Thresholds of energy security metrics: their purpose and assessment techniques

Yuri Kononov* and *Dmitrii* Kononov

Energy Systems Institute of Siberian Branch of the Russian Academy of Sciences, 664033 Lermontov St., 130, Irkutsk, Russia

Abstract. The study discusses the issue of enhancing the validity of projections of energy sector development by properly accounting for the effect of available options on energy security. To this end, it is possible to use a single overall index that measures the degree of deviation of individual energy security metrics from their threshold values. We detail different ways of calculating maximum allowable values of individual metrics. The study also provides the results of modeled calculations. We argue that any indicator-based analysis of thresholds should be preceded by an assessment of strategic energy security threats and identification of the stability range for the dynamics of key projected indicators. **Keywords:** energy security, energy sector, projections, threshold values.

1 Introduction

Threshold values of metrics that indicate the critical level of threats to national, economic, and energy security are used at different levels of governance. It is an important tool for systems analysis, forecasting, and socio-economic planning [1].

The need to develop quantitative thresholds of metrics was declared in the State Strategy of Economic Security of Russia as far back as 1996 when it was approved. The strategy stated the need to develop quantitative and qualitative parameters (thresholds) of the state of the national economy. Exceeding the thresholds indicated a threat to the economic security of the country.

Thresholds of economic security can be understood as the limits of its parameters, violation of which hinders the sustainable operation and development of the energy sector and economy and may contribute to transitioning to the state of instability and high risks in the production and consumption of energy carriers.

Methodological guidelines for energy security performance assessment of the Russian Federation at the federal level, developed in 2013 [2], recommended for the purpose of monitoring energy security performance to revise the adopted system of metrics with a certain frequency, and their numerical values should be compared against specified maximum permissible threshold values. According to the degree of deviation of individual metrics or their entirety (aggregated value) from their thresholds, energy security performance is deemed normal, pre-critical, or critical.

*Corresponding author: kononov@isem.irk.ru

Ref. [3] listed 29 metrics characterizing the reliability of fuel and energy supply to consumers and made a tentative assessment of their threshold values. It can be argued that in energy sector projections this mix of indicators, on the one hand, is excessive, and on the other hand, proves inadequate for capturing the economic and environmental aspects of energy security [4]. It should be noted that in the structure of composite indices used abroad to assess the performance of the country's energy security, the share of the economic component amounts to 25-30%.

It can be argued that the composition of the adopted energy security metrics should depend on the time frame being considered. As the projection time frame extends, the number and importance of metrics that are descriptive of the economic and ecological systems of energy security changes and increases.

2 An approach to compare energy sector development options with respect to the energy security criterion

We propose to use the following composite index (OESI, overall energy security index) to evaluate and compare energy sector development options with respect to the energy security criterion given the specified (expected) thresholds of energy security metrics:

$$\text{OESI} = \sum_i \left(1 - I_i / \overline{I_i}\right) \cdot \gamma_i \,, \qquad (1)$$

where I_i and $\overline{I}_i$ are the current value and threshold of the metric/indicator i, and γ_i is its specific weight (relative importance).

Available policy documents on strategic planning, targets defined by the energy strategy and long-term state energy policy can be used as a reference point for numeric estimates of future threshold values of some of the metrics related to the input data of projections.

The identification of stable boundaries in energy and economic dynamics can be instrumental in determining some thresholds of energy security metrics. A case in point is the so-called Bashmakov constant [5]. Its author found out that if a country's total expenditures on energy carriers as a GDP percentage is greater than 10-11%, that country's economy will compromise its ability to grow rapidly. If the share is below 8%, it is almost guaranteed that that economy will not be able to improve its energy efficiency quickly because energy as a resource is very cheap. The ratio of energy costs to GDP oscillates within a narrow range with an upper bound close to 10-11% and a lower bound close to 7-8%. According to the analysis by A. Konoplyanik [6], this range over long periods of time is typical of both net importers and net exporters and manifests itself not only in the energy sector as a whole, but also in its individual industries. The analysis of statistical data available on different countries confirmed the loss of sustainability of economic growth when the Bashmakov constant was exceeded. The results of such an analysis as applied to the USA were reported e.g., in [7].

