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SCIENTIFIC-METHODICAL APPROACH TO ASSESSING THREATS TO UKRAINE'S ENERGY SECURITY USING NEURAL NETWORKS

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ABSTRACT. The article substantiates the importance of ensuring Ukraine's energy security, the state of which is determined by the conditions of the internal environment of the functioning and development of the energy system, as well as the influence of external environmental factors. The spectrum of threats to Ukraine's energy security is identified in the following areas: threats caused by war; threats of a financial, economic, technical and technological nature; cyber threats and information attacks; environmental requirements and climate challenges; threats associated with corruption and ineffective management. A scientific and methodical approach to assessing the level of threats to energy security based on probabilistic neural networks is proposed. The input parameters for assessing the degree of threats to the country's energy security are proposed to be formed on the basis of an expert survey. To check the consistency of expert judgments, it is proposed to carry out clustering of expert assessments. The authors substantiate that a clear identification of threats in terms of their types, taking into account their content, qualitative and quantitative context of threats, and assessment of the probable degree of threats using the proposed scientific and methodical approach based on neural networks will serve as the basis for making informed management decisions to prevent / minimize / eliminate the negative impact of factors on the energy security of Ukraine.

Keywords: energy security, energy sector, threats, risks, assessment, management, economic and mathematical modeling, neural networks.

INTRODUCTION. Energy is a strategically important sector of the economy of any country and ensuring the country's energy security is extremely important. Energy security is influenced by various factors, the conditions of the functioning of the energy market. The key influence on Ukraine's energy security today is Russia's war against Ukraine (missile strikes have already caused large-scale damage to the energy industry and the country as a whole). Until February 24, 2022, Ukraine's energy system was connected to the energy systems of Russia and Belarus. After working in isolated mode for 21 days, on March 16, 2022, one of the key events in the Ukrainian energy sector took place: the national energy system merged with the European network of electricity transmission system operators ENTSO-E. Synchronization of the operation of the Ukrainian and European energy systems provides a number of advantages to electricity market participants, but also poses new challenges for them. Despite the full-scale war, Ukraine has been began exporting electricity from Ukraine to Europe after synchronization, which stopped on October 11, 2022 (the day after the first massive Russian attack on Ukrainian energy infrastructure) [1]. Responding to the challenges and needs of modern realities, on April 21, 2023, the Cabinet of Ministers of Ukraine approved the "Energy Strategy of Ukraine for the period until 2050" [2] (the previous "Energy Strategy of Ukraine until 2035" has lost its validity) [3]. According to the adopted Energy Strategy of Ukraine until 2050 [2], the energy sector, in particular, should be as close as possible to climate neutrality; it provides for the development of an innovative and decentralized energy system, the full functioning of the national energy market and its integration into international ones. Solving numerous problems of the functioning of the energy sector of Ukraine and ensuring its energy security is located in different planes (military-political, technical-technological, economic) and at different levels (global, national, meso- and micro-level). The issue of physical protection of energy facilities from missile and drone attacks is critically important, which lies primarily in the military-political plane of the solution. Significant amounts of destruction of energy facilities of Ukraine, the need for their restoration led to an increase in the electricity tariff for consumers from June 1, 2024 by almost 2 times (up to 4.32 UAH / kWh). That is, the consumer aspect of the functioning of the energy market today is accompanied by an increased burden on consumers, and should also be manifested in responsible electricity consumption, because lost energy generation capacity has caused its shortage. The economic component of the functioning of the energy system is very multifaceted. It also includes attracting investment and grant funds for the restoration of damaged facilities, the use of modern technologies in the energy sector, the need to diversify the development of the energy generation market.

In the face of a large number of threats, Ukraine faces the task of using effective risk management tools, making informed management decisions for the effective functioning, development of the energy sector and ensuring energy security. The basis for making balanced and effective management decisions should be an adequate assessment of threats, which determines the relevance of the research topic.

LITERATURE REVIEW, RESEARCH OBJECTIVES AND METHODS. A wide range of issues regarding the importance of the effective functioning of the energy sector and the development of the energy generation market, and the problems of ensuring energy security have been studied in publications by domestic and foreign scientists.

