

# SCIENTIFIC HORIZONS

Journal homepage: <https://sciencehorizon.com.ua>

*Scientific Horizons*, 24(4), 90-96



UDC 351:338.22

DOI: 10.48077/scihor.24(4).2021.90-96

## Methodical Approach to Assessing Level of the State Energy Security and Its Influence on the National Security and Economy of the Country

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### Article's History:

Received: 22.07.2021

Revised: 20.09.2021

Accepted: 23.10.2021

### Suggested Citation:

Semenenko, O., Solomitsky, A., Onofriichuk, P., Chernyshova, I., Skurinevska, L., & Pekuliak, R. (2021). Methodical approach to assessing level of the state energy security and its influence on the national security and economy of the country. *Scientific Horizons*, 24(4), 90-96.

**Abstract.** This paper presents possible methodical approach to assessing level of the state energy security and its influence on the national security. In order to ensure proper level of the national security of the state, it is necessary to assess dangers in a great variety of areas, particularly, in the energy sector. Authors of this paper propose a version of solving the problem with the help of application of the state-of-the-art information technologies on the basis of the intellectual analysis of statistical data. The authors provide general description of the methodical approach in order to assess dangers for the existing level of the energy security. This approach is based on the comprehensive application of the grouped expert estimates, as well as on the theory of the experiment planning (the experimental design theory) and on the group method of data handling. The proposed approach is characterised by its relative simplicity and usability from the point of view of application of the already existing software products. The results, which would be obtained with the help of this method, can be easily interpreted and analysed. In addition, this paper proposes more adequate approach to understanding level of the energy security, as well the level of the national security of the state. The paper presents the specific example for assessing level of the energy security as well as procedure for finding explicit form of the computational functional with the help of the software GMDH Shell, which makes it possible to increase validity of the derived data as compared with the known approaches. Subsequent investigations will be carried out with the purpose of development of the scientifically substantiated approach to identification of the relevant criterial values of the danger indicators in order to ensure making adequate decisions in respect of responding to these dangers

**Keywords:** national security, economy of the country, GMDH Shell software, information technologies, energy



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## INTRODUCTION

In these recent times, problems of the energy security of various countries grow worse and assume more importance. Manipulations with supplies of electric power and energy resources bring the state to the brink of catastrophe, because state of economy of various countries to a considerable degree depends on the state of assurance in energy resources. In these conditions, arrangement of conditions for neutralisation or elimination of hazards (both for the entire energy system, and for economy of the country) is the necessary condition of existence and development of the state. In other words, it is necessary to ensure energy security (hereinafter to be referred to as the "EnS") of the country. Energy security is one of the most important components of the national security; energy security is the condition, which is necessary in order to ensure sustainable development of the state. Energy security envisages achievement of the state of assurance (namely, state of the technically reliable, stable, economically efficient and ecologically safe assurance) of energy resources in the sphere of economy, as well as in the sphere of social protection of the state.

As for today, identification of the entire spectrum of hazards to the EnS, classification of these hazards, as well as identification of the approaches to assessing the energy security state of the country is the actual scientific task. Such assessing is of key importance for identification of the rational methods of the national security assurance (through increasing the national security). Analysis of the recent investigations and publications testifies that much attention is paid to investigation of issues of the EnS [1]. Unfortunately, lack of systematicity is inherent to the majority of papers. In other words, the EnS is only analysed in one of the aspects (resource, technological, and normative aspect). In these conditions, hazards of the economic nature are stated, for the most part, and considered as the main hazards. This fact significantly narrows down potentialities in respect of reliable and adequate assessing state of the EnS in the country. Hazards to the EnS are as follows: events of the short-time nature or long-run nature, which can destabilise operation of the entire energy sector, limit energy security or commit violation of energy security, as well as which can cause failures/emergencies and other negative consequences for the power industry, economy, and general public at large [2].

The analysis, which was carried out, has made it possible to perform conventional classification of various hazards to the EnS in accordance with several groups: economical hazards, social and political hazards, as well as external, technological, and natural hazards.

**Group of economical hazards** to the EnS includes the following hazards: lack of strategy of development of the fuel and energy complex; excessive energy consumption of economy, inefficiency of utilisation of fuel and energy resources, counterproductive structure of the fuel and energy complex of the state; shortage of funds available for investment (scarcity of investment resources);

financial instability, which is to ensure performance of the entire energy sector; inefficient utilisation of fuel and material resources; lack of reserves of the fuel and energy resources; low innovation activity of energy enterprises; inefficiency of tariff and price policy; high prices of fuel and material resources; monopolistic behaviour of producers, suppliers, and distributors of electric power and fuel resources; imbalance of production and consumption of fuel and energy resources.

