security of energy supply were proposed by Badea et al. [14] using ordered weighted averaging for the EU countries in 2010. In this study, the Baltic States are identified with the highest risk in terms of security of energy supply.

Number of studies, which concentrate on the energy security purely for the Baltic States, in particular using indicator approach, is quite limited at present to the best of authors' knowledge. Security of electricity supply of the Baltic States in future perspective was analysed by Bompard et al. [15], pointing out that the network security level in 2030 will be lower and even inferior to the security level compared with 2014 and 2020.

Study on the security of energy supply for the Baltic States proposed an index, which quantitatively assesses political vulnerability [16]. The analysis has revealed that the overall political vulnerability on the security of energy supply is the highest in Lithuania, considerably lower in Latvia, and the lowest in Estonia.

Various energy security indicators were analysed for the Baltic States for the period of 2003–2012 [17]. However, an aggregate measure has not been proposed and different indicators do not demonstrate the integral energy security level. Therefore, countries cannot be compared in terms of energy security.

One of the most recent studies of energy security trends in the

Baltic States for the period of 2008–2012 uses the multi-criteria decision-making technique for aggregate measures of energy security [18]. The study demonstrated that in terms of energy security Latvia performs the best, while Estonia and Lithuania are more similar lower-performing.

The reviewed studies revealed that energy security for the Baltic States is evaluated very differently, which results in a quite different performance of energy security within these States (Table 1).

The main reason for this discrepancy is non-existence of acceptable and agreed criteria or measure that would impartially and integrally allow to assess the energy security level. It still lacks a comprehensive analysis of energy security for the Baltic States that would allow to quantitatively measure different security dimensions by an integral metric. Also, uncertainties are neglected in most of the cases when analysing energy security indicators.

The study presented in this paper fills the gap of such type of analyses. Since the Baltic States is a specific case in terms of energy security within the EU, the analysed issue is particularly important when taking into account energy planning purposes. The importance of the Baltic States' role within the EU's energy system is highlighted in Section 3. Yet, it is extremely important to provide both simple and comprehensive measures for energy security to make the decision-making process most effectively. The study presented in this paper covers these aspects by both methodological and practical contributions.

The methodological contribution is represented by the indicator system, which forms a basis for an integral energy security measure that evaluates energy security quantitatively considering not only technical and economic but also geopolitical and sociopolitical dimensions. The practical contribution of this study is demonstrated by the comprehensive analysis of the energy security performance of the Baltic States, which enables a comparison of energy security dynamics from 2008 to 2016 within different dimensions and types of energy. The outcomes of the method application are beneficial for the decision-making process at the national, regional and EU levels when supporting energy planning and energy policy.

3. Energy profiles of the analysed countries

To better justify the application of indicators for energy security assessment of the Baltic States, a brief overview of the energy profile of each analysed country is provided. Though the Baltic States politically and economically are the members of the EU, however, their electricity and natural gas systems are still mostly connected with the systems of the former Soviet Union. This situation was determined both by historical and political circumstances and by limited internal energy resources.

For a long time, the Baltic States were called as an "energy island" in Europe, as it is underlined in the European Energy Security Strategy [19]. The Baltic States in the EU's energy system were without electricity networks, gas pipelines and interconnections with Western Europe [20]. From the point of view of European integration, the Baltic States in some extent still remain an isolated "energy island" since electricity systems were developed as an integral part of the Interconnected Power System/Unified Power System (IPS/UPS) and work synchronously with power systems of Belarus, Russia and other Eastern countries. In order to be integrated with the European electricity system, the project of synchronisation of the Baltic States' electricity grid with the European Continental Network (ECN) is foreseen to be implemented by 2025.

Table 1
Summary of energy security estimates for the Baltic States.

Study [ref.]	Index	Analysis period	Index estimate (in the latest year analysed)			Scale
			Estonia	Latvia	Lithuania	
WEC [4]	WETI	2014–2018	19th	11th	46th	Rank (out of 125) (higher values correspond to lower rank)
WEF [5]	EAPI (Energy Access and Security)	2013–2017	0.75	0.8	0.78	[0; 1] (higher values correspond to higher energy security)
Wang and Zhou [6]	ESI	Not specified	5th	2nd	2nd	9 sub-groups (higher values correspond to lower rank)
Chalvatzis and Ioannidis [7]	SWI[a]	1990–2012	0.81	1.21	1.49	≥0 (higher values correspond to higher diversity)
Matsumoto et al. [8]	SWI[a]	1990, 2002, 2013	0.81	1.38	1.26	≥0 (higher values correspond to higher diversity)
Radovanović et al. [9]	ESI	1990–2012	+92.01 (1st group)	−65.31 (4th group)	+62.12 (1st group)	Four groups: 1) > +55 2) [+15; +55] 3) [−25; +15] 4) < −25 (higher values correspond to higher energy security)
Erahman et al. [10]	ESI	2008–2013	0.641	0.610	0.598	[0; 1] (higher values correspond to higher energy security)
Le Coq et al. [11]	REES	2006	1.9 (Oil) 10.3 (Gas) 0.3 (Coal)	2.1 (Oil) 21.0 (Gas) 0.6 (Coal)	10.2(Oil) 20.1 (Gas) 1.0 (Coal)	≥0 (higher values correspond to higher risk)
Delgado [12]	Socioeconomic Energy Risk Index	2009	38.1	40.9	40.8	[0; 100] (higher values correspond to higher risk)
Muñoz et al. [13]	GESRI[b]	2000–2010	37.63	39.02	38.36	[0; 100] (higher values correspond to higher risk)
Badea et al. [14]	Composite indicator	2010	15th	17th	24th	Rank (out of 27) (higher values correspond to lower rank)
Česnakas et al. [16]	Political vulnerability	2004–2011	31.45	45.25	56.12	[0; 100] (higher values correspond to higher vulnerability)
Zeng et al. [18]	The integrated energy security indicator[a]	2008–2012	0.52	0.86	0.47	[0; 1] (higher values correspond to higher energy security)

[a] Values are estimated approximately since the study results are provided in the graphical form only.
[b] Values are aggregated over the 2000–2010.

Therefore, energy security is still an issue of the highest relevance for the Baltic States.

However, much effort has already been made to improve the situation and move towards energy independence and increased energy security. As an example, formerly an “energy island”, the Baltic States is now connected with the EU through recently constructed electricity lines with Poland, Sweden and Finland, it contributes to the establishing a unified European energy market.