In particular, the impact of energy on the development of the world economy was studied by H. Safa in the publication [4]. T. Šikiæ [5] described the impact of renewable and non-renewable energy consumption on the economic growth of 16 developed EU member states and 11 EU member states after the transition period. The role of primary energy supply in the economic growth of the EU-27 was studied by A. Deka et al in the publication [6]. Also, the authors [7] analyzed the impact of energy on economic development and the social sphere based on bibliometric analysis and economic and mathematical analysis of information. K. Sonowal & B. Ao [8] noted that energy security is a multifaceted and dynamic issue that affects the economic, social and environmental aspects of human life. The authors highlight their vision of the past and future of energy security from the perspective of its impact on socio-economic and environmental aspects in order to confront future challenges to maintain a sustainable energy future. M. Voynarenko et al [9] developed a mathematical model of the hierarchy of influence of factors on the energy security of the enterprise using graph theory tools.

The war of the Russian Federation against Ukraine has caused challenges and threats to the energy security of Ukraine and all of Europe, and has changed the energy landscape of the whole world. M. Dykha & V. Dykha highlighted key problems in the energy sector of Ukraine from the perspective of the war, and also substantiated the feasibility of modernizing the energy sector, developing renewable energy, and implementing mechanisms for the functioning of the energy market, taking into account the requirements of integration into European energy markets, and focused on the need to implement effective energy management in the publication [10]. V. Dykha et al highlighted modern challenges, the negative impact of the war of the Russian Federation against Ukraine on energy security, and reviewed international experience in the field of energy conservation and energy security management in the article [11]. A. Lisovyi also examined the current state and challenges for Ukraine's energy security, presented the facts of the destruction of the country's energy sector infrastructure as a result of Russian missile and drone attacks, proposed ways to solve the problems, and noted the importance of renewable energy sources for reducing dependence on energy imports and reducing greenhouse gas emissions in the article [12]. In this context, we also draw attention to the publication [13], in which the authors highlighted the impact of the Russian-Ukrainian war on the EU's energy security.

A. Mazaraki & T. Melnyk [14] described key global trends in changes in energy markets, outlined the types and forms of modern energy threats and risks, established the directions of the impact of the "green" transition according to the requirements of decarbonization and the abandonment of fossil fuels, new challenges associated with renewable energy sources. L. Gitelman et al [15] also substantiated the types and forms of energy threats and risks that are currently the tools for energy security management; analyzed the impact of structural shifts in the electric power industry on the cost of electricity; proposed a set of measures to neutralize negative scenarios in the field of energy security that arose due to geopolitical factors, structural changes in the economy and high volatility of energy prices.

J. Kim and F. Jaumotte [16] considered the historical determinants of energy supply security and analyzed the consequences of the green transition for energy security. Q. Wang, F. Ren & R. Li [17] investigated the impact of geopolitical dynamics on energy security.

In the article [18], A. Rao et al. analyzed the impact of decarbonization and government efficiency (including fairness and regulatory policy) on energy security of 20 countries using relationship modeling.

A significant range of parameters for the functioning of the energy market is determined by macroeconomic characteristics, regulatory policy at different levels, and state regulation of the development of the industry. In context of regulatory policy, the publication [19] deserves attention, which describes the system of components of the economic mechanism of state regulation, which are also inherent in the regulation of energy industry processes. Also in the publication [20] state-level measures are presented to minimize the damage caused to the electric power industry by terrorist attacks in Russia.

Ja. Brodny & M. Tutak [21] investigated the issue of energy security in the European Union, including through the prism of the war in Ukraine. The article presents the results of a study on assessing the level of energy security of the EU-27 countries from two positions. The first option is to assess the level of energy security of the EU-27 countries based on the traditional approach of taking into account the impact of economic and energy factors (availability of energy sources at affordable prices for energy resources). The second option is to assess the level of energy security in the context of sustainable development (taking into account, in addition to economic and energy factors, also environmental and social factors). The study is based on multi-criteria decision-making methods.

