“Assessment of an enterprise’s energy security based on multi-criteria tasks modeling”

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ASSESSMENT OF AN ENTERPRISE'S ENERGY SECURITY BASED ON MULTI-CRITERIA TASKS MODELING

Abstract

Today Ukrainian business entities operate in conditions of macroeconomic instability, environmental disturbance, energy dependence on risk of instable and interrupted supply and high cost of energy resources, excessive energy consumption and inefficient use of fuel and energy resources, which requires immediate actions as for finding solutions to ensure energy security. The goal of the article is to solve multi-criteria tasks focused on making managerial decisions regarding the development of enterprise energy security system based on evaluation of influence of numerous factors. As a result of this study, main components of energy security of the enterprise and most important influence factors are determined. The mathematical model of the hierarchy of factors in terms of their influence on the energy security of the enterprise with the use of graph theory is developed. Use of iterative procedure to determine the levels of hierarchy of factors allowed to assess the importance/priority of their influence on energy security of the enterprise. Thus, the developed model of hierarchy of factors based on the applied scientific and methodical approach to determine their influence on energy security of the enterprise provides the opportunity to get a detailed idea of factors interaction, interconnections and influence on energy security of the enterprise, which ultimately leads to elaboration of complex optimal/agreed managerial decisions in context of development and implementation of energy security system of the enterprise.

Keywords energy security, enterprise, factors of influence, theory of graphs, mathematical model, hierarchy, management decision

JEL Classification Q40, C60, M11

INTRODUCTION

Energy sector in terms of its influence on other components of the economy is of crucial importance. Unfortunately, we need to admit that energy intensity of the Gross Domestic Product of Ukraine is much higher compared to not only the world leading economies, but also to the neighboring countries of Central and Eastern Europe. Even more, since November 2013, the socio-economic situation in Ukraine has deteriorated, which requires immediate adoption of measures to ensure national security and safe economic environment in particular.

Energy security, in this context, is intended to stabilize the market of energy resources, especially uninterrupted, reliable and economically advantageous supply and satisfaction of social and industrial needs. It should be noted that modern understanding as for energy security guarantee is the achievement of technically reliable, stable, cost-effective and environmentally safe supply of energy resources to economic and social sectors of the country, as well as creation of conditions focused on development and implementation of the national energy security policy.

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Present-day global development trends greatly increased industrial risks and threats. Enterprises acutely face problems of excessive energy consumption and inefficient use of fuel and energy resources. Functioning of economic entities is also influenced by macroeconomic instability, structural imbalance, gaps in energy supply capacity and satisfaction of social and industrial needs due to the logistical risks when importing fuel and energy resources. Consequently, modern realities require from the enterprise to focus on development and implementation of successful energy security system in order to ensure timely detection and consideration of different factors of influence on it in the future.

Now, therefore, there's a need for applying economic-mathematical modeling as an effective tool for formalizing the impact of qualitative and quantitative characteristics inherent in the problem under this study.

1. LITERATURE REVIEW

Problems of ensuring the energy security, assessment of its level are highlighted in the works of leading foreign and Ukrainian scientists.

Among foreign scholars, it's important to mention scientific article of Sovacool and Brown (2010), where the authors study the development of industrialized countries in terms of their energy security and offer a standardized set of metrics as for properly responding to the emerging energy security challenges.

Head of the Energy Program at the Norwegian Institute of International Affairs, Overland (2016), highlights the importance of OSCE (Organization for Security and Co-operation in Europe), and studies empirical approaches of international energy organizations in addressing energy security and reducing energy risks.

Management and decision-making aspects as for energy security development are analyzed in "Modelling of safety management systems" by the group of authors (Hale et al., 1997).

Banovac et al. (2017) presented the model of global energy policy that aims to ensure not only effective environmental protection, but also reliability of energy supply. This model includes measures that need to be implemented globally, such as integrated energy planning, energy management, energy conservation, achievement of intensive use of renewable energy sources, use of modern logistic and transport technologies and limited use of fossil fuels.

Cherep and Lubenets (2010) dedicated their research to conceptual basis of energy security of enterprises. Exploring theoretical basis of energy security, Sukhodolia (2013) describes this concept as individual, society and the state vitally important "energy interests" security with protection from internal and external threats, which ensures uninterrupted customers' satisfaction with economically affordable fuel and energy resources of the appropriate quality under normal conditions and in emergency situations. That means, elimination/minimization of potential threats is important in ensuring energy security.

It is worth to mention the study of relationship between economic growth and energy consumption in V4 countries and 14 EU countries (Kasperowicz & Štreimikienė, 2016). The authors substantiate that energy consumption increase is a precondition to economic growth.

Energy policy of Ukraine choices in coordination with the European Union energy policy were investigated in the monograph by Shevtsov et al. (2004). Also strategic perspectives for modeling energy security of Ukraine under conditions of European integration processes are highlighted in the work of Voynarenko and Mykoliuk (2017). Continuing this research, Mykoliuk (2018) analyzes current situation with fuel and energy resources supply to local business entities and systematizes problem-solving tasks as for energy security increase in the context of European integration processes. The author defined main steps in ensuring energy security of Ukraine, expansion of cooperation with the European Union countries in order to strengthen cooperation in energy security sector.