**Social and political hazards.** This group of hazards include the following hazards: instability in society; negative social and political events; unsound competition; unlawful actions of authorities and managers of enterprises; low qualifications of personnel; criminalisation of the "power supply business".

**External hazards:** excessive dependence of economy on the external monopolistic sources of supply of fuel and energy resources, power-generating equipment, materials, failures in performance of the contractual deliveries; absence of diversification of the sources and methods of the electrical power supply; discrimination measures from the part of other countries; critical dependence of export and import on the conditions of transportation through territories of other countries.

**Technological hazards:** high degree of wear-and-tear of the basic production assets at the enterprises of the fuel and energy complex; low technical level and quality of equipment and systems; non-observance of: the operating and maintenance rules, workplace safety and health regulations, and fire-prevention measures.

**Natural hazards:** natural disasters; natural anomalous phenomena [3-5].

*The purpose of the study* is to present description of possible approach to assessing hazards to energy security of the country within the framework of influence of these hazards on the national security and economy of the country.

## MATERIALS AND METHODS

The main problem is connected with identification of influence of these hazards on the level of the energy security. In these conditions, classic approach in such situations envisages [6] procedure of making payments with the help of elements of the vector-matrix algebra. For example, level (the current state) of the EnS ( $E_{EnS}$ ) is usually calculated taking into account the specific contribution of each indicator.

Level of the energy security state is calculated as the weighted product of the security levels of various components of the energy system (1, 2):

$$E_{EnS} = \sum_{i=1}^n \alpha_i E_i \quad (1)$$

$$\sum_{i=1}^n \alpha_i = 1 \quad (2)$$

where:  $E_{EnS}$  is actual current state of the EnS (as the efficiency of performance of the entire energy system of the state);  $\alpha_i$  is the degree of influence of each  $i$ -th component of the energy system upon general security.

In other words, in order to implement this method, it is necessary to determine dependence  $E_i$  of the  $i$ -th group of factors and evaluate (with the help of the expert method or any other method) values of contributions  $\alpha_i$  of each factor from a group of factors to general level of the energy security [7].

That is, the task comes down to the fact that with the help of the known functions  $E_i(m_{ij})$  of the  $m_{ij}$  factors of each  $i$ -th group ( $i=1, n$ ) to assess general level of the EnS. From the point of view of the vector-matrix algebra, function of efficiency  $E_i(m_{ij})$  of any one of the components of the entire system can be presented by the multidimensional ( $j=1, m_{ij}$ ) by vector ( $\bar{E}_i$ ) in the coordinate form in such a manner (3):

$$\bar{E}_i = E_{i1}\bar{i} + E_{i2}\bar{j} + E_{i3}\bar{k} + \dots + E_{ij}\bar{s} + \dots + E_{im}\bar{l} \quad (3)$$

where:  $E_{i1}, E_{i2}, E_{i3}, \dots, E_{ij}, \dots, E_{im}$  are coordinates of the vector  $\bar{E}_i$  within the  $m$ -dimensional space with orthonormal basis, which is represented as the pairwise orthogonal

unit vectors  $\bar{i}, \bar{j}, \bar{k}, \dots, \bar{s}, \dots, \bar{l}$ ;  $m_{ij}$  is quantity ( $j=1, m_{ij}$ ) of the factors, which are usually taken into account in the  $i$ -th component ( $i=1, n$ ) of the system. In these conditions, it is assumed that multitude of coordinates (of elements)  $E_{ij}$  ( $i=1, n, j=1, m_{ij}$ ) creates matrix in the following form (4):

$$\|E_{ij}\| = \begin{pmatrix} E_{11} & E_{12} & E_{13} & \dots & E_{1j} & \dots & E_{1m} \\ E_{21} & E_{22} & E_{23} & \dots & E_{2j} & \dots & E_{2m} \\ E_{31} & E_{32} & E_{33} & \dots & E_{3j} & \dots & E_{3m} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ E_{i1} & E_{i2} & E_{i3} & \dots & E_{ij} & \dots & E_{im} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ E_{n1} & E_{n2} & E_{n3} & \dots & E_{nj} & \dots & E_{nm} \end{pmatrix} \quad (4)$$

