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ENTROPY AS A FACTOR OF INFLUENCE ON ENERGY SECURITY MANAGEMENT OF ENTERPRISES

Energy security management of the enterprise in conditions of entropy is an important aspect that includes adaptation to changes in the external environment and internal processes. The object of research is entropy, as a measure of uncertainty and chaos in energy systems, which affects the energy security management of enterprises. The problem of a comprehensive approach to the study and implementation of methods for calculating entropy indicators, which would take into account entropy in the energy security management, is solved.

The conducted analysis shows how the level of entropy in the supply of energy resources, in particular coal, electricity and alternative sources, affects the stability, sustainability and adaptability of management strategies aimed at ensuring energy security management.

The essence of the obtained results is that the study shows the importance of energy security management of enterprises in the conditions of entropy, which is a measure of uncertainty in energy systems. Entropy acts as a key factor influencing the energy security management, as it reflects the level of chaos and uncertainty in the supply of energy resources.

It is shown that the level of entropy directly affects the stability and adaptability of management strategies, which allows enterprises to better respond to external challenges and internal risks. The use of mathematical models, in particular Shannon's formulas, makes it possible to quantitatively assess the level of entropy and identify potential risks arising in energy systems. Awareness of the impact of entropy on management decisions helps enterprises to optimize processes, predict threats and reduce negative consequences.

The research results reflect the complex interplay between entropy, management strategies and external challenges, emphasizing the importance of an adaptive approach in energy security management.

The research focuses on practical aspects. From a practical point of view, awareness of the impact of entropy on management decisions allows enterprises to optimize management processes, predict potential threats, and reduce the negative consequences of external and internal risks.

The results of this research can become the basis for the formation of new management strategies capable of effectively responding to the modern challenges of the energy sector.

Keywords: *entropy level, energy security management, enterprise risks, entropy influence, management decisions.*

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1. Introduction

In today's world, the issue of enterprise energy security (ES) management is becoming more and more important in the context of global climate change, political instability, and the growing demand for energy resources, especially in the context of martial law.

Entropy, as an indicator of chaos and uncertainty in electric power systems at the macro, meso, and micro levels of the economy, can have a significant impact on energy security management of enterprises.

Energy security management of enterprises is a complex task, and taking entropy into account in this context is accompanied by several problems:

1. *Difficulty measuring entropy*. Entropy, as a measure of chaos or uncertainty, can be difficult to measure in the context of energy systems. This complicates the use of entropy indicators for risk assessment and management decision-making.

2. *System dynamics*. Energy systems are dynamic and subject to numerous changes, from technological to political. The variability of conditions makes it difficult to adapt models that take entropy into account to real operating conditions.

3. *Insufficient number of studies*. In various countries of the world, there are not enough studies that would study in detail the effect of entropy on energy security. This limits the possibilities for formulating practical recommendations.

4. *Problems with data integration*. Accounting for entropy requires the collection and analysis of large amounts of data from various sources. Integrating this data can be technically challenging and require significant resources.

5. *The need to adapt strategies.* Energy security management should be flexible and adaptive. A high level of entropy may require frequent adjustments to strategies, requiring additional resources and effort.

6. *Psychological aspect.* A high level of uncertainty associated with entropy can affect decision-making by the management of the enterprise. Fear of the unknown can lead to excessive caution or, conversely, to risky decisions.

An analysis of publications on the study of the definition and calculation of entropy indicators of complex objects was carried out. For example, in [1], improved algorithms for typical entropy calculation models were proposed, but an improvement in computing time for entropy calculation was not achieved. New approaches to entropy determination based on stochastic modeling are proposed in [2], however, the consideration of only average values of entropy indicators is noted as a drawback. In work [3], it is proposed to measure entropy by several methods with further comparison of the obtained results. The disadvantage is the complexity of entropy index calculations and their averaging. Methods for calculating configurational entropy in complex structures are additionally considered in [4], but not all entropy levels are used. Numerical modeling of entropy is considered in [5]. The disadvantage is that only general entropy values are modeled. Software for encoding and decoding entropy is proposed in [6]. This complicates the identification of entropy indicators. In [7, 8], entropy versus time in complex nonlinear systems was investigated. The disadvantage is the complex dependence of entropy indicators on time. The work [9] shows the application of entropy methods for the study of ecological systems. There are great difficulties in calculating entropy indicators depending on the indicators of the ecological system.