In scientific economic literature, considerable attention is paid to issues related to assessment of enterprises' security level. In particular, Shkarlet et al. (2016), which evaluating the energy security of economic entities, emphasize the importance to study the internal stability of the enterprise or its ability to recover from energy threats influences. According to the authors, the plurality of factors, criteria and indicators of enterprise's energy security analysis and the impact on energy security of certain destabilizing factors should be considered.

Theoretical basis for assessment and modeling of energy security is the scientific article by Bobrov (2012), which proposes to consider energy security of the state as a system of four functional components: economic, technical and technological, ecological-social, resource, as well as completed analysis of modern approaches to evaluation and energy security modeling.

Criteria for energy security evaluation on the basis of quantitative and qualitative analysis according to the doctrine on fuel and energy resources management based on sustainable development are considered in the scientific work by Mazur (2014).

Samborskyi (2014) stresses the importance of using indicative approach in evaluating the energy security of the enterprise and proposes assessment indicators, qualitative composition of which is determined by the possibility to use them for developing the energy security strategy of the enterprise.

Klopov (2016) reviews method of assessing enterprise's energy security level by using comparison of actual data with normative ones, which allows to characterize the level of energy security of an enterprise in three gradations: energy-safe, energy-dangerous, and critically dangerous.

Sophisticated study on the application of econometric and mathematical models for interpreting the enterprise security formation process belongs to the authors Tkach and Klopov (2015) who proposed a methodology for diagnosing threats to the enterprise's economic security on the basis of a model of maximizing the amount of damage from the onset of threats and decomposition of functional features. The application of the methodology makes it possible to classify the threats of the causes and areas of impact management, as well as assess the level of economic security of the enterprise.

Modeling of the processes of making managerial decisions in conditions of variability, uncertainty and multidimensionality of the market environment in order to develop a scientific and methodological approach to the selection of the most acceptable alternatives to the formation of enterprise security is also proposed in the scientific paper of Hryhoruk et al. (2017).

In the context of energy consumption and energy efficiency, Brożyna et al.'s research (2016) is valuable. The authors evaluated seasonal influence on energy consumption and developed energy consumption forecasts as one of the most important elements of modern economic systems using the TBATS model.

It is also important to note that energy consumption and energy intensity reduction, energy efficiency increase and energy security ensuring are strongly associated with intensification of investment and innovation activities of enterprises. In this context, publication of is worth Dykha et al. (2017) sharing. In the framework of implementation of the investment and innovation development strategy elaborated by the authors, on the one hand, fundamental and applied research will be carried out, new products and technologies will be developed (such as resource-saving, energy-saving/energy-efficient), system of accumulation and hunting for innovative ideas will work, and, on the other hand, fundraising, project bidding and implementation will take place. Authors' suggestions on prioritization of public finances "re-loading" for structural and innovation restructuring of the economy, as well as directions of development of venture business and promotion of high-tech, competitive products are very relevant and current.

In general, systematic approach to ensuring competitiveness, sustainable economic growth through implementation of state influence on socio-economic processes, including through economic reform, rational use of resources, energy modernization is described by Dykha (2016), including justification of components of economic mechanism of socio-economic development of the state.

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In view of the lack of investment resources that are essential for business entities' technical and technological modernization in order to solve high level of energy intensity problems in the context of fundraising, attention should be paid to alternative aid projects (see Pedchenko et al., 2018), for example, angel investments to modern technologies based on use of alternative energy sources.

It should also be noted that the energy security of Ukraine is regulated by legislative instruments and acts at the national level. One of the main legislative documents is the Law of Ukraine "On National Security" (2003), which defines basic principles of state policy focused on protection of national interests and guaranteeing security of every person, society and state of Ukraine from external and internal threats in all areas of life. Country's strategic document on energy security and energy sector sustainable development is the Energy Strategy of Ukraine until 2035: "Security, Energy Efficiency and Competitiveness" (2017). The Strategy outlines goals that our country needs to achieve in the energy sector in order to reduce energy intensity of the economy, optimize energy balance, strengthen energy, environmental and economic security, and increase domestic production.

Despite the significant scientific research and development results on energy security of the enterprise, there remain unsolved problems on energy supply and factors of influence. Therefore, the purpose of this article is to solve multi-criteria tasks of making managerial decisions regarding modeling of energy security of the enterprise, taking into consideration influence of different factors by means of economic-mathematical modeling methods.

2. METHODS

Methods of analysis and synthesis, principles of formal logic, methods of inductive and deductive analysis were used in this research. Empirical methods are used for data study and analysis.