Apart from being in BRELL (Belarus, Russia, Estonia, Latvia and Lithuania) ring and operating in parallel with the IPS/UPS, energy systems of the Baltic States have more features in common. All three countries are still strongly dependent on natural gas import, lack of own/local resources, face a similar environment of threats to energy security [21]. Nevertheless, each of the Baltic States has a focus on a different energy resource, especially when analysing energy production and consumption (Fig. 1).

However, all three States are quite consistent with their commitments regarding the share of renewable energy sources (RES) in final energy consumption and perform better than the EU28 average (Fig. 2).

These and similar aspects are also emphasized further in the country energy profiles and Section 5 of the results.

3.1. A general overview of the Lithuanian energy system

The considerable change in the Lithuanian energy system occurred at the end of 2009 after closing the Ignalina Nuclear Power Plant (NPP). It radically changed the energy resource structure and suddenly country from exporting electricity overnight became country importing electricity. This event increased energy dependence on Russia not only in terms of electricity import, but also dependence on natural gas import as the production of electricity from gas-fired power plants was also increased.

In 2016, total production of electricity in Lithuania amounted to 3.973 TWh [22]. As indicated in Fig. 1, the largest part of the production came from wind (28%), hydro (25%) and natural gas (21%) [23]. However, total demand for electricity in Lithuania in 2016 was 12.247 TWh [22]. It means that 68% of demanded electricity was imported, particularly from Latvia (35.8%), Russia (29.9%), Sweden (27.3%), Poland (4.8%), Belarus (1.5%) and Estonia (0.6%) [24].

At the end of 2015, two new power connection lines, accordingly “LitPol Link” with Poland of 500 MW and “NordBalt” with Sweden of 700 MW were commissioned, thus, their real benefit in terms of decreased electricity price and diversification of electricity supply is felt from 2016. It was major step in terms of strengthening the country’s energy independence and security.

Till 2015, Lithuania relied on a single source of natural gas supply from Russia. However, diversification of gas supply was reached by introducing a liquefied natural gas (LNG) terminal in Klaipėda at the end of 2014. It has enabled the formation of a natural gas market in Lithuania and a decrease in natural gas prices in the country, and most importantly, strengthened national energy security [25].

The main strategic directions of energy policy development pointed out in new National Energy Independence Strategy (NEIS) of Lithuania are energy security, competitiveness, green energy development and innovations [26]. According to the NEIS, the main vision of the Lithuanian energy sector is complete independence from fossil fuels by 2050. It seems this vision can be fulfilled since the share of RES in gross final energy consumption increased from 17.2% to 25.6% between 2004 and 2016. As illustrated by Fig. 2, the country in 2014 has already reached the national RES target of 23% for 2020 defined by the renewable energy directive [27].

3.2. A general overview of the Latvian energy system

RES have a dominant share in total production of electricity in

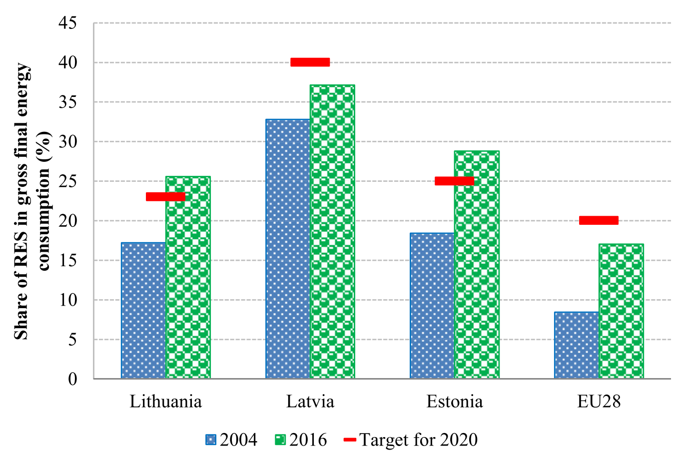

Fig. 2. Share of RES in gross final energy consumption in 2004 and 2016.

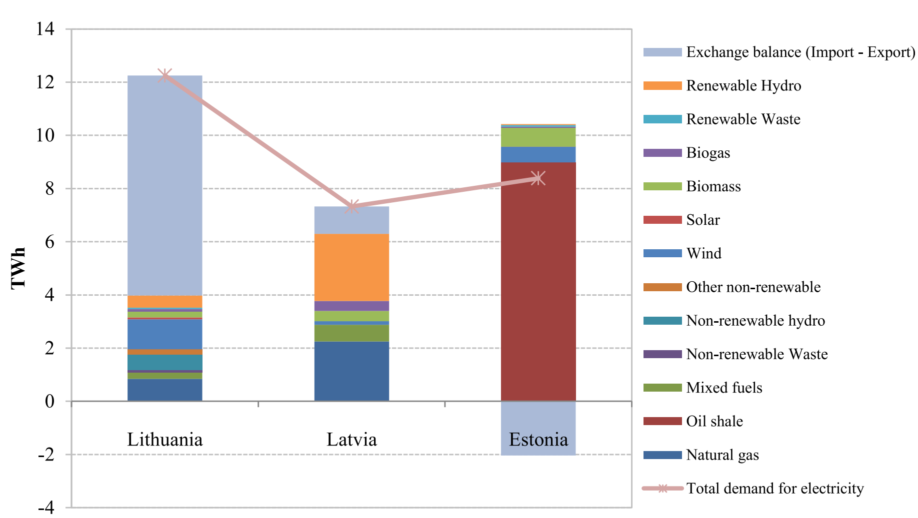

Fig. 1. Electricity production and consumption balance in the Baltic States in 2016.

Latvia (54% in 2016), mainly being generated by hydro (40%), biomass (6%), biogas (6%) and wind (2%) [23]. As indicated in Fig. 1, the other part of 6.293 TWh produced electricity in 2016 came from fossil fuels. As total demand for electricity in 2016 was 7.323 TWh, the rest of the demanded electricity (14%) was imported, mostly from Estonia (61.8%) and Russia (22.9%) [23]. Heat production also mostly relies on natural gas. Since Latvia does not have its own resources, all natural gas consumed is imported from a single source – Russia.

Unlike the other Baltic States, Latvia operates the Inčukalns Underground Gas Storage Facility, which ensures the stability of regional natural gas supply [29]. Natural gas is injected into the storage during the summer, when consumption is low, and supplies gas during the heating season.

Due to strong hydropower production, Latvia is one of the leading countries according to the share of energy from RES in the EU and is close to achieve its 2020 RES target. In 2016, the share of RES in gross final energy consumption amounted to 37.16%, which is more than twice higher than the EU28 average (Fig. 2). Furthermore, Latvia's RES target for 2020 is 40%, which is also twice as high as the EU average of 20%, defined by Ref. [27] and Latvia is very close in achieving it.