Thus, the literature review shows that there are a number of serious problems in calculating entropy indicators in complex systems, which in our study are energy system enterprises at the macro-, meso- and micro-levels of the economy.

These problems require an integrated approach to the study and implementation of models that would take into account entropy in the energy security management.

Based on this, let's note the main factors of entropy influence on energy security management of enterprises:
- increasing complexity of power systems at the macro, meso, and micro levels (for example, modern power systems are becoming increasingly complex, which increases the level of entropy);
- economic challenges (for example, energy companies face numerous economic challenges, including fluctuating energy prices);
- environmental aspects (for example, high entropy often indicates inefficient use of resources, which leads to environmental problems);
- technological innovations (for example, the development of new technologies in the field of electricity, such as renewable energy sources, requires new approaches to management);
- military, political and social factors (for example, martial law conditions often affect the energy security management of enterprises);
- scientific research (for example, interest in interdisciplinary approaches in science is growing today).

Therefore, the accounting and research of the factors considered above will allow solving the task of reducing the influence of entropy on the energy security management of enterprises of the electric power system, at the expense of [10]:
- forecasting, assessment and management of threats and risks of energy security of enterprises;
- optimization of the management decision to reduce material costs and increase economic efficiency;
- reducing the negative impact on the external and internal environment under martial law conditions;
- adaptation of strategies in response to changes in the external and internal environment under martial law conditions;
- discovery of new opportunities for innovative solutions and theoretical models.

Based on this, the relevance of research of the influence of entropy on the energy security management of enterprises is determined by the complexity of modern enterprises of electric power systems that function in the context of environmental, economic and socio-political challenges in the conditions of martial law. Entropy, which reflects the level of chaos and uncertainty, appears to be a critical factor affecting the ability of enterprises to adapt to the dynamic conditions of martial law. The study of this topic has theoretical and practical significance. From a theoretical point of view, it contributes to the expansion of knowledge in the field of risk management and sustainability of energy enterprises, forming new approaches to modeling management strategies in relation to energy security. From a practical point of view, awareness of the impact of entropy allows energy companies to optimize management decisions, predict potential threats and reduce the negative consequences of external and internal risks.

Thus, scientific research on this topic, which is devoted to the influence of entropy on the energy security management of enterprises, is extremely relevant and requires detailed research in view of its multifaceted nature and importance for the practical significance of the sustainable development of enterprises of the electric power system at the macro, meso, and global levels of the economy.

The aim of research is to study entropy as an indicator of chaos and uncertainty in energy systems, with an emphasis on its influence on the state of energy security of electric power system enterprises at the macro, meso, and micro levels, as well as to identify the main problems of entropy measurement and analysis in the context of ensuring energy management security.

2. Materials and Methods

Entropy in the energy security management of an enterprise is an important concept that allows to assess the level of uncertainty in energy processes at enterprises. Determining the level of entropy through spatial-dynamic monitoring provides the enterprise with the opportunity to adapt its strategies, improving the efficiency of energy resource management and reducing the risks associated with the instability of the enterprise's energy security management. A systematic approach to data monitoring and analysis allows enterprises to achieve higher stability and energy security in conditions of constant changes inherent in entropy.

Based on this, *the object of research* is entropy, as a measure of uncertainty and chaos in energy systems, which affects the energy security management of enterprises. This study analyzes how the level of entropy in the supply of energy resources (in particular, coal, electricity and alternative sources) affects the stability, sustainability and adaptability of management strategies aimed at ensuring energy security management.

Let's consider the main areas of entropy research as an object of research:

– mathematical models for entropy estimation (for example, the use of Shannon's formulas and other models for quantitative entropy estimation in energy systems);
– analysis of the impact on energy security management (for example, studying how changes in the entropy level affect management decisions in the field of energy security);
– management strategies (for example, development of recommendations for optimizing management practices to reduce the negative impact of entropy on the energy security of enterprises);
– interdisciplinary approach (for example, the involvement of knowledge from economics, ecology and risk management to form a holistic vision of the impact of entropy on energy security).

The study of entropy, in the context of energy security management, has an important theoretical and practical significance, as it contributes to the formation of more flexible and sustainable management systems capable of effectively responding to modern challenges.

The specific tasks of entropy research are to quantify the level of entropy in energy systems to identify factors that contribute to uncertainty to ensure energy security management of the enterprise.