In particular, in the process of identifying the factors and assessing the importance of their influence on energy security of the enterprises, methods of analysis, comparison and synthesis, logical method are used; Saaty hierarchy method – as a mathematical tool for a systematic approach to complex decision-making problems; graph method – to plot a directed graph; formalization method and principles of formal logic – to develop hierarchy model of factors of influence on energy security of enterprises; induction and deduction method – for theoretical generalization of the existing concepts; system approach was used in the process of research and substantiation of scientific and methodological fundamentals of modeling and implementation of energy security of the enterprise, elaboration and application of hierarchy model of influence of different factors on energy security level of the enterprise.

3. RESULTS

Energy security at macro and micro levels of the country is one of the key issues today. Ensuring its appropriate level is of primary importance for developing the conditions for effective functioning of economy and business.

Modeling the energy security of the enterprise requires finding the solution of multi-criteria task of managerial decision-making regarding its arrangement with due regard of various influence factors.

In our opinion, fundamental and determinative components of energy security are: resource-energy, technical and technological, social and environmental, economic and organizational and management. In the context of each component, the indicators, which fully characterize activities of an enterprise, are distinguished, and reflect current situation and potential for future development, in accordance with the identity of the specific indicator to the functional component of energy security.

Resource and energy component of energy security of the enterprise characterizes the interrelation between the results of economic activity and the enterprise and corresponding fuel and energy resources consumption (expenditures). In this context, senior management of the enterprise should focus on measures and methods of rational use of energy resources through development and implementation of fuel and energy resources efficiency programs.

Technical and technological component reflects the degree of technical excellence of consumption technologies, transportation and storage of fuel and energy resources of the enterprise. Functioning of this component depends on existing and potential technologies analysis in accordance with the production needs of the enterprise, assessment of technological processes peculiarities and scientific-technical information regarding modern developments of the industry, and internal reserves monitoring in order to reduce energy intensity of the technologies used and their efficiency reserves.

Ecological and social component of enterprise's energy security should be considered from the point of view of environmental and social justification of fuel and energy resources consumption (and expenditures) in order to achieve socially acceptable and environmentally safe standards of living. Enterprises of production industry should reduce consumption of non-renewable natural resources and increase use of high-tech alternative energy sources, non-waste technologies, this will ensure production of high quality ecologically and socially acceptable products and, as a result, social conditions and standards will be improved.

Economic component of energy security of the enterprise creates an idea of economic fuel and energy resources cost-effectiveness to achieve the main goal of economic activity. In this context, it makes economic sense to introduce energy-saving technologies, energy-efficient equipment, as well as economic incentives for increasing energy efficiency of enterprises by exempting them from the income tax, and applying "green tariff" for electricity generated from alternative sources.

Management system effectiveness and successful management structure functioning, delegation of rights and responsibilities between employees of different departments formulates organizational and managerial component of energy security of the enterprise. Such favorable organizational and managerial energy security ensuring conditions are based on the appropriate organizational structure, personnel motivation policy, energy consumption culture, etc. Senior management of the enterprise is responsible for this component, as well as structural divisions' management, as their duties are to maintain routine organizational avtivities related to the monitoring and diagnosis of the existing and potential threats to energy security system functioning, timely implementation of decisions, provision of normative, methodical, logistic support within the given powers and SOW; generalization of case law reviews and elaboration of proposals for improvement of energy security of the enterprise. In addition, organizational and managerial activities include measures to control energy security level, relevance of decisions made, holding of seminars and advance training for energy security personnel.

In the context of each component of energy security, it is important to identify several factors that are subject to qualitative and quantitative evaluation and provide an opportunity to determine the current level of energy security and its potential.

It should be noted that formulated combination of the most important factors enables to accurately assess of the level of energy security of the enterprise and, if necessary, development of specific measures based on rational management decisions to strengthen the energy security and prompt reaction to changing market situation and organization activities adjustment to changing market conditions.

However, making the managerial decisionы, especially enterprise security-relating issues, requires solusions of specific tasks of operational, tactical and strategic nature. Because quite often decision-making takes place under condition of uncertainty and risk as for achievement of goals and objectives of the enterprise, it is natural that top management is looking for best ways to bring multi-purpose decision-making tasks to tasks with one functional evaluation. In this case, hierarchical structure methods can be used for solving such problems.

Completed analysis of Saty's (1982) scientific works and developments, according to the hierarchy method, makes it possible to assert that each element of a higher level of the hierarchy

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can be broken down into several lower-level elements, which, in turn, are detailed by a plurality of elements of the next (lower) level, etc. At the lowest level of such hierarchical structure, there are elements of the target assessment functionals with task solutions for every separate functional. One of them must be accepted. At the upper level of this structure, there is only one element – integrated evaluation functionality. This integrated evaluation functionality is an information base (a set of levels) for each decision, which allows you to choose the best of them (one with the highest level).