Elements of rows of this matrix are coordinates of relevant vectors  $\bar{E}_i$ . These coordinates are initial / original data for calculation of values of modulus of the vector  $\bar{E}_i$ . Provided that this modulus is determined as the scalar product of this same vector with itself (it is equal to the sum of products of the coordinates having the same names) or as the squared elements of the  $i$ -th rows of the matrix  $\|E_{ij}\|$  in such a manner (5):

$$|\bar{E}_i| = E_i = \sqrt{(\bar{E}_i \cdot \bar{E}_i)} = \sqrt{E_{i1}^2 + E_{i2}^2 + E_{i3}^2 + \dots + E_{ij}^2 + \dots + E_{im}^2} = \sqrt{\sum_{j=1}^m E_{ij}^2} \quad (5)$$

In principle, this expression determines value of efficiency  $E_i$  of one or another component of the entire system. Each coordinate of the  $\bar{E}_i$ -th of vector (of the  $i$ -th component), in its turn, is the function of the relevant ( $m_{ij}$ -th) of the factor, which assists in increasing this function.

### RESULTS AND DISCUSSION

In accordance with such approach, the most complicated problems are the following ones: identification of weight of factors ( $\alpha_i$ ); identification of the actual form/view of the function  $E_{EnS} = f(E_i)$  (1).

In order to solve these problems, it is proposed to use the following approach [8], which is based on the theory of the experiment planning (the experimental design theory) [9], as well as on the group method of data handling (GMDH) [10-14].

The following proposition is made for the selected experts in the EnS issues: to assess influence of the assembly of the identified hazards to energy security upon general level of the energy security. It is proposed the following for these experts: to fill in the table of plans of the experiment (Table 1), which was compiled in accordance with results of papers [12; 14].

**Table 1.** Plan of the experiment for assessing level of the energy security ( $E_{the\ EnS}$ )

Seq. Nos. of hazards	Value of the partial parameter					Value of the integral parameter $E_{EnS}$ , in the opinion of the expert
	$E_{ec}$	$E_{sp}$	$E_z$	$E_t$	$E_n$	
1.						
2.						
...						

In other words, these experts will determine general form of the dependence  $E_{EnS} = f(E_i)$  [11] with the help of their intuitive methods. In these conditions, this function will have the following form for the above-proposed list of hazards:

$$E_{the\ EnS} = f(E_{ec}, E_{sp}, E_{ext}, E_t, E_n) \quad (6)$$

where:  $E_{ec}, E_{sp}, E_{ext}, E_t, E_n$  are levels of economical, social and political, external, technological and natural hazards respectively.

At this stage, value  $E_{EnS}$  is determined at the discretion of the selected expert in accordance with the values of the input variables, while from this point on this value will be used in order to ensure formalisation

of this dependence. In the cases of selection of several experts, it is necessary to determine one of them, estimates of which are the most reasonable. With this aim in view, it is proposed to apply the “Kemeny median” [15]. Particularly, in order to derive the averaged outcome estimate of the agreed group of experts, it is necessary to minimise the total distance (metric) between binary relations [11; 16].

Distance (metric) between binary relations  $A$  and  $B$ , which are described as matrices  $\|a_{ij}\|$  and  $\|b_{ij}\|$ , respectively, is the following number (7):

$$d(A, B) = \sum |a_{ij} - b_{ij}| \quad (7)$$

Summation is performed over all values  $i, j$ , that is, the Kemeny distance is equal to the sum of modules of differences of those elements, which stand at the same places in the relevant matrices [17]. In order to perform subsequent analysis, it will be necessary to select those results of the experts’ work, which are the most averaged values in respect of other estimates. In these conditions, it is necessary to take into account that coefficient of concordance (which characterises degree of the opinion consistency of experts) must be not less than 0.75 [15].

$$y = f(x) = a_0 + \sum_{j=1}^k a_j x_j + \sum_{j=1}^k a_{jj} x_j^2 + \sum_{j,\gamma=1}^k a_{j\gamma} x_j x_\gamma + \dots + \sum_{j=1}^k a_{jjj} x_j^3 + \dots \quad (8)$$

where:  $j < \gamma < k$ .

Immediate assessing the level of the energy security is performed due to substitution of actual values of the partial indicators ( $E_{ec}, E_{sp}, E_z, E_v, E_n$ ), which were identified by experts, to the computational dependence, which was derived on the basis of GMDH.