P. Ziemba devoted his research [22] to the problem of assessing the energy security of countries in different periods of time (past, present and projected future). Author developed the Dynamic Multi-Criteria Decision Making methodology for assessing energy security, which is based on classical and fuzzy multi-criteria decision-making methods and the International Energy Security Risk Index.

A. Bilbao-Terol et al [23] present an approach to risk assessment based on multi-criteria analysis of indicators. The authors focused on studying the influence of factors and conditions of the energy market of Spain and Portugal in order to develop risk management solutions.

The main aspects of risk identification and assessment, the importance of using qualitative and quantitative risk assessment methods, decision-making models for risk management (threat prevention, their mitigation or adaptation to new conditions), which are also relevant for risk management in the energy sector, are described in the publication [24]. In this context, we also draw attention to the results of the study [25], in which the authors presented an integrated multifactor risk management model aimed at achieving the strategic goals defined by the Energy Security Strategy.

In the context of threat assessment, it is important to understand the interaction of threats of different levels and systems. M. Dykha et al [26] pay attention to modeling the impact of systemic risk on the economic security of an enterprise. The authors developed recommendations for mitigating the impact of investment, financial and operational risks on the economic security of an organization; a methodology for assessing these types of risk based on matrix and expert approaches was proposed. These techniques can also be used in assessing risks and threats to energy security.

Therefore, energy security is a critically important component of the national security of any country, and for Ukraine in particular, especially in the context of external and internal challenges in the energy sector. To ensure energy security, it is necessary to respond in a timely manner to potential risks, develop strategies for diversifying energy sources and strengthening infrastructure protection, and ensure the stability of the energy sector even in times of crisis and conflict.

Without diminishing the significant achievements of scientists on energy security, but taking into account modern geopolitical challenges and the war in Ukraine; cyber threats and technological risks; socio-economic and environmental aspects of threats, we note the need for an effective methodology for assessing threats to Ukraine's energy security. The assessment of the level of threats and the probable damage from potential threats will determine the energy security management system of Ukraine in order to ensure its sufficient level.

Therefore, **the purpose of the article** is to develop a methodology for assessing threats to Ukraine's energy security using economic and mathematical modeling tools based on building neural networks.

Research methods. The methodical basis of the study and the presentation of its results was formed by general scientific theoretical methods: explanation and comparison, methods of analysis and synthesis, methods of inductive and deductive analysis, logical method and theoretical generalization, the methods of desk research, abstraction and visualization. In particular, in the process of identifying threats to energy security, methods of analysis and synthesis were used. Economic and mathematical modeling was used to develop a scientific and methodical approach to assessing the degree of threats to Ukraine's energy security. To assess the initial parameters of the impact of threats on Ukraine's energy security, it was proposed to use an expert survey. The graphical method was used to visualize the results of the study. In general, the results of the study are based on the provisions of the systems approach, neural network diagnostics, riskology, as well as scientific works of domestic and foreign scientists on energy security management.

RESULTS. Management decisions on preventing / minimising / levelling negative impacts on energy security should be based on objective assessments of existing threats, which must first be identified.

Obvious threats to Ukraine's energy security are threats caused by the war. The Russian Federation's war against Ukraine has caused unprecedented challenges to ensuring Ukraine's energy security. Since the beginning of the full-scale war, Russia has occupied more than 16 GW of Ukrainian generation capacity (including the largest Zaporizhzhia NPP in Europe with a capacity of 6 GW, Zaporizhzhia, Luhansk and Vuglehirsk TPPs with a total capacity of 7.7 GW, Severodonetsk and Mironivsk TPPs - 0.5 GW, as well as 1.2 GW of wind power plants and 0.9 GW of solar power. In addition, the Kakhovka HPP (0.3 GW) was blown up). As of April 2023, the available power capacity of the power system due to the occupation and massive enemy attacks since the beginning of the war has decreased by half - to 18 GW, which corresponded to the winter peak of consumption. However, as a result of the resumption of attacks starting in March 2024, about 10 GW of capacity was lost, some of which was completely destroyed. [27]. Ukrainian power engineers are restoring damaged infrastructure with the help of international partners who provide assistance in the supply of equipment and in financing of restoration work. Information on energy generation capabilities, the condition of infrastructure facilities changes depending on the pace of restoration and current data on damage/destruction in the energy sector. As of March 2025, the total available capacity of the power system of Ukraine is estimated at approximately 12 GW. Unfortunately, Ukraine has turned from a net exporter to a net importer of electricity as a result of massive missile and drone attacks on its power system.