Based on hereinafter considerations, in order to solve the task of constructing a hierarchical model of influence of a plurality of factors on the energy security of the enterprise, it is expedient to specify the most important ones, namely:

1. energy intensity of production – f_1;
2. share of renewable energy resources in the consumption structure – f_2;
3. share of imported fuel and energy resources – FER (natural gas) in the consumption structure – f_3;
4. energy intensity of fixed productive assets – f_4;
5. share of innovative technologies use – f_5;
6. level of depreciation of fixed productive assets – f_6;
7. energy efficiency level – f_7;
8. power supply per production unit/energy intensity – f_8;
9. investment in the environment level (ecological and economic feasibility of energy resources substitution) – f_9;
10. level of engagement of enterprise personnel in energy efficiency measures – f_{10};
11. energy resources cost per real output – f_{11};
12. energy efficiency of product – f_{12};
13. share of fuel and energy resources – FER consumption in product cost – f_{13};
14. energy-efficient measures implementation efficiency – f_{14};
15. energy-efficient measures implementation coefficient – f_{15};
16. stimulation of energy-saving measures efficiency – f_{16}.

Let $F=\{f_i\}$, where $i=\overline{1,n}$ is the set of the most significant factors. To formulate and solve the problem of constructing a hierarchical model, we'll use Berge's (1957) and Wilson's (1972) theory of graphs and Altman's (1984), Hale et al.'s (1997) system analysis methods.

Since the reflection of the model of investigated set of factors is a cognitive map in the form of directed graph, where vertices are the subject-domain factors, and arcs – relations between them, we need to create its graphical interpretation (Figure 1).

According to the theory of graphs, vertices of the oriented graph are elements of the set F, and the edges connect adjacent pair vertices (f_i, f_j), where factors' inter-influence is determined. If the vertex f_i is the initial for the edge (the edge starts from this vertex), and the vertex f_j is finite for this edge (the edge enters this vertex), then, the factor f_i in some way affects the factor f_j. The vertex f_j is from the vertex f_i, if in the graph there is a path where from the vertex f_i it is possible to the vertex f_j. Then, the vertex f_j is called achievable from the vertex f_i. Let us denote the set of achievable vertices by $R(f_i)$. Analogously, the vertex f_i is the precursor of the vertex f_j, if the vertex f_j is reached from the vertex f_i. Let us denote the set of vertices of the precursor by $A(f_i)$. Then, the common elements of the sets $R(f_i)$ and $A(f_i)$ form the set $R(f_i)=A(f_i)\cap R(f_i)$.

Each factor is determined by the influence of others (marked by entering arrows) and influence on others (marked by outgoing arrows).

For example, f_{12} – energy efficiency of product is determined by the following factors: .f_2 – share of renewable energy resources in the consumption

Source: Compiled by the authors.

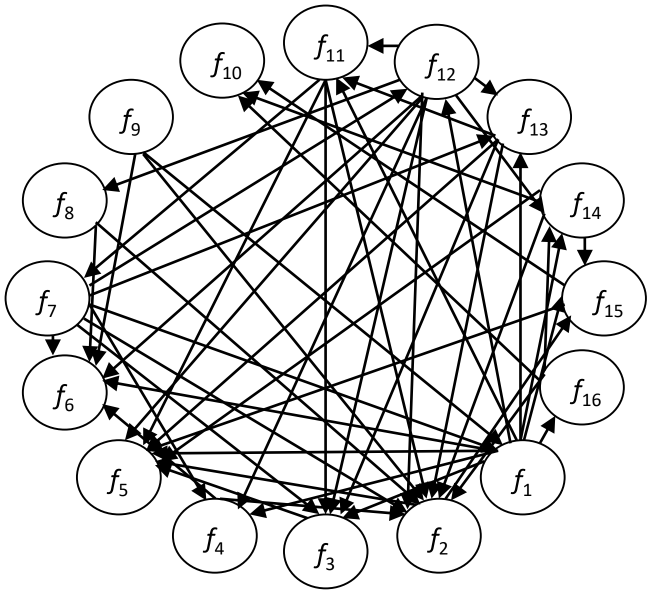

Figure 1. Graph of interrelations between the energy security of the enterprise and the influence factors

structure, $.f_3$ – share of imported fuel and energy resources – FER (natural gas) in the consumption structure, $.f_4$ – energy intensity of fixed productive assets, $.f_5$ – share of innovative technologies use, $.f_6$ – level of depreciation of fixed productive assets, $.f_8$ – power supply per production unit / energy intensity, $.f_{11}$ – energy resources cost per real output, $.f_{13}$ – share of fuel and energy resources – FER consumption in product cost, $.f_{14}$ – energy-efficient measures implementation efficiency. In its turn, power supply per production unit/energy intensity – f_8 influences f_2 – share of renewable energy resources in the consumption structure and f_6 – level of depreciation of fixed productive assets.

Note that this set of factors is determined for the enterprises of machine-building industry with the special focus on specifics of production process. However, this does not limitate possibility to use this model in other industries: food industry, agriculture, light industry, etc., but under condition of formulation of set of energy security influence factors.

Based on the oriented graph (Figure 1), let us develop the binary matrix "*B*" of dependence of influence factors on energy security of the enterprise for the set of vertices f_{ij} according to the condition:

$$f_{ij} = \begin{cases} 1, \text{ if factor } i \text{ depends on factor } j; \\ 0, \text{ if factor } i \text{ does not depend on factor } j. \end{cases}$$

If there is a relation between the factors f_i and f_j, then, vertices f_i and f_j are called adjacent.