With the purpose of simplification of perception of the derived results, it is proposed to perform normalisation of the calculated values within the range  $0 \div 1$  (or  $0 \div 100\%$ ) provided that the following condition will be kept and valid: the higher value, the higher hazard. In accordance with the results of assessing a hazard (on the condition of application of the inverse analysis [10]), it is possible to ensure formation of the list of main hazards to energy security of the state, as well as to ensure development of propositions in respect of neutralisation

In the case of non-performance of this condition, group of experts must be collected and formed once again.

In order to derive the dependence (2) in the explicit form (in the form of a functional), the experiment plan, which was completed by the selected expert, will be further processed with the help of the GMDH, which makes it possible to obtain the mathematically formalised connection between values of the partial indicators and value of the summarising indicator. In other words, it will be possible to obtain the formalised description of the expert’s subjective opinion [13]. The statement of the problem in general terms will be presented as follows: let there be a sample of “ $A$ ” observations of the input  $X(i)$  and of output  $Y(i)$  vectors. In accordance with the results of these observations, it will be necessary to determine  $F(x)$  on the condition that structure of the  $F(x)$  model is not known. The most comprehensive dependence between  $X(i)$  inputs and  $Y(i)$  outputs can be presented with the help of the Kolmogorov-Gabor polynomial (as generalized polynomial) [18].

Therefore, let there be the sample of  $X = \{x_1, \dots, x_N\}$ , then such polynomial must have the form, which is presented in formula (8):

of these hazards, as well as in respect of minimisation of possible negative consequences for the national economy of the state. In accordance with results of the known approaches ([10; 19; 20]), it is proposed (in the course of such analysis) to determine general level of the national or economical security depending on the current state of the energy security  $Q(E_{EnS})$  (taking into account goal of the investigation, it is possible to ignore groups of the factors, which are not connected with the energy security, and consider these factors as constants) as dependence of such form:

$$Q(E_{the EnS}) = 1 + e^{-E_{EnS}} \quad (9)$$

Graph of the function  $Q(E_{EnS})$  is presented in Figure 1.

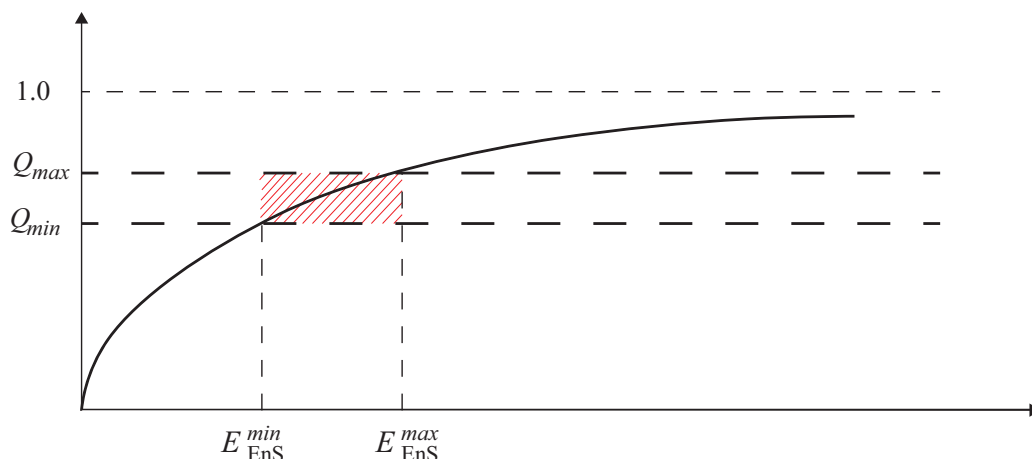


Figure 1. Dependence of the national security of the state on the energy security

In the case of application of such approach, expression (1) will be presented in the form of (10) however, this expression (as it was demonstrated by

results of practical investigations [11]) does not correspond to actual processes.

$$E = \sum_{i=1}^n \alpha_i E_i = \sum_{i=1}^n \alpha_i \sqrt{(\bar{E}_i \bar{E}_i)} = \sum_{i=1}^n \alpha_i \sqrt{\sum_{j=1}^m E_{ij}^2} = \sum_{i=1}^n \alpha_i \sqrt{\sum_{j=1}^m (1 - e^{-m_{ij}})^2} \quad (10)$$

In order to increase reliability of the results, it is proposed to apply the S-shaped curve (the Verhulst equation) (Fig. 2) (11):

$$Q(E_{EnS}) = \frac{1}{1 + e^{-E_{EnS}}} \quad (11)$$

In the case of application of such approach, range of the acceptable values of the EnS narrows down, however, rate of change in the relevant indicators is changed, and this fact is confirmed by practice. In these conditions, there will be no limitations in respect of consistency of forms of the functions  $Q(E_{EnS})$  and  $E_{EnS} = f(E_{ec}, E_{sp}, E_z, E_r, E_n)$ .