In addition to the direct threats caused by the war, the consequences of the war have caused challenges or exacerbated existing threats in the financial, economic, social, environmental, etc. contexts.

A generalized list of threats to the functioning of the energy market and ensuring Ukraine's energy security by areas that may be internal and/or external in nature is presented in Table 1.

Table 1. Threats to the Energy Security of Ukraine by Direction

Threats	Characteristics
War-induced	Targeted attacks on the energy system. Seizure and mining of critical facilities. Use of energy as a means of pressure to weaken the Ukrainian economy. Destruction of generating capacities, energy infrastructure, destruction of power plants, transformer substations, gas pipelines, gas storage facilities and oil depots. Attacks on critical infrastructure cause disruptions in the supply of electricity and heat. Due to the loss of generating capacities and damage to energy networks, Ukraine is forced to periodically limit consumption. Shortage of personnel to ensure the functioning of the energy sector. In general, the consequences of the war have caused challenges or exacerbated existing threats in the economic, social, etc. contexts.
Financial and economic	Dependence on energy imports (Ukraine has reduced its dependence, but still imports energy from the EU, which makes it vulnerable to price fluctuations and global market trends). High energy prices (fluctuations in gas, oil, and electricity prices on world markets make Ukraine's energy sector less predictable). Dependence on external demand and export quotas are a risk for the energy sector. Destabilization of energy supplies to the EU (Ukraine is integrated into the European energy system ENTSO-E, but due to military strikes and destruction of capacities, electricity exports to the EU have been stopped, which reduces foreign exchange earnings in Ukraine). In conditions of electricity shortage, Ukraine is forced to import electricity. Financial instability of the energy sector (debts of enterprises to Naftogaz of Ukraine and electricity producers complicate the development of the industry. Manipulations in the electricity market, corruption schemes affect its stability). Insufficient investment for development, modernization, reduced investment in the energy sector due to war, instability, lack of incentives. Lack of investment in renewable energy slows down the decarbonization of the economy. Rising tariffs affect social stability.
Technical and technological	The operation of thermal power plants, hydroelectric power plants, and nuclear power plants beyond their design life increases the risk of accidents. The deterioration of the energy infrastructure, outdated substations and power grids cause energy losses during its transportation. Low energy efficiency. The Ukrainian economy remains one of the most energy-intensive in Europe. Vulnerability of the energy management system (insufficient level of automation and digital technologies. Lack of a unified monitoring system to prevent accidents).

Cyber threats and information attacks	Cyberattacks on the power system (Ukraine has repeatedly suffered hacker attacks on the power grid). Use of viruses to disable dispatching systems. Disinformation and manipulation, false messages of Russian propaganda.
Environmental requirements and climate challenges	Climate change and water shortages (an increase in average temperature affects the stability of hydroelectric power plants. Periods of drought can cause a decrease in river water levels, which complicates the operation of hydroelectric power plants). Energy disasters (radiation threats, in particular the situation around the occupied Zaporizhzhia NPP, shelling of the non-operating Chernobyl NPP can cause an environmental disaster. Attacks on oil depots and thermal power plants lead to environmental pollution). Destruction, oil product leaks, etc. pollute the environment. The energy industry is the "leader" of CO_2 emissions. Dependence on fossil fuels. Ukraine has significant coal reserves, but due to environmental restrictions and military operations (many mines are in occupied territories), production is decreasing. The introduction of the Carbon Border Adjustment Mechanism may complicate the export of products produced on the basis of fossil fuels. The European Green Deal and Ukraine's adoption of decisions on decarbonization are forcing a reduction in coal use.
Corruption and poor governance	Abuse in the energy market, manipulation of tariffs and non-transparent pricing. Behind-the-scenes distribution of state resources between energy companies. Bureaucratic procedures and corruption hinder infrastructure renewal, systemic modernization. Monopoly of the energy market. Inefficient functioning of energy market entities. High energy intensity, insufficient efficiency of energy management at all levels, insufficient measures and means to increase energy efficiency and strengthen the energy security of Ukraine.