When determining the thresholds of the metrics in question, it is essential to analyze the trends in their change in relation to the conditions of economic and energy development. The upper limit of the oscillation in the value of a metric, i.e., the standard deviation from the trend (σ), can serve as a reference point. In this case, its threshold can be assumed to be equal, for example, to a deviation of 2σ.

Optimization models of the energy sector, systems of its individual industries, and overall economy are an important methodological tool for estimation of threshold values of a number of energy security metrics that are calculated as part of projections. They make it possible to measure the effect of changes in the given and desired variables on the optimality criterion used (objective function of the model) under the assumed conditions and in compliance with requirements of balanced development. Depending on the aims and the object of projections, the criteria to be optimized may be, for example, the minimum of the cost of energy supply or the maximum of the GDP. In this case, however, there is a problem of determining the permissible limits of change of the criterion itself.

In general, we can assume that uncertainty of input data affects the error of calculation results. Then

$$\Delta F \leq \sum_i Y_i \gamma_i \,, \tag{2}$$

where ΔF is the acceptable error of the model's objective function, %; Y_i is the uncertainty interval of input data, γ_i is their weight (the extent to which they influence the objective function).

Projections of the development of the energy sector and its constituent systems of individual industries require consideration of several scenarios and multiple options. The results of contingency calculations allow one to form a rightward-expanding "cone of uncertainty" of possible dynamics of some key indices. Its boundaries can be indicative of the threshold values of some of the energy security metrics.

3 Results

One of the important energy security metrics used (with a high weight assigned to it) in all comprehensive assessments of energy security performance published abroad is the cost of electricity. Our research aimed to assess the effect of various factors on the value of this metric and its thresholds (Fig. 1).

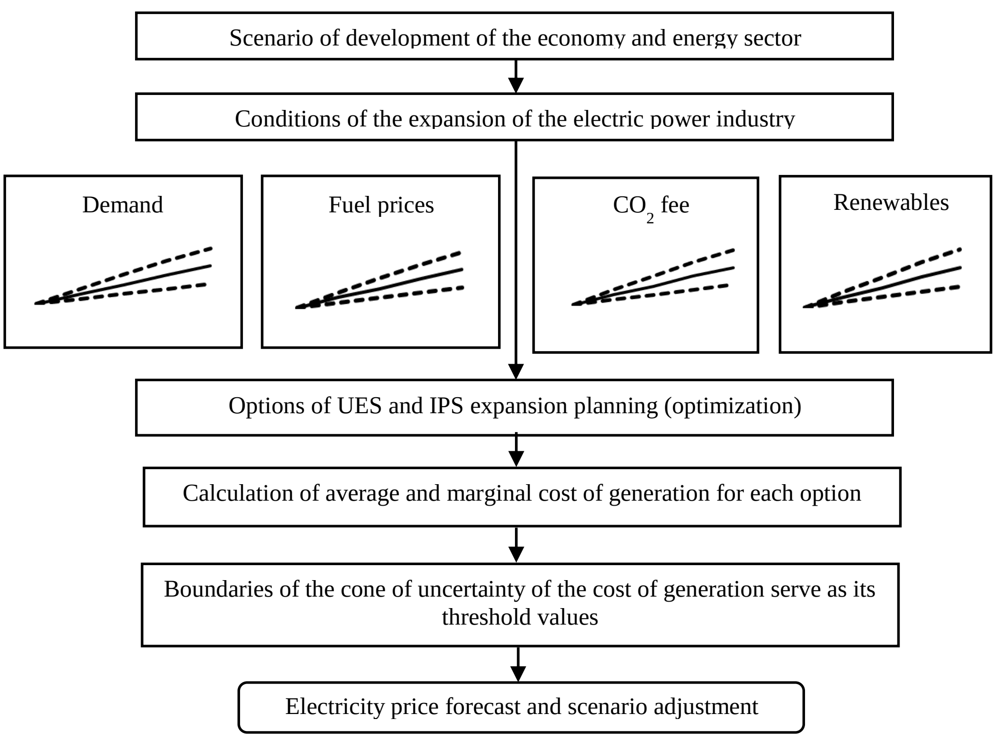

Fig. 1. Flowchart of the procedure for the calculation of threshold values of the cost of electricity generation in the UES.