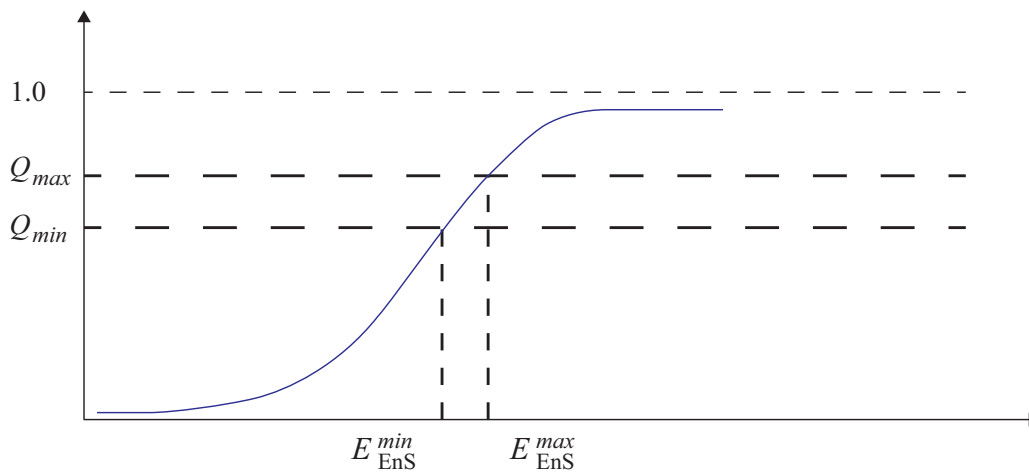


Figure 2. Dependence of the national security of the state on the energy security (the version, which is proposed to apply)

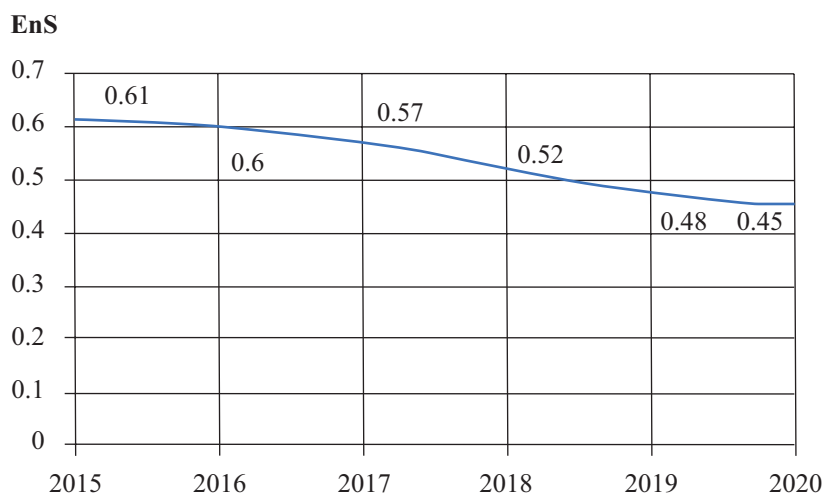
Example of practical assessing the level of the energy security. In order to ensure immediate and direct assessing the level of the energy security, three experts were selected, who have completed relevant tables (Table 1) and assessed general level of the EnS depending on the values of partial hazards. These data were further processed with the help of the GMDH Shell software application, therefore, it was possible to derive relevant functional, which describes connection between the input

and output parameters (this description was not included to this paper due to great volume of this description). The derived model is characterised by sufficiently high accuracy in respect of the initial/original data (Fig. 3), and this fact evidences working capacity of this model and possibility of its application in the course of practical activities. The derived values of the EnS and  $Q(E_{EnS})$  levels are presented in Figure 4 and Figure 5 (these results are presented as the data of a hypothetical nature).