Source: *compiled by the authors.*

The assessment of threats to energy security should take into account the "nature"/essence of threats in terms of their types, qualitative and quantitative characteristics of threats.

The qualitative context of threats to energy security is determined by the intensity of threats, which is characterized by the number of threatening situations for the energy system over a certain period of time. Here we can give an example of the emergence of a dangerous situation for the city's infrastructure (sewerage networks) if a monthly rainfall rate has fallen during the day. The intensity of threats, as well as the specific conditions of their expression, determine the amount of potential damage to the energy system. The degree of danger (damage) depending on the intensity of threats is presented in Fig. 1.

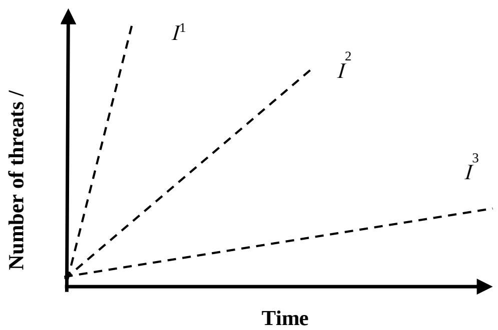

Fig. 1. The degree of danger (damage) depending on the intensity of threats,
developed by the authors

Rays I^1, I^2 and I^3 (Fig. 1) describe the degree of dangers/damage to the country's energy security depending on the number of threats to the energy market per unit of time. Ray I^1 describes the situation with the highest degree of security threats. Rays I^2 and I^3 characterize a smaller number of threats/damage per unit of time.

The quantitative context of threats to ensure the country's energy security is determined by the level of their strength, which causes a certain level (volume/scale) of damage. It is important to assess the synergistic aspect of potential threats. For example, significant damage to the country's energy security, in particular, to energy market entities, can be caused by threats of low or medium strength, but which occur with high intensity. And of course, the greatest damage is caused by high-strength threats, which are implemented with high intensity.

In the context of the argumentation of the level of damage, we note that the massive targeted shelling by Russia of Ukrainian energy facilities causes significant destruction, a shortage of power generation capacity, and the supply of energy to subscribers according to schedules for the period of repair work.

The level of dangers/damage to the country's energy security depending on the "strength of threats" and "intensity of threats" is presented in Fig. 2.