Thus, we obtain a binary matrix "*B*" with the dimension of 16×16 elements. Matrix "*B*" is called the adjacency matrix and it is presented in Table 1. For better informativeness, we'll add a row and a column with the mnemonic names of the factors.

Consequently, if the vertices f_i and f_j are adjacent, then, at the intersection of the corresponding row and column, this fact is denoted by "1", otherwise it is "0".

Since the relationship between the factors is not the property of reflexivity (the factor f_i does not affect itself), then, the diagonal elements of the matrix "*B*" are zero.

The set theory studies the set of input and output processes, the equations that establish the relationships between the sets of input and output quantities with the help of transition operators.

Note that the matrix of adjacency is a mathematical object presented in the form of a rectangular

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Table 1. Matrix of interrelations between the factors of influence on energy security of the enterprise

Source: Compiled by the authors.

Factors	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}	f_{15}	f_{16}
f_1	0	0	1	1	1	1	0	0	0	0	1	1	1	1	1	1
f_2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
f_3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
f_4	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
f_5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f_7	1	1	1	1	0	1	0	0	0	0	0	1	1	0	0	0
f_8	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
f_9	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
f_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f_{11}	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0
f_{12}	0	1	1	1	1	1	0	1	0	0	1	0	1	1	0	0
f_{13}	0	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0
f_{14}	0	1	0	0	1	0	0	0	0	1	0	0	0	0	1	0
f_{15}	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
f_{16}	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0

matrix where elements establish links and relations between the constituent parts of the system. As a rule, adjacency matrices describing the structure of the system are sparse matrices, that is, matrices of large sizes where considerable number of elements is zero. Kieth's (1994) set theory examines the set of input and output processes, the equations that establish the relationships between the sets of input and output quantities with the help of transition operators.

Consequently, based on the results of matrix "*B*", we construct a matrix of reachability. In the reachability matrix, information is displayed on the existence of paths between the vertices of the oriented graph. Way from the vertex f_i to the vertex f_j is called a finite sequence of edges, which leads from f_i to f_j, where each two neighboring edges have a common vertex and no edge appears more than once (Berge, 1957; Wilson, 1972; Ljamec & Tevjashev, 2004).

We form a binary matrix $(I+B)$, where I is a unit matrix. There is the least integer k for which $(I+B)^{k-1} \le (I+B)^k = (I+B)^{k+1}$, meaning that each element of the matrix $(I+B)^{k-1}$ is less or equal to the corresponding element of the matrix $(I+B)^k$, and the corresponding elements of the matrices $(I+B)^k$ and $(I+B)^{k+1}$ are equal.

Hence, the matrix $(I+B)^k$ is called the reachability matrix.

The matrix of reachability of the oriented graph (defined as a binary matrix consisting of one unit if the vertex f_j is achievable by any path from the vertex f_i, otherwise the elements of this matrix are zero). In order to model the matrix of reachability, let's execute Warshall algorithm (1962), using C Sharp software (Figure 2).

Matrix of reachability allows us to divide the set of factors F into the set of levels. The vertex f_j is called achievable from the vertex f_i, if there is a path in the oriented graph from f_i to f_j. The vertex f_j is called the precursor of the vertex f_i, if f_i can be obtained from f_j.

From the set of factors F, two subsets should be distinguished: the set of vertices of reachability and the set of vertices of predecessor. Let us denote the set of vertices of reachability by $R(f_i)$ and the set of vertices of predecessor by $A(f_i)$.

$R(f_i)$ is the set of reaches of the vertex $f_i \in F$, which consists of all vertices of the set of factors

Source: Compiled by the authors.

$$
(I+B)^k = \begin{array}{cccccccccccccccc}
1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
0 & 1 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 1
\end{array}
$$

Figure 2. Matrix of reachability fragment on C Sharp software

F, which lie on paths starting from f_i.

Thus,

$$R(f_i) = \left\{ f_i \in F \,\middle|\, \text{the element } (i,j) \text{ in } (I+B)^k \text{ equals } 1 \right\}.$$

$A(f_i)$ is the set of vertices of precursor for the vertex $f_i \in F$, which consists of all vertices of the set of F factors lying on paths containing f_i, but do not start from f_i.

Thus,

$$A(f_i) = \left\{ f_j \in F \,\middle|\, \text{element } (j,i) \text{ in } (I+B)^k \; i \text{ equals } 1 \right\}.$$

The set of vertices f_i, for which $A(f_i) = R(f_i) \cap A(f_i)$ is executed, cannot be reached from any vertex of the set of F factors that remain, and, accordingly, can be defined as level of hierarchy.

The process of constructing a hierarchy starts from the vertex (goals from the point of view of management) through the intermediate levels (criteria on which the next levels depend) to the lowest level, which is usually a list of alternatives. The hierarchy is considered complete if each element of a given level functions as a criterion for all the elements of the level below. On the other hand, the hierarchy is incomplete.