3.3. A general overview of the Estonian energy system

Estonia is the only country in the world that has oil shale as the primary energy source in the country and as a dominating fuel in the energy mix. On the one hand, such high consumption of oil shale as a local fuel ensures high level of energy security. On the other hand, it is highly carbon-intensive fuel, thus oil shale based energy production processes emit a large amount of greenhouse gas (GHG), which has negative impact to the environment.

For this reason, Estonia in 2015 within the EU countries with regard to GHG emissions intensity of the economy was in the first place (index of GHG emissions/GDP (EU28 = 100) was 217) and with regard to GHG emissions per capita was in the second place (13.7 t CO_2 eq. per capita) [30]. This makes Estonia's economy more than twice as carbon dioxide (CO_2) intensive as the EU average. In order to significantly reduce CO_2 emission and to lessen the negative environmental impact, the Estonian Government is phasing out old power plants and developing new technologies [31].

Estonia's electricity production is slightly higher than consumption, thus it exports electricity. In 2016, total production of electricity in Estonia amounted to 10.423 TWh, whereas total demand for electricity was 8.387 TWh [23]. As detailed in Fig. 1, most of the electricity production came from oil shale (86%), less noticeable was biomass (7%), wind (6%) and, renewable waste (1%) power plants. 2.036 TWh of electricity was exported to Latvia (84%) and Finland (16%) [32].

In 2014, new power connection line "EstLink 2" has added 650 MW of transmission capacity between Finland and Estonia, which allowed to increase for total of 1000 MW capacity since the first high-voltage direct current interconnection "EstLink 1" with nominal transmission power of 350 MW was already commissioned in 2006 [33].

Though Estonia has reliable electricity supply and local oil shale resources, but all the country's natural gas and oil products consumed are imported from neighbouring countries, specifically from Russia. Nevertheless, Estonia is actively promoting the development of RES and has already in 2011 reached the national RES target of 25% for 2020 [28]. Thus, it made Estonia the first country in the EU to achieve this target [34]. From 2004 to 2016 in Estonia the share of RES in gross final energy consumption increased from 18.4% to 28.8% (Fig. 2).

4. Methodology

The main goal of the presented methodology is to propose a measure for an integral energy security level. The background of the methodology are previous authors' studies [35,36], which were based on the work of Bykova [37]. In these studies, the concept of energy security indicators was presented. During the implementation of projects of the National Research Programme "Future Energy" in Lithuania from 2010 to 2014, the methodology of assessment of ESL was developed [38,39]. Besides, it was applied in 2015–2016 when conducting the energy security study, which was a part of preparing a new National Energy Independence Strategy of Lithuania [26].

The proposed methodology in the paper is an upgrade of previous studies discussed above. The special attention was paid to reconstruction and significant improvement of the system of indicators, which enable to cover numerous aspects of energy security peculiarities. Also, the system was designed to be as general as possible and suitable for any application. Using the methodology, estimation of ESL in general might be applied for both past and future energy systems.

4.1. System of indicators

According to the methodology, ESL is assessed regarding all factors that have an impact on energy security. A system of energy security indicators is developed and converted to an integral energy security measure. The energy security indicator is a special index, which provides numerical values. Selected indicators are divided into three blocks – technical, economic and sociopolitical.

Blocks are divided into the specific groups, which should be formed according to the type of energy source or fuel used in the energy system, e.g. electricity, heat, natural gas, oil, coal, nuclear or other.

The normalized value of an indicator is denoted as I_{ijk}, where $i = 1, \ldots, n$ is the number of block, $j = 1, \ldots, m_i$ – the number of group in the i^{th} block and $k = 1, \ldots, l_j$ – the number of the indicator in the j^{th} group. General scheme of ESL is presented in Fig. 3.

Indicators I are formed from various indexes, which of the proposed methodology for each of the blocks are described in detail below.

4.1.1. Technical block

The technical block consists of 8 key indexes that reflect technical aspects of energy security. Most of these indexes are formed as ratios or shares of particular parameters that relate to the technical block dimension. Mathematical approach of technical indexes is presented further.

1) Ratio of total installed capacity to maximum demand for capacity

$$T_1 = TCin_j / MD_j, \quad (1)$$

where $TCin_j$ – total installed capacity of energy source j, MD_j – maximum demand for capacity of energy source j.

2) Ratio of total capacity of supply to final consumption

$$T_2 = TCsu_j / FCon_j, \quad (2)$$

where $TCsu_j$ – total capacity of supply of energy source j, $FCon_j$ – final consumption of energy source j.

3) Ratio of the installed capacity of the largest unit to total installed capacity

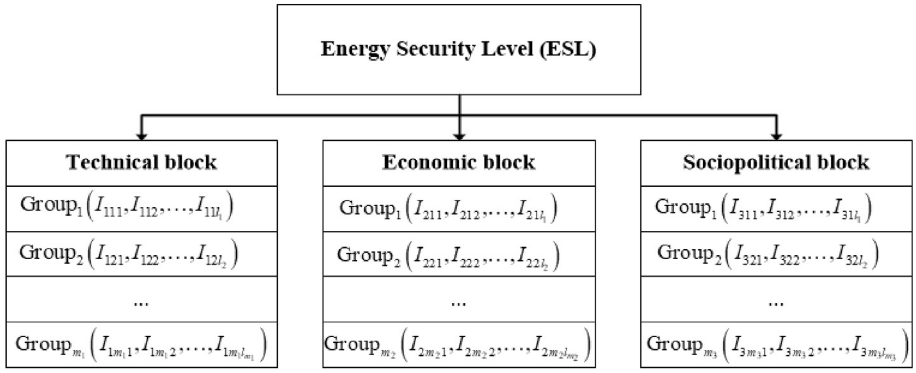

Fig. 3. Blocks, groups and indicators of energy security level.

$$T_3 = LCin_j / TCin_j, \tag{3}$$

where $LCin_j$ – the installed capacity of the largest unit of energy source j.

4) Ratio of the capacity of the largest supplier to final consumption

$$T_4 = LCsu_j / FCon_j, \tag{4}$$

where $LCsu_j$ – the capacity of the largest supplier of energy source j.

5) Share of the largest production of one technology in total production

$$T_5 = LPro_j / TPro_j, \tag{5}$$

where $LPro_j$ – the largest production of one technology of energy source j, $TPro_j$ – total production of energy source j.

6) Ratio of the amount of accumulated reserves to final consumption

$$T_6 = AR_j / FCon_j, \tag{6}$$

where AR_j – the amount of accumulated reserves of energy source j.