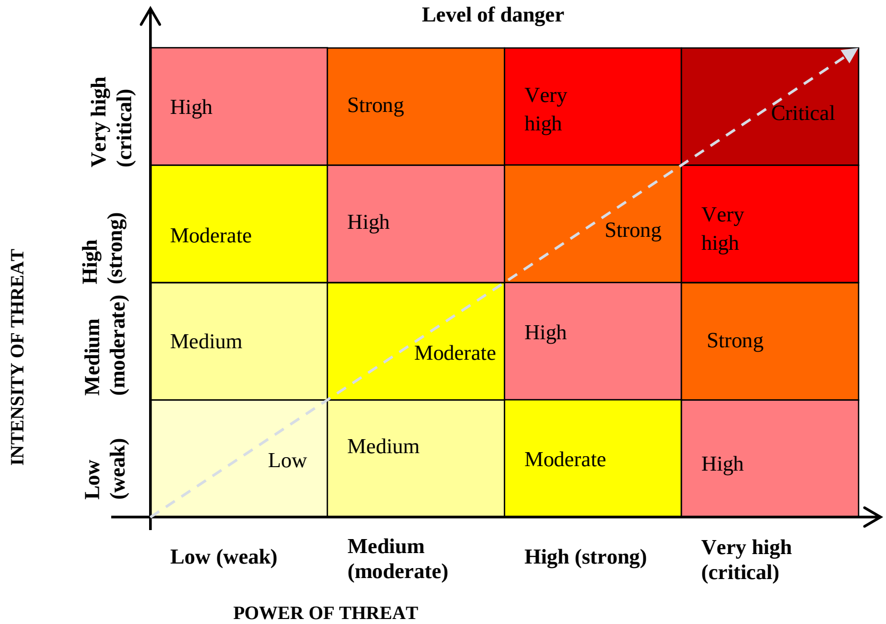

Fig. 2. The impact of "threat strength" and "threat intensity" on the level of danger, *developed by the authors.*

It should be noted that the above approach to analyzing threats by their strength and intensity is used by seismologists to assess the level of hazards due to earthquakes. Experts distinguish between different aspects of seismic activity of earthquakes: magnitude (earthquake energy), which is measured on the Richter scale, and intensity (destructive consequences) of the earthquake, which is measured on the Mercalli scale. Thus, the intensity of an earthquake in different places will be different, but it will be characterized by the same magnitude at all points. Analysis of threats depending on their "strength" and "intensity" is the basis of earthquake-resistant design and assessment of seismic safety of objects in construction. For example, when choosing a location for the construction of nuclear power plants, the aspects of seismic earthquakes, the maximum values of the strength and intensity of probable earthquakes are taken into account, in accordance with which the requirements for the seismic resistance of buildings, structures, systems and elements of nuclear power plants are provided [28].

To assess the impact of potential threats on Ukraine's energy security, the probabilistic neural network methodology can be used, which is the most accurate among all neural networks using radial basis functions. It is a mathematical object that implements a three-stage computational procedure that occurs at the input, radial, and output layers of the neural network [29].

We propose to assess the impact of threats in terms of factors on Ukraine's energy security and determine the degree of threats based on statistical classifiers [30].

We can determine the threats to Ukraine's energy security (Z) based on the impact of a set of factors, where Z_i is the *i-th* factor or *i-th* feature of the threat (in the terminology of statistical classifiers) that negatively affects energy security (i.e., increases the degree of security threats), and is the total number of these features:

$$Z = \{z_i\}_{i=1}^{N} \qquad (1)$$

Set (1) may contain several dozen influence factors, on the basis of which it is necessary to determine the degree of threat. For further consideration, set (1) will be represented as a union of subsets of external and internal factors:

$$Z = \{Z_{i=1}\}_{i=1}^{N} = Z_{ext} \cup Z_{int} = \left\{z_{i_1}^{(ext)}\right\}_{i_1=1}^{N_{ext}} \cup \left\{z_{i_2}^{(int)}\right\}_{i_2=1}^{N_{int}} \qquad (2)$$

where Z_{ext} and Z_{int} are subsets N_{ext} of external and N_{int} internal factors, and $N = N_{ext} + N_{int}$.

The degree of threats to energy security is denoted by:

$$S = \{s_k\}_{k=1}^{M} \qquad (3)$$

In the set of M degrees of threat to Ukraine's energy security, s_k is the k-th kind/type of threat. That is, the set (3) can be formed from four degrees of threat (in order of increasing potential negative consequences): low (weak), medium (moderate), high (strong), very high (critical). Such a division is conditional (it is shown in Fig. 2); it may vary, but it is clear that when "superimposing" factors that negatively affect energy security, their cumulative negative impact is amplified.

To determine the level of threats to Ukraine's energy security (the set of threats to Ukraine's energy security Z), it is formally necessary to evaluate the set of threat degrees S based on the study N of features in the set Z.