Beyond that, hierarchical models have significant advantages over models of other types (Saaty, 1982; Altman, 1984):

- give an opportunity to study the "degree of influence" of priorities at upper levels on the priorities of lower-level elements;
- provide detailed information about the structure of the system;
- usually stable/resistant (small disturbances cause little effect);
- flexible (additions to a well-structured hierarchy do not ruin its characteristics).

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For modeling the energy security influence factors hierarchy, it is necessary to apply the following iterative algorithm procedure (see Table 2):

1. create a table with elements f_i, $R(f_i)$, $A(f_i)$, $R(f_i)\cap A(f_i)$;
2. identify the elements in the table that satisfy the condition $A(f_i)=R(f_i)\cap A(f_i)$. These elements form the first level;
3. delete this set from the table and apply the second step, etc.

Execution of the above-mentioned procedure gives us the opportunity to get the first level of hierarchy (the lowest level in the assessment of importance) of the factors affecting the energy security of the enterprise. Factors of first level of the hierarchy are the least influential for the investigated process. Second column of Table 2 defines the serial number of the individual elements of the corresponding rows of the reachability matrix; the third column defines the serial number of the individual elements of the columns of the same matrix. In the fourth column, the elements reflect the order numbers of the factors affecting the energy security of the enterprise, which satisfy the condition $R(f_i)\cap A(f_i)$, that is, common elements of the second and third columns. For example, for the first row, these are elements 1, 7, 11, 2, 13.

By the algorithm for constructing a resulting graph, described above, we remove the ninth row, and in the second and third columns, we delete the element "nine". Here we get the factors of the second level of hierarchy. We accept this step as the basis for calculating the second iteration, which determines the next level of hierarchy of factors. At this stage, the equation $A(f_i)=R(f_i)\cap A(f_i)$ is executed for the first, seventh, eleventh, twelfth, thirteenth rows. The listed factors form one level of importance as for the influence on energy security. We remove the listed rows and elements with corresponding numbers in the second column and get the factors of the third level of hierarchy. Third iteration determines next hierarchical level: the third, fourth, eighth, and sixteenth factors. By analogy, we obtain data for the next iteration of the fourth level of hierarchy. Condition $A(f_i)=R(f_i)\cap A(f_i)$ is fulfilled for the

Table 2. Sequence of iterations determining the hierarchy levels of factors influencing the energy security of the enterprise

Source: Compiled by the authors.

First iteration of influence factors (lowest level)			
i	$R(f_i)$	$A(f_i)$	$R(f_i)\cap A(f_i)$
1	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 9, 11, 12, 13	1, 7, 11, 12, 13
2	2, 5, 10, 15	1, 2, 4, 7, 8, 9, 11, 12, 13, 14, 16	2
3	3, 5	1, 3, 7, 9, 11, 12, 13	3
4	2, 4, 5, 6, 10, 15	1, 4, 7, 9, 11, 12, 13	4
5	5	1, 2, 3, 4, 5, 7, 8, 9, 11, 12, 13, 14, 15, 16	5
6	6	1, 4, 6, 7, 8, 9, 11, 12, 13	6
7	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 9, 11, 12, 13	1, 7, 11, 12, 13
8	2, 5, 6, 8, 10, 15	1, 7, 8, 9, 11, 12, 13	8
9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	9	9
10	10	1, 2, 4, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	10
11	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 9, 11, 12, 13	1, 7, 11, 12, 13
12	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 9, 11, 12, 13	1, 7, 11, 12, 13
13	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 9, 11, 12, 13	1, 7, 11, 12, 13
14	2, 5, 10, 14, 15	1, 7, 9, 11, 12, 13, 14, 16	14
15	5, 10, 15	1, 2, 4, 7, 8, 9, 11, 12, 13, 14, 15, 16	15
16	2, 5, 10, 14, 15, 16	1, 7, 9, 11, 12, 13, 16	16

Table 2 (cont.). Sequence of iterations determining the hierarchy levels of factors influencing the energy security of the enterprise