7) Share of RES in gross final energy consumption

$$T_7 = RECon_j / FCon_j, \tag{7}$$

where $RECon_j$ – the amount of RES consumed for energy source j.

8) Share of production which can be replaced by alternative fuel

$$T_8 = AFPro_j / TPro_j, \tag{8}$$

where $AFPro_j$ – the amount of production of energy source j using alternative fuel.

4.1.2. Economic block

The economic block consists of 9 key indexes that reflect the economic aspects of energy security. As in the case of the technical block, most of the economic indexes are formed as ratios or shares. Mathematical approach of economic indexes is presented further.

1) Ratio of the amount purchased in the market to final consumption

$$E_1 = M_j / FCon_j, \tag{9}$$

where M_j – the amount of energy source j purchased in the market.

2) Ratio of the purchase price to the average price of the EU countries

$$E_2 = Pri_j / EUPri_j, \tag{10}$$

where Pri_j – the purchase price of energy source j, $EUPri_j$ – the average price of energy source j of the EU countries.

3) Ratio of the purchase price to the average price in the available markets

$$E_3 = Pri_j / MPri_j, \tag{11}$$

where $MPri_j$ – the average price of energy source j in the available markets.

4) Ratio of the production price to the average production price of the EU countries

$$E_4 = ProPri_j / EUProPri_j, \tag{12}$$

where $ProPri_j$ – the production price of energy source j, $EUProPri_j$ – the average production price of energy source j of the EU countries.

5) Share of consumers who may choose a supplier of energy source/fuel j freely (E_5). This index shows which part of the consumers can freely choose the supplier of the corresponding energy source or fuel.

6) Ratio of the amount of energy source which can be produced using fuel imported only from a single supplier to total amount of production

$$E_6 = FSsu_j / TPro_j, \tag{13}$$

where $FSsu_j$ – the amount of energy source j which can be produced using fuel imported only from a single supplier.

7) Share of the import/supply from a single supplier

$$E_7 = ImpSsu_j \Big/ TImp_j, \tag{14}$$

where $ImpSsu_j$ – the amount of the imported energy source j from a single supplier, $TImp_j$ – total amount of the imported energy source j.

8) Ratio of the amount of import to final consumption

$$E_8 = TImp_j \Big/ FCon_j. \tag{15}$$

9) Ratio of the amount of the local fuel, used for the production, to final consumption

$$E_9 = LFPro_j / FCon_j, \tag{16}$$

where $LFPro_j$ – the amount of the local fuel, used for the production of energy source j.

4.1.3. Sociopolitical block

The sociopolitical block is described by 7 key indexes that mostly cover geopolitical and sociopolitical dimensions of energy security. Mathematical approach of sociopolitical indexes is presented further.

1) Energy dependence

$$SP_1 = \sum_j TImp_j \Big/ \sum_j FCon_j. \quad (17)$$

2) The weighted mean of political risk factors of the countries

$$SP_2 = \sum_c (w_{c,k} \times R_c), \quad (18)$$

where $w_{c,k}$ – weight according to the criteria k of country c, R_c – political risk factor of country c.

Criteria k is as follows:

$k = 1$ – according to the size of import of energy sources from countries c; $k = 2$ – according to the size of transit of energy sources through countries c; $k = 3$ – according to foreign countries c that have invested into national energy system; $k = 4$ – according to the size of connections of countries c that electricity transmission network is connected with.

3) The political risk factor of the country

$$SP_3 = R_c. \quad (19)$$

4) Share of energy expenses per household in total household expenses

$$SP_4 = EHE/THE, \quad (20)$$

where EHE – energy expenses per household, THE – total household expenses.

5) Degree of undertaking the commitment with regard to share of RES in final energy consumption

$$SP_5 = T_7/RET, \quad (21)$$

where T_7 – the share of RES in gross final energy consumption evaluated by index T_7 using formula (7), RET – the national RES target for 2020 defined by the EU renewable energy directive [27].

6) Degree of following the commitment with regard to the reduction of greenhouse gas emission (SP6). This indicator shows country's trend in total man-made emissions of the "Kyoto basket" of greenhouse gases. It presents annual total emissions in relation to 1990 emissions [40].

7) Degree of undertaking the commitment with regard to the EU energy efficiency target

$$SP_7 = \sum_j FCon_j \Big/ EET, \quad (22)$$

where EET – the national energy efficiency target for 2020 defined by the EU energy efficiency directive [41].

4.2. Energy security level

Usually, factual values of indicators have various dimensions and scales with different maximal values. Thus, primarily all values of indicators should be normalized, i.e. turned into a 100% scale by using a compression ratio.

In order to evaluate ESL, the state of each indicator should be identified according to its direction. There are denoted 3 states of indicator (as well as for general ESL): normal, pre-critical and critical. These states are separated from each other by threshold values of the indicator: I_{ijk}^{pc} – pre-critical threshold value; I_{ijk}^{c} – critical threshold value. The threshold values of each indicator are determined using expert evaluation method. According to their nature indicators could be of the 2 directions: oriented to maximal value (when $I_{ijk}^{pc} > I_{ijk}^{c}$) and oriented to minimal value (when $I_{ijk}^{pc} < I_{ijk}^{c}$). In the first case, the higher value of the indicator corresponds to the higher level of security, whereas in the second case it is vice versa. The initial idea of using such a scale of threshold values was taken from Bykova [37]. However, the authors estimated the indicators in points from 0 till 100 using their factual values, an evaluation scale (see Fig. 4 c)) and considering direction and threshold values (I_{ijk}^{pc} and I_{ijk}^{c}) of each indicator (see Fig. 4 a) and b)). According to obtained points, the state of the indicator is determined as critical (0–33 points), pre-critical (34–66 points) and normal (67–100 points).

The integral characteristic of ESL is evaluated using (23) formula and taking into account weights of indicators, groups and blocks:

$$ESL = \sum_{i=1}^{n} \left(s_i \sum_{j=1}^{m_i} \left(s_{ij} \sum_{k=1}^{l_j} s_{ijk} I_{ijk} \right) \right), \quad (23)$$

where $s_{ijk} = 1/l_j$ – weight of the k^{th} indicator in the group, s_{ij} – the weight of the j^{th} group in the block, $s_i = 1/n$ – weight of i^{th} block, $i = 1,\ldots,n$; $j = 1,\ldots,m_i$; $k = 1,\ldots,l_j$. The weight s_{ij} for the technical and economic blocks is determined as the share of each fuel, electricity and heat final consumption comparing to total final consumption. For sociopolitical block the weight $s_{ij} = 1/m_i$, $i = 1, \ldots, n$; $j = 1,\ldots,m_i$.