Determining the degree of threats (according to which S^*(4) is the most relevant degree of threat among all M degrees) can be done using such a statistical classifier as a probabilistic neural network.

$$s^* \in S = \{s_k\}_{k=1}^{M}, \qquad (4)$$

A probabilistic neural network is a mathematical object that implements a three-stage computational procedure. This procedure occurs at the input, radial, and output layers of the neural network [29]. A probabilistic neural network is very easy to build in the Matlab environment. To do this, it is necessary to form an input matrix [31]:

$$\mathbf{F} = \left[f_{ij} \right]_{N \times (mM)}, \qquad (5)$$

where $m \epsilon \{1,2,3 \ldots\}$, and the value of the element f_{ij} is a numerical estimate (fractional or integer, as well as from an arbitrary interval) of the feature Z_i in the state (class) S_k for

$$k = j - M \times \Psi(\frac{j-1}{M}), \qquad (6)$$

where the auxiliary function Ψ(x) returns the integer part of the number x.

Matrix (5) can have size $N \times M$, where will be $m = 1$ and $k = j$ according to formula (6). In this case, each feature in each state (threat level) will have only one estimate. This case is possible in calculations, but its implementation requires very reliable estimates (all you need to provide $N \times M$ with such estimates):

$$\mathbf{F} = \left[f_{ij} \right]_{N \times M}, \qquad (7)$$

However, matrix (5) can have size $N \times (2M)$, where $m = 2$ and $k = j$ will be by formula (6). That is, using matrix (8) each pair of feature and its state/threat degree (9) can be evaluated twice:

$$\mathbf{F} = \left[f_{ij} \right]_{N \times (2M)}, \qquad (8)$$

$$\{z_i, s_k\} \ (i = \overline{1, N} \ \text{ and } \ k = \overline{1, M}), \qquad (9)$$

This approach to threat assessment is more flexible, since the requirements for the reliability of the estimates are not as high as in the case of matrix (7). In this case, the "left" and "right" submatrices must be (somewhat) different, otherwise such a double assessment will not have any practical meaning.

Next, it is necessary to form the target matrix of classes / states (10), which is a sequential horizontal concatenation m of unit matrices of size $M \times M$, where $m \epsilon \{1,2,3 \dots\}$:

$$\mathbf{T} = \left[t_{ij} \right]_{M \times (mM)}, \qquad (10)$$

For example, if $m = 1$ and the number of states (threat levels) $M = 4$ (low/weak, medium/moderate, high/strong, very high/critical), then the target state matrix, whatever the number of features N, will be as follows:

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \qquad (11)$$

If, for example, $m = 3$, then the target state matrix (10) will be three times "wider", that is, the matrix will have the form:

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{bmatrix}, (12)$$

After matrices (5) and (10) are prepared, a probabilistic neural network $\mathbf{n}_{pnn}(N, M)$in the Matlab environment is built using the built-in Matlab function "newpnn", which accepts as input the matrices **F**and **T** together with the parameter of the spread of radial basis functions ρ:

$$\mathbf{n}_{pnn}(N, M) = \text{newpnn}(\mathbf{F}, \mathbf{T}, \rho), \qquad (13)$$

By default, the parameter ρ=0,1 (however, this value should not be considered a recommended value for the dispersion parameter). If this parameter is close to 0, the probabilistic neural network acts as a "nearest neighbor" classifier.

If the parameter ρ is increased, the probabilistic neural network takes into account several nearby (according to the corresponding Euclidean metric) vectors in the matrix (5).

Using a ready-made probabilistic neural network (13) is simple. If $\mathbf{V}$ is a vector of N features, that is:

$$\mathbf{V}=[v_i]_{N\times1} \in \mathbb{R}^N, \quad (14)$$

then in the Matlab environment using the built-in Matlab function "sim" we get:

$$\mathbf{A} = \mathrm{sim}\big(\mathbf{n}_{pnn}(N,M),\mathbf{V}\big), \quad (15)$$

Where $\mathbf{A}$ is M a dimensional vector in which $M-1$ the element has the value 0 and only one element has the value 1.

The index of the element with the value 1 corresponds to the state number, which is the most relevant threat level among all M levels. Thus, the response vector of the probabilistic neural network (13):

$$\mathbf{A}=[a_k]_{M\times1} \text{ at } a_k \in \{0,1\}, \quad (16)$$

where

$$a_k = 0 \text{ at } k \in \{\overline{1,M}\}/\{k^*\} \text{ and } a_{k^*}=1, \quad (17)$$

and $s^* = s_{k^*}$ is the most relevant level of threat.