We considered power supply options for European Russia, the Ural, Siberia, and the Russian Far East under different gas prices for power plants, different penalties for CO2 emissions, and other conditions. Electricity demand and capacity constraints for new power plants were assumed based on the reference case scenario detailed in "The Master Plan of Placement of Electric Power Industry Facilities to 2035" (approved by the Government in 2017) [8]. It should be noted that the cost of electricity and other costs were not reported in Ref. [8].

We relied on the MISS-EL model [9] to perform our calculations. The model combines optimization of regional energy supply system development with the Monte Carlo method [10]. Another feature specific to the model (computer program) is the possibility of specifying all input data and constraints as ranges of their probable values. These features allow us to obtain and summarize multiple variants (hundreds thereof) that prove balanced with respect to the criterion of minimum costs for power supply of the geographic area in question.

The calculations revealed pronounced regional disparities not only in the cost of electricity generation, but also in the response to changes in scenario conditions. For example, its maximum deviation from the cost in the reference case amounted to 10% in the North-Western region (IPS), 16% - in the Central region, and 20% - in the Ural.

The results of contingency calculations are summarized in Fig. 2, which shows the possible dynamics (cone of uncertainty) of the marginal cost of electricity under the considered conditions. The dynamics is indicative of the cost per kWh at balancing power plants and can serve as a reference point for the threshold value of the cost of electricity generation in the investigated geographical area. In market-driven economies, marginal cost serves as the basis for electricity pricing (including transportation tariffs and taxes).

Outcomes yielded by a quantified assessment of thresholds of energy security metrics depend on a given economic and energy development scenario. They are also influenced by the results of identification of strategic threats. Their thresholds, in turn, depend on the range of stability of the dynamics of key metrics that are calculated as part of long-term projections.

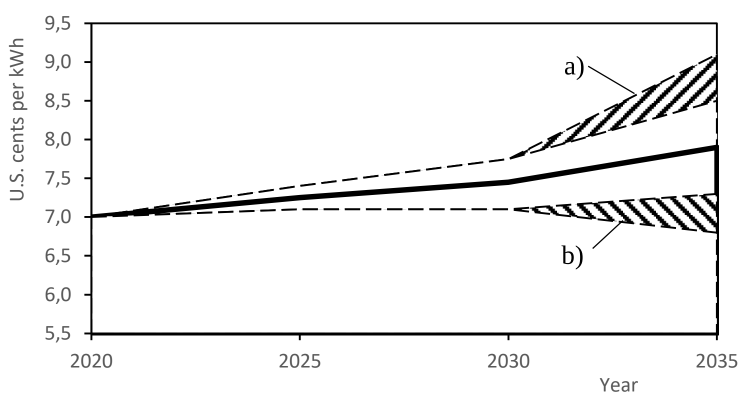

Fig. 2. Uncertainty range (cone) of the weighted average marginal cost of electricity generation in the Unified Energy System (UES) of the country.

Note. Results of modeled calculations to 2035 at an average annual GDP growth rate of 2.6%. The reference case is indicated by the bold line, Area a) stands for cost increase with CO2 emissions penalty, Area b) stands for a cost decrease with reduction in the discount rate (return on investment) from 10 to 5%.

As the projection time frame extends further into the future, there is a decrease in importance of quantified assessments of thresholds of individual energy security metrics and indicator-based analysis of energy security performance as a whole. Furthermore, an increasingly important role is played by the assessment of strategic threats and, as a result, that of the scope of the opportunities available for energy sector development under different scenarios of economic growth (Fig. 3).

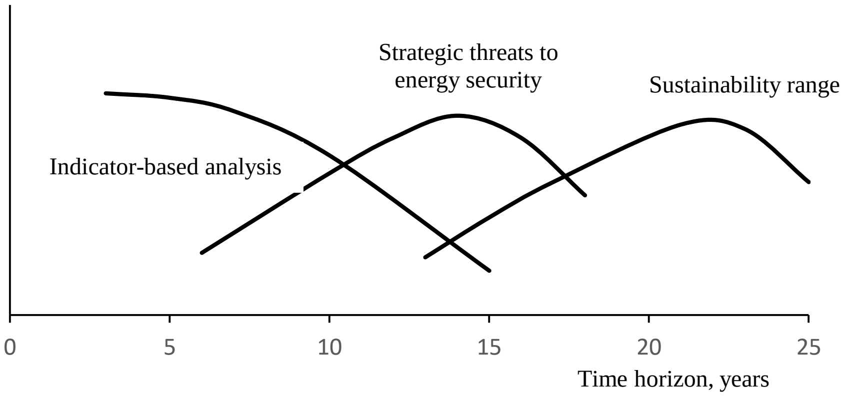

Fig. 3. The preferred method of assessing energy security performance as a function of the time frame considered.