In summary, the model for ESL estimation deals with two types of parameters:

1) Indicators (I). If ESL is evaluated for the past, indicator values are collected from the available statistical data using reliable data sources. Thus, it is hardly to expect any uncertainty or one can expect very low uncertainty in the initial data. However, if ESL is evaluated for the future, indicator values use predictions or forecasts, which might lead to the uncertainties. In order to avoid misleading results, uncertainty analysis of indicator parameter shall be performed in this case.
2) Weights (s). The model considers three types of weights: block, group and indicator. In the analysis, it is assumed that all three dimensions (technical, economic, socio-political) have the same impact on energy security in general. Thus, the weight for each of the block is considered as equal (1/3). Group weights are determined directly from the statistical data, therefore the uncertainties are avoided. However, selection of indicator weights might be subjective since equal weights are considered. In order to analyse what impact on the ESL results the selection of these weights might have, sensitivity and uncertainty analysis should be conducted.

5. Results and discussion

Methodology, presented in Section 4, was applied for construction of an indicator system that consists of 67 indicators (listed in the supplementary material). The indicator system was adopted separately for each analysed country. Based on the proposed methodology, the assessment of ESL for the Baltic States was carried out for 2008–2016. Values for indicators were calculated for each year as well as the ESL, which is the main result of the presented study (Subsection 5.2). The key data sources used in the

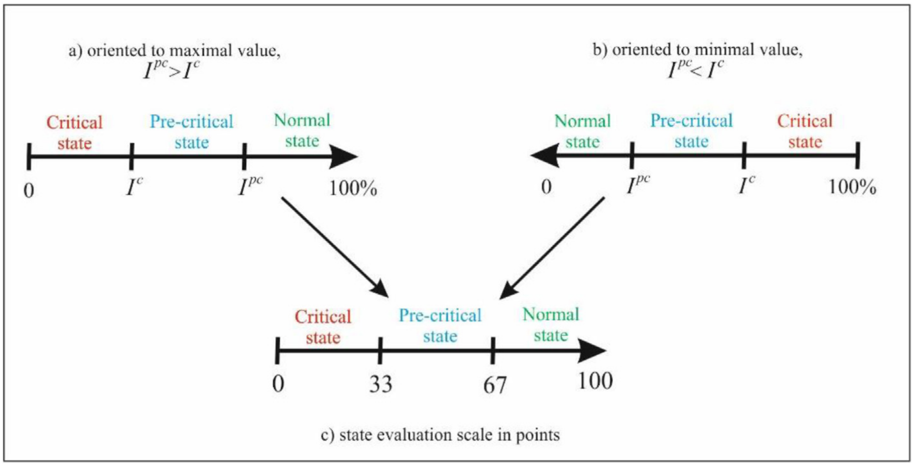

Fig. 4. Scales of indicator state assessment.

study are discussed further in Subsection 5.1.

5.1. Data

In order to assess ESL, statistical data for the indicator values during 2008–2016 was collected. The technical data such as installed capacities, maximum demand, energy consumption, production, supply, reserves, share of RES in gross final consumption, alternative fuels and other was collected from electricity transmission system operators [22,23], EUROSTAT database [40], annual reports “Energy in Lithuania” [44], national and international district heating associations [45,46], International Atomic Energy Agency [50], national statistical departments databases [32,42,43]. The economic data such as purchased, market and production prices of energy sources and fuels, import dependency and other was collected from Lithuanian, Latvian and Estonian competition authorities [24,48,49], national statistical departments databases [32,42,43], annual reports “Energy in Lithuania” [44]. Data for energy dependence indicator was derived from EUROSTAT database [40], the political risk factor of countries is reported by International Country Risk Guide [47], household expenses for energy was collected from national statistical departments databases [32,42,43]. National targets for RES, energy efficiency and reduction of greenhouse gas emissions were defined by EUROSTAT database [40] and EU directives [27,41]. In addition, data sources used for each indicator are provided in the supplementary material.

5.2. Results

The obtained results demonstrate that ESL in Latvia and Estonia are higher than in Lithuania during the entire analysis period (Fig. 5). The ESL of Estonia falls under the normal state, in Latvia, it is close to the normal state, while in Lithuania it is worse and only in 2016 the ESL of Lithuania equates to the normal state.

The main negative factor for the decrease of ESL in 2010 in Lithuania was the closure of Ignalina NPP, which highly impacted the electricity sector. As a result, mostly the energy dependency indicator was worsened since Lithuania from electricity exporting country suddenly became electricity importing country. The greatest negative influence on energy security is caused by countries’ high dependency on import from one country and disproportionally high expenses of inhabitants for energy services in comparison to average income. In Lithuania, the sharp drop of the ESL was also offset by many positive factors, such as the emergence of the electricity market, change of the largest electricity generation unit, which resulted in more diversified electricity production. In the case of Latvia and Estonia, the main factors that negatively influenced energy security occurred in the geopolitical indicators. In 2010, a decrease in the risk ratings of the analysed countries was observed, which led to a general drop in ESL.

The highest impact on the increase of the energy security level in Lithuania from 2012 to 2016 had reduction of the dominating generator capacity, decline in gas consumption, decreased gas prices for consumers due to new Klaipėda LNG terminal, greater diversification of suppliers due to new electricity connections with Sweden and Poland. Other positive factors for better energy security performance were increased share of biofuels in the heating sector as well as a decrease in the heat prices, improved rankings of countries from which energy sources are imported.

The moderate increase of ESL in Latvia during the same period was influenced by falling gas prices, greater diversification of production and fuel mix in the heat sector, improving risk ratings of both country under analysis and its neighbouring countries, which are suppliers of energy sources.

In the case of Estonia, from 2012 to 2016 major impact on increased energy security had factors related to the possibility for consumers to freely choose suppliers of electricity and gas, a decrease of gas prices and the fulfilment of commitments in the EU.

The overall dynamics of ESL could also be explained analysing the variation of group weights. Fig. 6 demonstrates the dynamics of group weights in technical and economic blocks. As for Latvia and Estonia group weights didn’t change significantly during the analysed period, weights for Lithuania varies considerably.