Entropy research aims to provide enterprises with knowledge and tools for more effective energy security management, which in turn will contribute to sustainable development in the face of uncertainty.

The direction of research is a complex of management solutions aimed at ensuring the energy security of enterprises in conditions of increasing entropy, which reflects the level of chaos and uncertainty at enterprises in electric power systems. In today's conditions, in particular in the conditions of martial law and global challenges, such as climate change and political instability, the energy security management becomes a complex and multifaceted process.

The main goal of management decisions is the adaptation of enterprises to dynamic conditions arising as a result of increased entropy. This includes forecasting possible risks and developing strategies to neutralize them.

Let's consider the components of the research object:

1. *External influencing factors:*
– global climate changes, which affect the availability and reliability of energy resources, causing the need to adapt management strategies;
– political instability, which creates risks for energy supply and investment, which requires the development of flexible management solutions.

2. *Internal processes of enterprises:*
– management decisions related to strategic planning, resource management, risk assessment and technological innovations aimed at ensuring the stability of energy supplies;
– technological innovations that require adaptation of existing management models.

3. *Systematic approach:*
– the research is based on a systemic approach that takes into account the relationship between different levels (macro-, meso- and micro-levels) of energy systems and the corresponding management decisions, which allows to assess how changes in one element of the system can affect others.

There are several entropy calculation methods that have been proposed to be used to assess the level of uncertainty in various systems, including energy security. Here are some of them:

1. *Shannon's classic method*, which allows to predict potential risks associated with the supply of energy resources (for example, if entropy indicates a high probability of changes in supply, enterprises can take measures to diversify sources of supply).

Entropy, according to Shannon information theory, is a measure of uncertainty or chaos in a system. It is used to estimate the amount of information contained in the probability distribution of events. In the context of energy systems, entropy can reflect the level of uncertainty associated with energy supply, price fluctuations, and other factors affecting energy security. Entropy measures how much information is needed to describe a system, given all possible events and their probabilities. The higher the entropy, the greater the uncertainty in the system.

Knowing the level of entropy can help in determining optimal management decisions (for example, with high entropy, enterprises can invest in energy storage technologies or renewable energy sources). Using entropy, it is possible to assess how competitive the market for energy resources is, which allows enterprises to adapt their strategies in accordance with changes in the market situation. In systems with a high level of entropy, enterprises face greater risks. By knowing the level of entropy, adaptive management strategies can be developed that reduce these risks.

Thus, the classical Shannon method is a powerful tool for estimating the level of uncertainty in energy systems. Using this method, enterprises can develop more effective energy security management strategies that allow them to adapt to dynamic market conditions and reduce risks associated with energy resources.

The entropy *H(X)* for a discrete random variable *X* with *n* possible outcomes is determined by the formula:

$$H(X) = -\sum_{i=1}^{n} p(x_i)\log p(x_i), \tag{1}$$

where $H(X)$ – the entropy of the random variable (X); $p(x_i)$ – event probability (x_i); n – the number of possible events.

2. *The Renyi entropy method* is a statistical tool for the generalization of the classical Shannon entropy, which allows taking into account more complex probability distributions and evaluating the uncertainty or diversity of the system, in particular in the context of energy security. This method is based on information theory and can be used to analyze complex systems that have many different components.

Renyi entropy determination method is proposed to be applied in energy security to analyze the probability of various scenarios in the energy system (for example, when assessing the risks of supply failures, energy costs, or environmental impact).

Using this method allows:
– assess risks and uncertainties in energy systems;
– identify critical points and vulnerabilities that require attention;
– optimize management decisions, taking into account the diversity of energy sources and their impact on overall security.

Advantages of the Renyi entropy method:
– flexibility, which makes it possible to vary the parameter (α) and analyze systems with different characteristics and ensure adaptation to specific conditions;

– complexity, which gives the ability to process a variety of data and probabilities, makes it effective for multivariate analysis.

Thus, the Renyi entropy method is a powerful tool for energy security management, as it allows not only to assess risks, but also to focus on the optimization of management strategies. This is important for ensuring the stability and reliability of energy systems under conditions of uncertainty.

Renyi entropy is calculated by the formula:

$$H_\alpha(X)=\frac{1}{1-\alpha}\cdot\log\left(\sum_i p_i^\alpha\right)=\frac{1}{1-\alpha}\cdot\log\left(p_i^{\alpha-1}\right), \quad (2)$$

where $H_\alpha(X)$ – Renyi entropy; p_i – probability of events; α – parameter that determines the order of entropy (for the formula turns into Shannon entropy).