4 Conclusion

We argue that evaluating energy sector development options should be based not only on their economic feasibility, but also on their impact on energy security performance and respective strategic threats. To that end, an important role can be played by the numerical assessment of thresholds of indicators and indices of energy security dealing with its economic component.

Indicator-based analysis of the energy security of the country and its regions is key for projections that extend 5 to 10 years into the future. It should result in an overall energy security index. The index can be formed not only as a sum of individual metrics having different weights assigned to them to reflect their importance (as it is done abroad), but also can be determined so as to factor in their deviation from specified threshold values.

Methods for evaluating thresholds of metrics capturing the likely energy security performance of the country and its regions await further development.

One of the essential and still unresolved problems in energy security studies is to assess thresholds of metrics of the economic component of energy security as a function of the scenarios of socio-economic development of the country, forecasts of technological change, and other factors.

Projections of likely electricity price dynamics is of particular practical importance in the development of energy strategy and policy. It is also crucial to estimate its thresholds for both producers and consumers under different scenarios of external and internal conditions. Further development of the methods and techniques of systems analysis is required to address this challenge. Such methods and techniques should take into account price elasticity of demand, price interrelationships in the energy sector and the economy, and the ability to adapt to strategic threats to energy security.

The research was carried out under State Assignment Project No. FWEU-2021-0003 (reg. No. AAAA-A21-121012090014-5) of the Basic Research Program of the Russian Federation for 2021-2030 using the resources of the High-Temperature Circuit Multi-Access Research Center (Ministry of Science and Higher Education of the Russian Federation, project no 13.CKP.21.0038).

References

1. V.K. Senchagov, Economic Security of Russia: A General Course. Textbook, Moscow, Delo, 896 p. (2005) (in Russian)
2. Methodological guidelines for energy security performance assessment of the Russian Federation at the federal level, Ed. by S.M. Senderov, Irkutsk, 35 p. (2013) (in Russian)
3. S.M. Senderov, V.I. Rabchuk, N.I. Pyatkova, S.V. Vorobev, Ensuring Russia's energy security: setting priorities, Novosibirs, Nauka, 116 p. (2017) (in Russian)
4. Yu.D. Kononov, Assessment and factoring in of the economic component of energy security in projection studies of the energy sector, *Stud. Russ. Econ. Dev.*, **32**, p. 155-159, (2021) DOI:10.1134/S1075700721020076
5. I.A. Bashmakov, Three Laws of Energy Transition, *Energy Policy*, **35**, p. 3583-3594 (2007) DOI: 10.1016/j.enpol.2006.12.023
6. A.A. Konoplyanik, Energy Suicide of Europe, *Ekspert*, **11**, p. 66-69 (2022) (in Russian)
7. F. Fizaine, V. Court, Energy expenditure, economic growth, and the minimum EPOI of Society, *Energy Policy*, **95**, p. 172-186 (2015)
8. The Master Plan of Placement of Electric Power Industry Facilities to 2035. 80 p. URL: http://static.government.ru/media/files/zzvuuhfq2f3OJIK8AzKVsXrGIbW8ENGp.pdf (Accessed on: 26.10.2023) (in Russian)
9. Yu.D. Kononov, V.N. Tyrtyshny, Assessment of the impact of initial-data uncertainty on the efficiency of regional power and fuel supply scenarios in forecasting research, *Stud. Russ. Econ. Dev*., **24**, p. 67-70 (2013) DOI: 10.1134/S1075700713010061
10. S.M. Ermakov, Monte-Carlo methods and related problems, Moscow, Nauka, 1975, 472 p. (in Russian)