With the closure of Ignalina NPP in 2009, the nuclear group was removed from the ESL assessment. The biggest part of nuclear weight passed to gas. As a result, the weight of the gas group in 2010 increased from 25.2% to 34.3%. As the gas supply at that time was provided from one country, this fact is one of the main reasons of the significant decrease of ESL in Lithuania. For example, the weight of the gas group for Latvia in 2010 increased less than 2% points – from 16.3% (2009) to 18.1% (2010) as well for Estonia remained the same – approximately 6.6%. Also, these differences in weights reflected to differences of energy security level for all analysed countries. However, from 2010 to 2016 wt of gas groups decrease drastically – from 34.3% (2010) to 21.6% (2016). The main reason is that majority of district heating utilities drastically changed fuel from gas to biofuel. Another reason is that Lithuania became electricity importer country instead electricity exporter

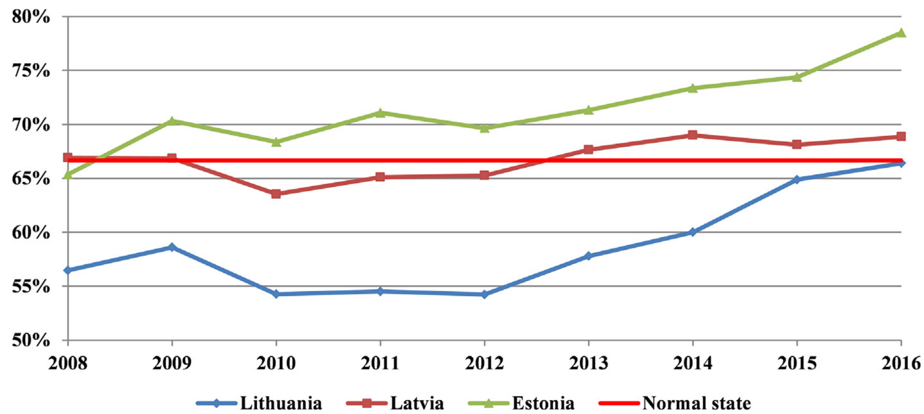

Fig. 5. The dynamics of energy security level in the Baltic States.

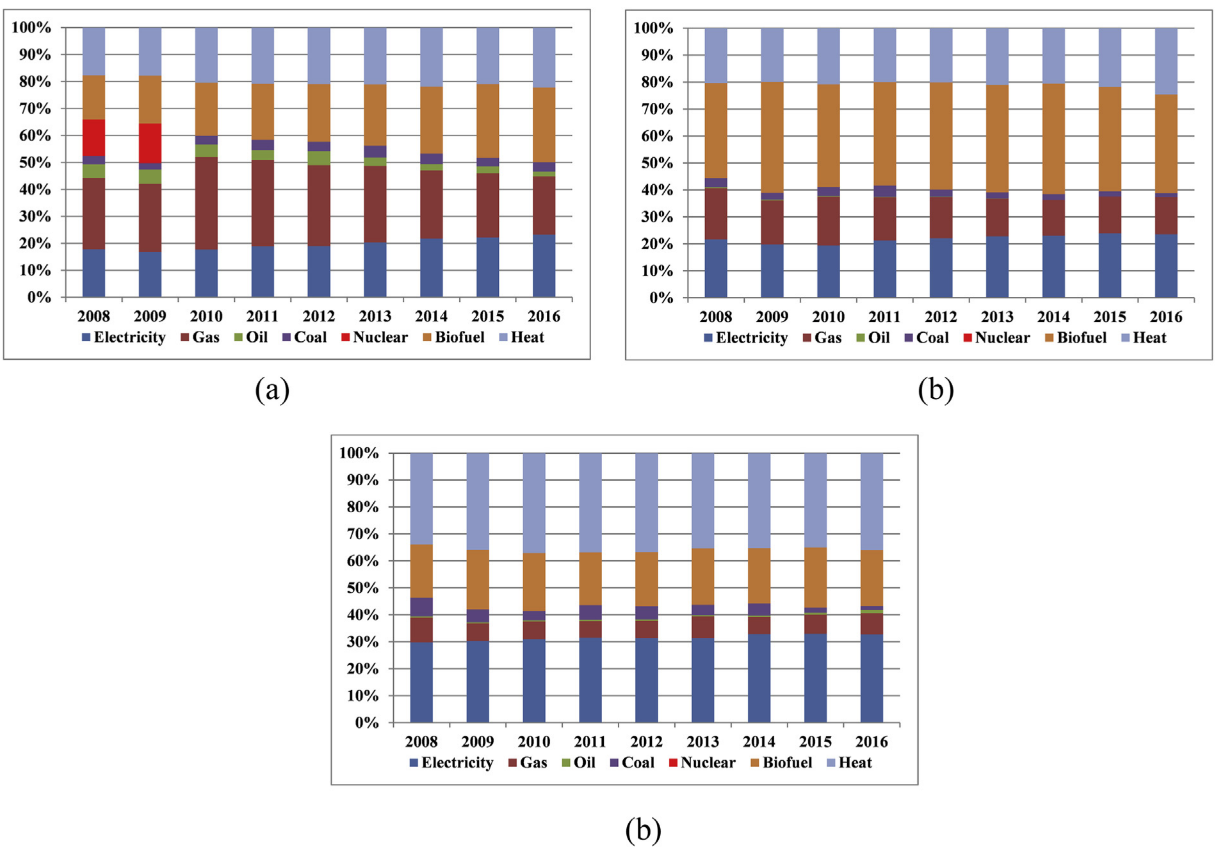

Fig. 6. The variation of weights composition in the technical and economic blocks: a) Lithuania, b) Latvia, c) Estonia.

country.

The results demonstrate that the performance of the ESL of Estonia and Latvia on average is higher in comparison to Lithuania during 2008–2016 due to various factors, discussed in this Section.

To verify whether the obtained results do not contradict with the results of other studies, summarized in Table 1, a comparison of relative country ranking according to energy security estimates was conducted. The Baltic States in each reviewed study were ranked according to the performance of index estimate. The mean rank for each country was calculated and compared to the country ranking in the presented study (see Table 2).

The ESL results of the presented study fit very well with the results of energy security estimates of other studies (see Table 2). Estonia in majority reviewed studies (11 out of 15) has the highest rank, while Latvia and Lithuania are indicated as rank 1 only in 4 studies and 1 study respectively. When comparing the mean ranking, it is observed that Estonia has the highest evaluation, Latvia is ranked as second and Lithuania – as third according to

Table 2
Comparison of relative Baltic States ranking with other studies according to energy security estimates.