Second iteration of influence factors			
i	$R(f_i)$	$A(f_i)$	$R(f_i) \cap A(f_i)$
1	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 11, 12, 13	1, 7, 11, 12, 13
2	2, 5, 10, 15	1, 2, 4, 7, 8, 11, 12, 13, 14, 16	2
3	3, 5	1, 3, 7, 11, 12, 13	3
4	2, 4, 5, 6, 10, 15	1, 4, 7, 11, 12, 13	4
5	5	1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 14, 15, 16	5
6	6	1, 4, 6, 7, 8, 11, 12, 13	6
7	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 11, 12, 13	1, 7, 11, 12, 13
8	2, 5, 6, 8, 10, 15	1, 7, 8, 11, 12, 13	8
10	10	1, 2, 4, 7, 8, 10, 11, 12, 13, 14, 15, 16	10
11	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 11, 12, 13	1, 7, 11, 12, 13
12	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 11, 12, 13	1, 7, 11, 12, 13
13	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16	1, 7, 11, 12, 13	1, 7, 11, 12, 13
14	2, 5, 10, 14, 15	1, 7, 11, 12, 13, 14, 16	14
15	5, 10, 15	1, 2, 4, 7, 8, 11, 12, 13, 14, 15, 16	15
16	2, 5, 10, 14, 15, 16	1, 7, 11, 12, 13, 16	16
Third iteration of influence factors			
i	$R(f_i)$	$A(f_i)$	$R(f_i) \cap A(f_i)$
2	2, 5, 10, 15	2, 4, 8, 14, 16	2
3	3, 5	3	3
4	2, 4, 5, 6, 10, 15	4	4
5	5	2, 3, 4, 5, 8, 14, 15, 16	5
6	6	4, 6, 8	6
8	2, 5, 6, 8, 10, 15	8	8
10	10	2, 4, 8, 10, 14, 15, 16	10
14	2, 5, 10, 14, 15	14, 16	14
15	5, 10, 15	2, 4, 8, 14, 15, 16	15
16	2, 5, 10, 14, 15, 16	16	16
Fourth iteration of influence factors			
i	$R(f_i)$	$A(f_i)$	$R(f_i) \cap A(f_i)$
2	2, 5, 10, 15	2, 14	2
5	5	2, 5, 14, 15	5
6	6	6	6
10	10	2, 10, 14, 15	10
14	2, 5, 10, 14, 15	14	14
15	5, 10, 15	2, 14, 15	15
Fifth iteration of influence factors			
i	$R(f_i)$	$A(f_i)$	$R(f_i) \cap A(f_i)$
2	2, 5, 10, 15	2	2
5	5	2, 5, 15	5
10	10	2, 10, 15	10
15	5, 10, 15	2, 15	15

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Table 2 (cont.). Sequence of iterations determining the hierarchy levels of factors influencing the energy security of the enterprise

Sixth iteration of influence factors			
i	$R(f_i)$	$A(f_i)$	$R(f_i) \cap A(f_i)$
5	5	5, 15	5
10	10	10, 15	10
15	5, 10, 15	15	15
Seventh iteration of influence factors (highest level)			
i	$R(f_i)$	$A(f_i)$	$R(f_i) \cap A(f_i)$
5	5	5	5
10	10	10	10

factors: sixth and fourteenth, which determine the next level of hierarchy in the resulting graph. According to the algorithm, we obtain a set that determines the factors of the next level of hierarchy. Every next level of hierarchy defines the second row, which corresponds to the particular factor. In order to carry out next iteration, let us form factors of the sixth level of hierarchy. According to the corresponding algorithm, we obtain next level of hierarchy, which corresponds to factor with serial number of fifteen. Let us remove the fifteenth row and element fifteen from third and fourth columns. Here we obtain the seventh level of hierarchy, which is the highest, according to the method used.

Therefore, the proposed approach of using hierarchies' analysis method in identifying the levels of influence of the factors on energy security of the enterprise allows us to assess the relative priorities of choosing alternatives in accordance with the established criteria.

Use of scientific method approach to determining the factors of influence on energy security of the enterprise by hierarchy levels is a reflection of real situation, provides the opportunity to get detailed idea of interaction of factors, their interconnections and influence on the energy security of the enterprise, which ultimately leads to elaboration of the complex of agreed managerial decisions.

As a result of execution of the procedures with iterative transformations, it is possible to form a hierarchical model (Figure 3), which demonstrates significance of influence of certain factors on energy security of the enterprise.

Factors are placed by the priority of their influence on energy security of the enterprise. Note that the presence of several factors is arranged formally on the same level (levels VI-VI), the advantage is given to a factor with a greater number of input arrows (influence on other factors as demonstrated on the oriented graph). Under condition when effects between factors are equal, an additional research should be conducted.

Consequently, as a result of completed actions on the basis of scientific method approach, a hierarchical model of energy security of the enterprise influence factors is developed, which reflects the priority of influence of the determined factors, and combines all possible connections between the factors, was reflected in the oriented graph.

In that way, factors – share of innovative technologies (f_5) and level of personnel involvement to implementation of energy efficiency measures (f_{10}) – are at the top of the model of hierarchy of factors of influence on energy security of the enterprise, since they are at level I. Factor f_{15} – coefficient of implementation of energy efficiency measures – is at level II of the hierarchy of factors of influence on energy security and causes less impact on the influence factors of the level I. The influence of the factors of each subsequent lower level decreases.

Thus, the received model of hierarchy of factors of influence on energy security of the enterprise (Figure 3) reflects their ordered effect and is intended to create best conditions for effective system of energy security of the enterprise.

Source: Compiled by the authors.