3. *The Kullback-Leibler entropy determination method (KLD)* is an important tool in information theory, which is used to measure the distance between two probability distributions. This method can be particularly useful for energy security analysis and management.

The Kullback-Leibler method can be used for:
– risk analysis and assessment of the difference between actual and predicted probability distributions of events (for example, energy supply, energy demand);
– optimization of management decisions and identification of deviations in systems, which can help in the development of strategies to reduce risks and improve resilience;
– monitoring and forecasting, to measure changes in the distribution of energy resources in time and space.

Thus, the Kullback-Leibler entropy method is a powerful tool for the analysis and energy security management, as it allows the estimation of differences between expected and actual conditions in energy systems. This can contribute to the adoption of informed decisions to ensure the stability and reliability of energy resources in difficult conditions.

The Kullback-Leibler entropy method is calculated by the formula:

$$D_{KL}(P\,\|\,Q)=\sum_i p_i\log\left(\frac{p_i}{q_i}\right), \quad (3)$$

where D_{KL} – KL-divergence index between two probability distributions P and Q; p_i – probabilities of events in the P distribution; q_i – probabilities in the Q distribution.

Formula (3) indicates how much one distribution differs from another.

The use of different entropy calculation methods allows for a more in-depth analysis of energy systems, taking into account various aspects of uncertainty and risk, which can be useful for enterprises seeking to improve energy security management and optimize energy processes.

In all methods, the estimation of entropy indicators is based on probability distributions and statistical analyses. This allows enterprises to analyze risks related to energy security and adapt their management strategies. Different methods can complement each other, providing a more comprehensive picture of the uncertainty in the system.

3. Results and Discussion

In the work, entropy indicators were calculated at three thermal power plants (TPS) from 2012 to 2022:
– Vuhlehirska TPP (R_{yst}=3600 MW), where the main fuel is: coal – 60 % (p_i=0.6); gas – 30 % (p_i=0.3); fuel oil – 10 % (p_i=0.1);
– Burshtyn TPP (R_{yst}=2334 MW): coal – 40 % (p_i=0.4); gas – 50 % (p_i=0.5); fuel oil – 10 % (p_i=0.1);
– Kryvyi Rih TPP (R_{yst}=2334 MW): coal – 30 % (p_i=0.3); gas – 60 % (p_i=0.6); fuel oil – 10 % (p_i=0.1).

Shannon method, Renyi method, and Kullback-Leibler method were used to calculate entropy values for three thermal power plants. Calculation of entropy indicators was carried out for each TPP.

Let's calculate the entropy index using Shannon method for Vuhlehirska TPP as of 2012, according to expression (1):

$$H(X)=$$
$$=-\left[0.6\cdot\log(0.6)+0.3\cdot\log(0.3)+0.1\cdot\log(0.1)\right]\approx 0.510.$$

Let's calculate the entropy index using the Renyi method for the Vuhlehirska TPP as of 2012, according to expression (2):

$$H_\alpha(X)=\frac{1}{1-2}\cdot\log\left(0.6^2+0.3^2+0.1^2\right)\approx 0.517.$$

Let's calculate the entropy index using the Kullback-Leibler method for the Vuhlehirska TPP as of 2012, according to expression (3), taking into account if to take q_i as a uniform distribution (1/3):

$$D_{KL}\approx 0.069.$$

Using similar formulas (1)–(3), entropy indicators were calculated for the Burshtyn and Kryvyi Rih TPPs, after which the obtained results were summarized in the Table 1, where the values for the Renyi method are calculated with an indicator of α=2, and for the Kullback-Leibler method, the results are obtained on the basis of a uniform distribution.