Country	Estonia	Latvia	Lithuania
Number of rank 1 (out of 3)	11	4	1
Number of rank 2 (out of 3)	3	6	6
Number of rank 3 (out of 3)	1	5	8
Mean rank	**1.33**	**2.07**	**2.47**
Ranks in the presented study	**1**	**2**	**3**

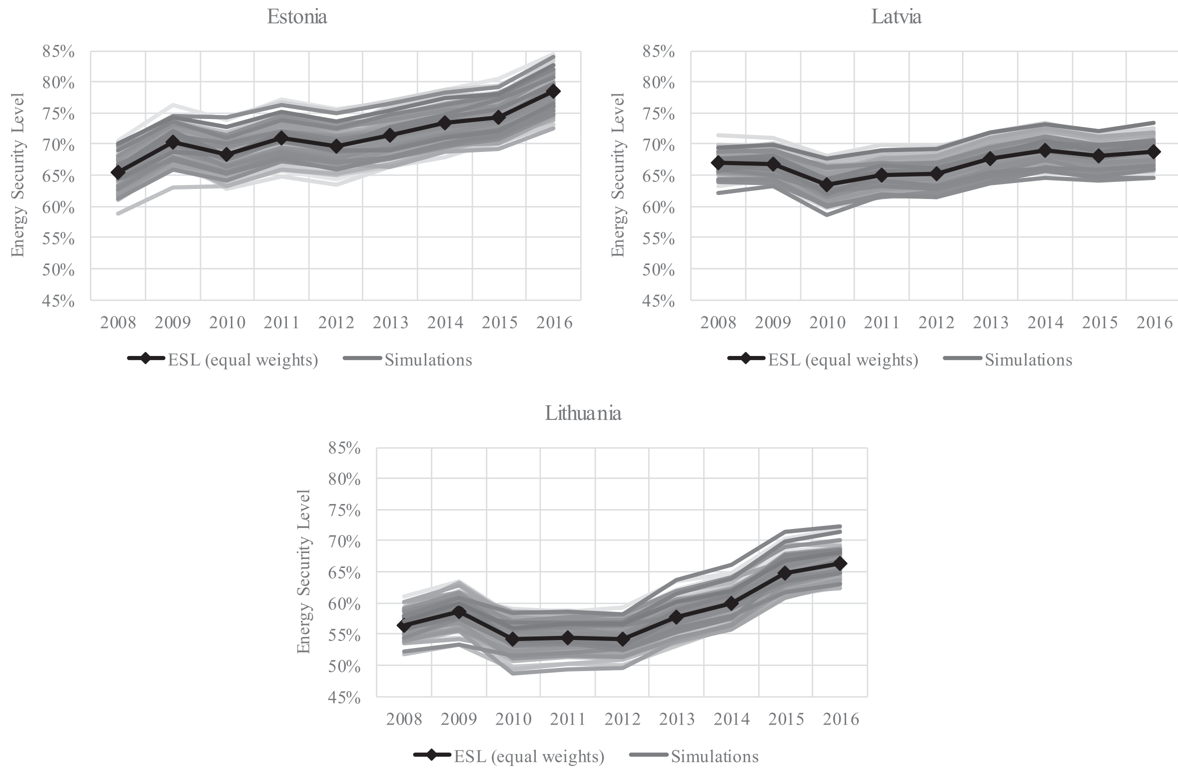

Fig. 7. The dynamics of ESL in 100 simulations.

energy security estimates.

In order to investigate the influence of indicator weights on ESL, the uncertainty and sensitivity analysis of these weights was carried out for the analysed countries. Indicator weights in the group were randomly simulated using Monte Carlo method. For simulations, Uniform probabilistic distribution with parameters [0, 1] was used. 100 runs were performed and the dynamics of ESL for these simulations are presented in Fig. 7. The analysis was performed by employing Software for Uncertainty and Sensitivity Analyses (SUSA) [51,52].

Main descriptive statistics of ESL simulations were calculated and the average ESL of simulated weights approach was compared with the ESL, obtained using equal weights approach. As seen in Fig. 7, the uncertainty analysis for analysed countries resulted in a very similar outcome, therefore results in more detail are presented only for Lithuania (Table 3) since the influence of indicators is dispersed the most.

It was observed that differences between ESL of indicators equal weights approach and average ESL of simulated weights approach are not more than 0.34% in the case of Lithuania (Table 3). For Latvia and Estonia, this difference resulted even in lower estimates, 0.15% and 0.18% accordingly.

Results in Table 3 demonstrate that the difference between minimum and maximum values of simulated ESL varies from 9.25 (in 2008) to 10.69 (in 2015). The dispersion of ESL simulations was evaluated by the relative standard deviation. The maximum relative standard deviation for Lithuania is 3.99% in 2010, while Latvia and Estonia resulted in 3.02% and 3.69% accordingly, which demonstrates low degree of uncertainty in the ESL results.

A sensitivity analysis was performed to evaluate the influence of individual indicator weight on the energy security level and identify the key input indicators on the results. The sensitivity of indicator weights was measured by standardized regression coefficient (Pearson's ordinary). Higher absolute values of this coefficient indicate higher impact of the indicator to the ESL. All indicators were ranked and five indicators with the highest rank were selected for each analysed country. Dynamics of standardized regression coefficients for these five indicators for each analysed country are presented in Fig. 8.

The results of sensitivity analysis demonstrate that indicators[1] from the socio-political block are among mostly contributing to the uncertainty of ESL. Indicators from gas group more contribute to uncertainty in the ESL in Latvia and Lithuania, while ESL of Estonia is more impacted by heat group indicators. In summary, the results of sensitivity and uncertainty analysis demonstrate that selection of indicator weights has low uncertainty in the ESL results.

5.3. The area of methodology application

The methodology presented in this study might be applied not only for the Baltic States, but for any country or energy system. For this purpose, groups and indicators (Fig. 3) should be selected according to the configuration or structure of the country under consideration. Various types of energy or fuels might be analysed (supplemented or neglected of the existing ones). For instance, if the country does not have a district heating system or nuclear energy, it can be removed from the list of indicator group or, vice versa, if the country has a specific type of fuel used for energy production or consumption, it can be included in the list of indicator group. Thus, the main modification needed for applying the methodology for energy security level quantification for other countries is only for indicator groups. The algorithm of calculations, described in subsection 4.2, does not need to be modified.

The obtained results in the presented study are beneficial for the

[1] List of all indicators is provided in the supplementary material.