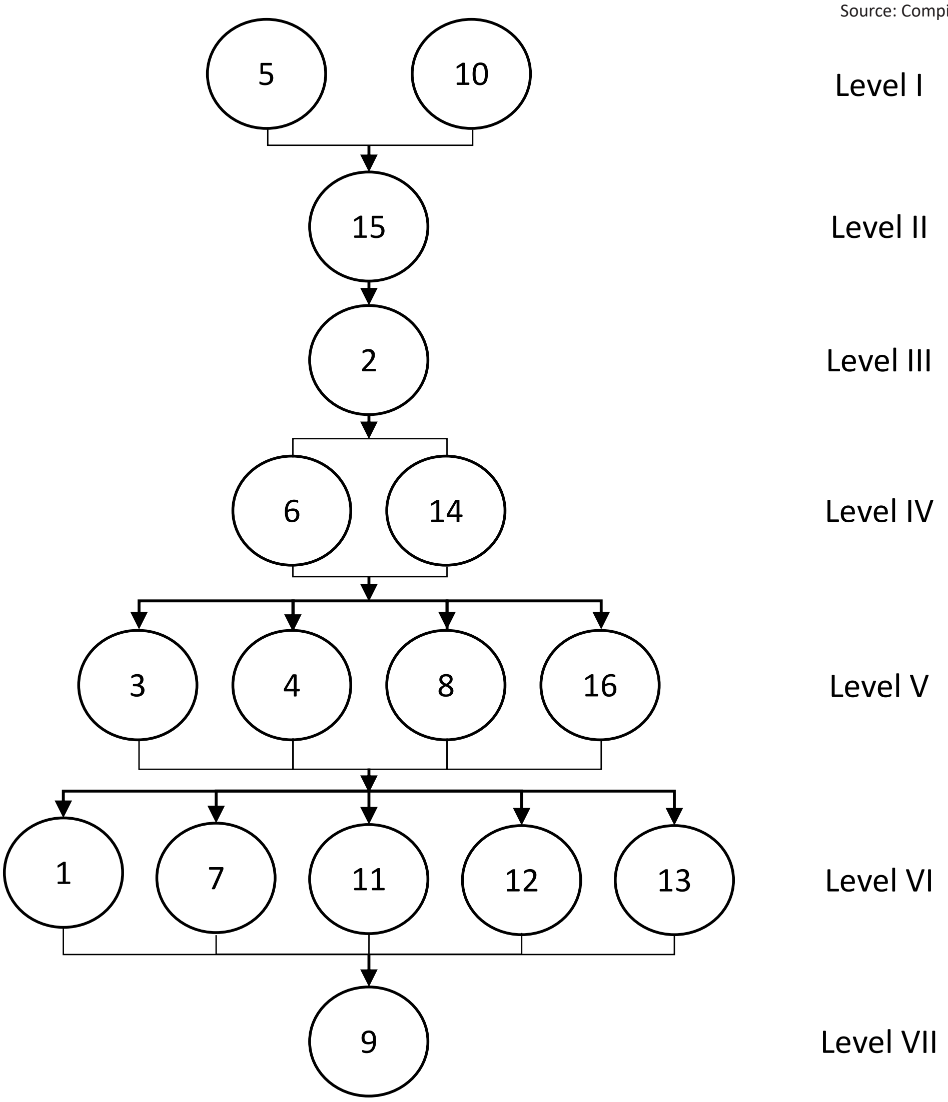

Figure 3. Model of hierarchy of the factors of influence on energy security of the enterprise

CONCLUSION

Energy security is a prerequisite for efficient and sustainable development of the enterprise, and reflects its energy resources security in the context of the existing and possible threats of internal and external nature.

The results of this study made it possible to identify main components of energy security: resource and energy, technical and technological, environmental and social, economic, organizational and management, which are characterized quantitatively and qualitatively.

Selection of factors is defined for machine-building enterprises with special focus on specifics of production process. Among many factors influencing energy security of the enterprise, the most important ones are highlighted. The influence and interconnection of factors on the level of energy security by means of constructing a mathematical model in the form of hierarchical structure with application of graph theory was determined.

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As a result of the use of C Sharp software, a hierarchically structured model is created that demonstrates the priority of influence of certain factors on energy security of the enterprise. Factors are placed by the priority of their influence on enterprise energy security. If case when several factors are located at the same level, the advantage is given to a factor with greater number of input arrows (or effluence on other factors, which are reflected in the oriented graph).

The created model of hierarchy of factors based on scientific and methodical approach for determining their influence on energy security of the enterprise reflects the interaction of factors, their interconnections and influence on energy security of the enterprise, which ultimately is the basis for making the substantiated/agreed managerial decisions on development and implementation of energy security policy of the enterprise.

The presented scientific methodological approach to gradation of levels of hierarchy to determine the importance of energy security influence factors solves the problem of multi-criteria choice by ordering the set of alternatives, comparative analysis, optimization of internal processes of organization; can serve as a superstructure for other methods designed to solve inadequately formalized tasks where experience and intuition are used vs. complex mathematical calculations. It is important that this approach can be used to create a model of hierarchy of factors of influence on energy security in other sectors (food industry, agriculture, light industry, etc.), under condition that a set of significant factors is determined for each industry.

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