Table 1

Results of calculations of entropy indicators for Vuhlehirska, Burshtyn, Kryvyi Rih TPPs according to the Shannon, Renyi, Kullbak-Leibler methods for the period 2012÷2022

Year	Vuhlehirska TPP			Burstyn TPP			Kryvyi Rih TPP		
	$H(X)$	$H_\alpha(X)$	D_{KL}	$H(X)$	$H_\alpha(X)$	D_{KL}	$H(X)$	$H_\alpha(X)$	D_{KL}
2012	0.510	0.517	0.069	0.486	0.493	0.056	0.511	0.519	0.071
2013	0.497	0.504	0.065	0.494	0.500	0.054	0.498	0.510	0.070
2014	0.480	0.489	0.062	0.490	0.487	0.052	0.487	0.505	0.068
2015	0.510	0.517	0.069	0.472	0.475	0.051	0.493	0.511	0.069
2016	0.532	0.539	0.071	0.489	0.495	0.055	0.510	0.520	0.072
2017	0.523	0.530	0.070	0.494	0.492	0.054	0.474	0.484	0.066
2018	0.510	0.517	0.069	0.486	0.493	0.056	0.490	0.498	0.070
2019	0.497	0.504	0.065	0.495	0.501	0.054	0.511	0.520	0.072
2020	0.480	0.489	0.062	0.492	0.487	0.053	0.502	0.511	0.071
2021	0.510	0.517	0.069	0.486	0.493	0.056	0.511	0.519	0.071
2022	0.520	0.527	0.068	0.488	0.495	0.055	0.495	0.503	0.070

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In addition, entropy values may be rounded. This table makes it easy to compare the results of different methods for each TPP during the specified period. Such calculations help to understand how different types of fuel affect the EB of each TPP. Entropy indicators for each TPP indicate a different level of EB.

Based on the obtained results of calculating entropy indicators (Table 1), the influence of entropy on the state of energy security of Vuhlehirska TPP, Burshtyn TPP, and Kryvyi Rih TPP was considered:

– at the Vuhlehirska TPP, the entropy indicators indicate stability, but the dependence on coal increases the risks of TPP energy security;

– at the Burshtyn TPP, the entropy indicators indicate a more balanced structure, which reduces the risks of dependence on one source, which increases the state of TPP energy security;

– at the Kryvyi Rih TPP, entropy indicators indicate a high dependence on gas, which increases vulnerability, despite generally moderate entropy indicators.

These results highlight that, in general, energy systems show a positive trend towards reducing risks and inequalities, although there are fluctuations in the level of uncertainty.

Thus, the analysis of entropy indicators emphasizes the importance of a variety of fuel sources for maintaining the state of energy security of enterprises of the electric power system at the macro-, meso- and micro-levels of the economy.

Entropy, as a measure of uncertainty or distribution of energy resources, plays an important role in assessing the energy security of thermal power plants.

Dependencies of entropy indicators on the main fuel (coal, gas, fuel oil) in the period from 2012 to 2022 at the Vuhlehirska, Burshtyn, and Kryvyi Rih TPPs are shown in Fig. 1, where the curves on the graphs make it possible to assess the influence of entropy on the state of energy security of the enterprise.

The analysis of entropy indicators using various methods for the Vuhlehirska, Burshtyn and Kryvorozhskaya TPPs allows to draw several key conclusions:

– the stability of the Vuhlehirska TPP, since the entropy indicators according to the Shannon method vary between 0.480÷0.532, according to the Renyi method it shows similar results within the range of 0.489÷0.539, confirming the presence of a stable distribution of resources, but regardless of stability, high dependence on coal (60 %) increases energy security risks. This means that any interruptions in the supply of coal can lead to serious consequences for the energy system;

– Burshtyn TPP, as a more balanced system, as the entropy indicators according to the Shannon method vary between 0.472÷0.495 (40 % coal, 50 % gas), which reflects better resistance to risks, but the impact on energy security showed that a balanced structure of energy consumption reduces dependence from one type of fuel, which increases the overall level of energy security. This suggests that the TPP has lower risks in case of fluctuations in prices or supplies of gas or coal;

– the vulnerability of the Kryvyi Rih TPP, since the entropy indicators according to Shannon's method fluctuate between 0.474÷0.511, which indicates a certain uncertainty. Also, high dependence on gas (60 %) increases risks, despite moderate entropy values, but the impact on energy security showed that dependence on one type of fuel, in particular gas, makes Kryvyi Rih TPP vulnerable to energy price fluctuations and possible supply interruptions, which can lead to increased energy security risks.