Table 3
Results of uncertainty analysis for indicator weights for Lithuania.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016
ESL (equal weights)	56.46	58.61	54.26	54.51	54.22	57.8	60.01	64.88	66.41
Average ESL (simulated weights)	56.47	58.78	54.28	54.52	54.28	57.92	60.15	65.1	66.54
Mean difference, %	0.02	0.29	0.04	0.02	0.11	0.21	0.23	0.34	0.20
Minimum ESL (simulated weights)	51.75	53.36	48.74	49.28	49.55	53.15	55.7	60.72	62.46
Maximum ESL (simulated weights)	61.00	63.51	59.04	58.74	59.26	63.66	66.10	71.41	72.23
Difference between min and max ESL	9.25	10.15	10.30	9.46	9.71	10.51	10.40	10.69	9.77
Relative standard deviation, %	3.08	3.70	3.99	3.81	3.83	3.96	3.54	3.31	2.91

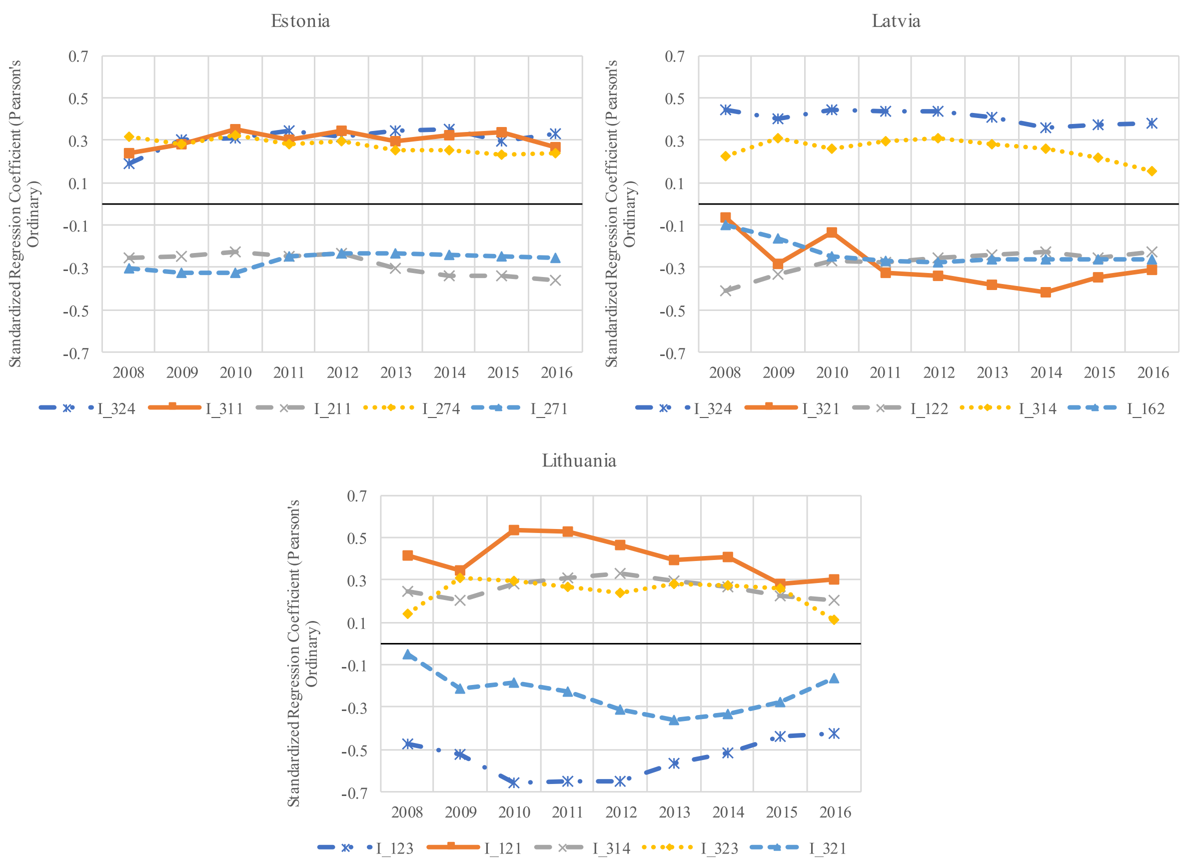

Fig. 8. Results of sensitivity analysis for highest rank indicators for each analysed country.

decision-making process at the national and European levels, showing the direction for the energy infrastructure, technologies, policy and other energy related improvements. It was already a case for the NEIS of Lithuania. Usually, strategic energy infrastructure projects have to be analysed not only from the technical and/or economic point of view, but also from the energy security perspective. For instance, a successful example of LNG terminal in Lithuania triggered the development of this technology in the entire EU. The presented study demonstrated that LNG terminal was one of the key factors to improve the energy security situation in the region.

6. Conclusions

In this paper, an analysis of three Baltic States (Estonia, Latvia and Lithuania) with regard to the level of energy security is presented. The methodology applied for this analysis is based on energy security indicator approach. Various indexes are integrated into composite energy security measure called the energy security level which allows to estimate the status of energy security of analysed country or energy system. ESL also demonstrates which measures increase or decrease energy security and can be used as a tool for decision making in energy policy and energy planning.

Energy security level in 2008–2016 for the Baltic States was evaluated using the proposed methodology. The obtained results indicate that Estonia has the best performance in terms of energy security in comparison with Latvia and Lithuania during the analysed period. All three Baltic States the highest energy security level observed in 2016–78.5% for Estonia, 68.9% for Latvia and 66.4% for Lithuania out of 100%. Estonia the lowest energy security level recorded in 2008–65.4%, while Latvia and Lithuania in 2010–63.5% and 54.2% respectively.

Estonia resulted as the best-performing country regarding energy security mainly due to domestically extracted oil shale as local fuel, high share of RES, low energy dependency, good fulfilment of EU commitments and low dependency on natural gas. The main difficulties in Estonia to have even better energy security performance were a large amount of GHG emissions, low share of purchased electricity in a free market.

The moderate energy security level of Latvia was maintained due to high share of RES (mainly hydropower), improving country's risk rating. The main obstacles to increasing energy security for Latvia were the delay in the implementation of the third energy package, particularly, in the gas sector, low share of purchased electricity in a free market, the dependence of supply of energy sources from a single supplier.

Lithuania resulted as the country with a rapidly improving energy security level during 2012–2016. This is related to new electricity connections with Sweden and Poland and LNG terminal, which allowed to eliminate dependency on a single electricity and gas supplier. Other contributing factors were a decrease in gas consumption and, at the same time, an increase of the share of local biofuels in electricity and heat production. The main difficulties in Lithuania to have higher energy security were still high energy dependency from other countries, lack of own energy resources and high share of electricity import.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Juozas Augutis: Conceptualization, Methodology, Writing - review & editing, Supervision. **Ričardas Krikštolaitis:** Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Linas Martišauskas:** Methodology, Software, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Sigita Urbonienė:** Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Rolandas Urbonas:** Methodology, Formal analysis, Writing - review & editing. **Aistė Barbora Ušpurienė:** Writing - review & editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.energy.2020.117427.

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