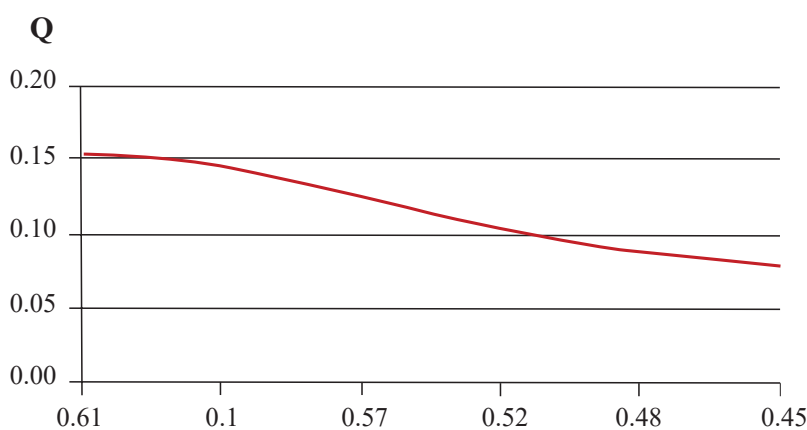
Error measure	Absolute ▼	Target: K	
Postprocessed results		Model fit	Predictions
Number of observations		16	4
Max. negative error		-1,22569E-13	-4,61853E-14
Max. positive error		7,81597E-14	1,30562E-13
Mean absolute error (MAE)		4,90719E-14	5,42899E-14
Root mean square error (RMSE)		5,87076E-14	7,07333E-14
Residual sum		-1,24345E-14	7,86038E-14
Standard deviation fo residuals		5,87025E-14	6,79488E-14
Coefficient of determination (R <sup>2</sup> )		1	1
Correlation		1	1

} It must be close to 0  
 } It must be close to 1

Figure 3. Estimate of accuracy of the derived model



**Figure 4.** Change in the level of EnS for Ukraine during 2015-2020



**Figure 5.** Change in the level of the national security depending on the EnS value

## CONCLUSIONS

The proposed methodical approach is based on the application of the state-of-the-art information technologies in respect of the intellectual analysis of the data. It makes it possible to ensure adequate assessing the level of the state energy security and its influence on the national security. In future, this approach makes it possible to carry out more substantiated investigations of the energy security of the state, particularly, to determine degree of influence of hazards, their interconnection, as well as to develop the comprehensive system of relevant indicators for assessing efficiency of the measures with

the purpose of further increasing level of the energy security.

The above-presented example of the procedure of calculations confirms working capacity of this approach and possibility of its application in the course of assessing general state in the energy sphere. Subsequent investigations will be carried out with the purpose of development of the scientifically substantiated approach to identification of the relevant criterial values of hazard indicators in order to ensure making adequate decisions in respect of making relevant decisions.

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### Методичний підхід до оцінювання рівня енергетичної безпеки держави та її впливу на національну безпеку та економіку країни

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**Анотація.** У статті викладений можливий методичний підхід до оцінювання рівня енергетичної безпеки держави та її впливу на національну безпеку. Для забезпечення належного рівня національної безпеки держави потрібно оцінити загрози у широкому колі сфер, зокрема у енергетичній сфері. Автори пропонують варіант розв'язання цієї проблеми за допомогою застосування сучасних інформаційних технологій на основі інтелектуального аналізу статистичних даних. У науковій статті автори надають загальний опис методичного підходу оцінювання загроз рівня енергетичної безпеки. Підхід ґрунтується на комплексному використанні групових експертних оцінок, теорії планування експерименту та методу групового врахування аргументів. Запропонований підхід характеризується відносною простотою та зручністю з точки зору використання вже існуючих програмних продуктів. Отримані за його допомогою результати легко інтерпретуються та піддаються аналізу. Крім цього у статті пропонується більш адекватний підхід до визначення зв'язку рівня енергетичної безпеки та національної безпеки держави. У статті пропонується приклад оцінювання рівня енергетичної безпеки з визначенням явного виду розрахункового функціоналу за допомогою програми GMDH Shell, що дозволяє підвищити достовірність отриманих даних порівняно з відомими підходами. Подальші дослідження будуть проводитися в напрямі розроблення науково обґрунтованого підходу до визначення відповідних критеріальних значень показників загроз для забезпечення прийняття адекватних рішень щодо реагування на ці загрози

**Ключові слова:** національна безпека, економіка країни, програмне забезпечення GMDH Shell, інформаційні технології, енергетика