To assess the degree of threats to the country's energy security, it is advisable to conduct an expert survey.

Experts should assess the intensity of the impact of external (N_{ext}) and internal (N_{int}) factors in terms of the characteristics of each factor, their impact on the degree of threat $S_k,\ k=\overline{1,M}$. At the same time, a certain degree of threat to energy security will correspond to a list of management decisions that theoretically does not contribute to the elimination of this threat (as a result, we need to find another list that will contribute to the gradual elimination of threats). The assessment of these lists will be simply a number, that is, an integer from 1 to $\sum_{k=1}^{M} J(s_k)$. Since we strive to work with data within a unit interval (with normalized data), that is:

$$f_{ij} \in [0;1] (i=\overline{1,N} \text{ and } j=\overline{1,mM}), \quad (18)$$

then the values f_{1j} $(j=\overline{1,mM})$ are obtained by dividing the threat list number on $\sum_{k=1}^{M} J(s_k)$.

The expert questionnaire for estimating the input matrix of the first probabilistic neural network, which will be processed using the Matlab environment, will have the form (Table 2).

Table 2. Questionnaire for Expert Evaluations of the Matrix F (from 0 to 1)

List of threats by factors	Threat level				
	S_1	S_2	…	S_{M-1}	S_M
Z_1			…		
Z_2			…		
	⋮	⋮	⋮	⋮	⋮
Z_N					

Source: *formed by the authors.*

In the future, it is necessary to identify adequate management decisions to prevent/minimize/neutralize threats, negative impacts, measures and means to ensure a sufficient level of energy security of Ukraine. The list of management decisions to prevent / minimize / eliminate threats, their selection for implementation can also be formed, based on the results of expert opinions using the methodology presented above. A more detailed substantiation of these issues will be the subject of a separate study.

CONCLUSIONS. Energy security of Ukraine, stable functioning of the energy system is an important condition for ensuring people's livelihoods, the functioning and development of all sectors of the national economy.

The state of energy security of Ukraine is determined by the conditions of the internal environment of the functioning and development of the energy system, as well as the influence of external environmental factors, including institutional conditions at different levels, global geopolitical transformations, etc.

A spectrum of threats to the energy security of Ukraine has been identified by threat areas (caused by war, financial and economic, technical and technological, cyber threats and information attacks, environmental requirements and climate challenges, corruption and inefficient management). Large-scale challenges and threats to the energy security of Ukraine were caused by the full-scale invasion of the Russian Federation into the territory of Ukraine. Ukraine has lost huge amounts of capacity. Due to the loss of capacity located in temporarily occupied territories and the loss of capacity due to massive missile and drone attacks on the energy system, Ukraine, unfortunately, has turned from a net exporter into a net importer of electricity. The financial and economic context of threats is manifested depending on the import of energy resources, price fluctuations, trends in the global market, financial instability of the energy sector, and insufficient investment resources for development and modernization. The technical and technological characteristics of the energy sector indicate the wear and tear of the energy infrastructure, the obsolescence of substations and power grids, which cause energy losses and low energy efficiency. The energy sector has not been spared by the latest types of threats - cyber threats and information attacks. In the context of sustainable development goals, it is important to comply with environmental requirements and respond to climate challenges. Threats to the effective functioning of the energy market and ensuring the country's energy security are corruption and ineffective management.

A scientific and methodical approach to assessing the level of threats to energy security based on probabilistic neural networks is proposed. The input parameters for assessing the degree of threats to the country's energy security are proposed to be formed on the basis of an expert survey. To verify the consistency of expert judgments, it is proposed to carry out clustering of expert assessments, since the optimal number of clusters is actually already determined in the proposed economic and mathematical model.

Therefore, a clear identification of threats by their types, taking into account their content, qualitative and quantitative context of threats, and assessing the probable degree of threats will serve as the basis for making informed management decisions to prevent / minimize / level the negative impact of factors on the energy security of Ukraine.

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