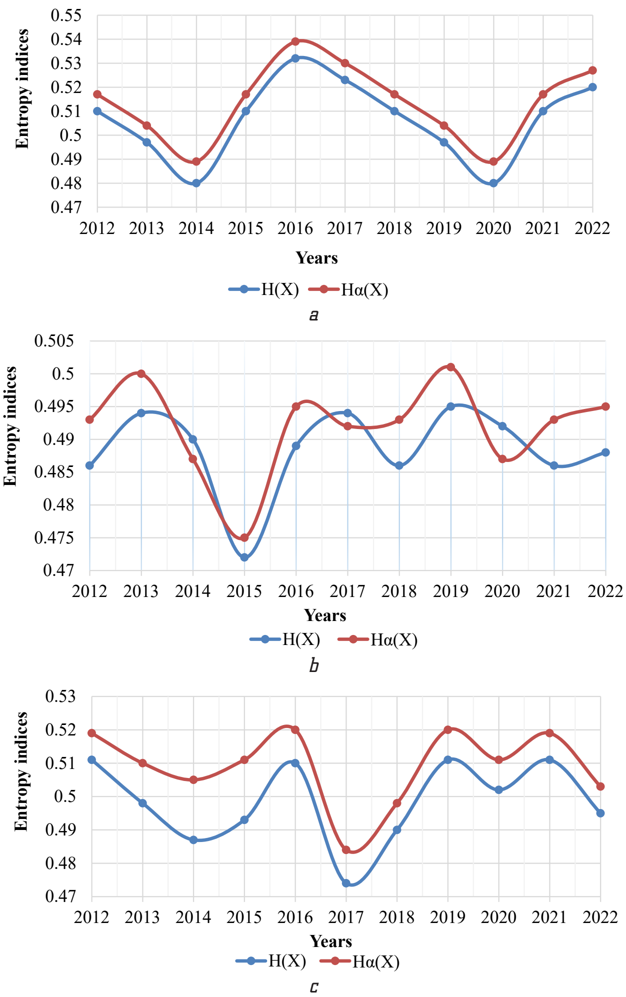

Fig. 1. Graph of the dependence of entropy indicators on the main fuel (coal, gas, fuel oil) in the period from 2012 to 2022: *a* – Vuhlehirska TPP; *b* – Burshtyn TPP; *c* – Kryvyi Rih TPP

The theoretical results of the study of entropy indicators, calculated according to the methods of Shannon, Renyi, and Kullback-Leibler, make it possible to assess the level of diversity and uncertainty in the distribution of energy resources at TPPs (Fig. 1). They demonstrate how structural changes in fuel consumption affect overall energy security.

The state of energy security of the TPP was studied. It showed that Vuhlehirska TPP, despite the stability of entropy indicators, has a high dependence on coal, which increases energy security risks. Burshtyn TPP demonstrates a balanced consumption structure, which reduces the risks of dependence on a single source. The Kryvyi Rih TPP, with a high dependence on gas, shows vulnerability, despite moderate entropy indicators. The relationship between entropy indicators and energy security was obtained. High entropy indicators indicate a greater diversity of energy resources, which, in turn, reduces risks. The study emphasizes the importance of diversity of fuel sources for maintaining the stability of energy systems.

The results of the study are explained by different structures of fuel consumption at TPPs. A coal-fired thermal power station, which is heavily dependent on coal, is more vulnerable to market fluctuations. Thanks to the diversification of sources, the Burshtyn TPP demonstrates a higher level of energy security. External factors, such as political stability, economic situation and changes in legislation, also affect energy security, forming corresponding risks.

The use of entropy as an indicator of energy security is a new approach in the analysis of energy systems, which differs from traditional methods of risk assessment, which usually do not take into account the diversity of energy sources. The study focuses on an integrated approach to energy security assessment, which includes not only economic indicators, but also the structure of consumption, which previously may not have been sufficiently taken into account in scientific studies. The research results highlight the importance of diversifying energy sources to reduce risks, which may differ from traditional approaches that often focus only on technological or economic aspects.

The practical significance of the obtained results is that the results of the analysis of entropy indicators serve as an important tool for the formation of reasonable management decisions to ensure the energy security management of the enterprise. Depending on different types of fuel, TPP management can effectively adapt its strategies, reducing the vulnerability of the system to possible risks. Determining entropy indicators allows enterprises to optimize the structure of energy consumption. This provides an opportunity to implement strategies that include diversification of fuel sources, which, in turn, increases the overall level of energy security.

The obtained results support a systematic approach to energy security management. The use of entropy indicators in combination with other analytical tools allows to take into account the complex interrelationships between energy resources, market conditions and risks.

One of the key limitations of research is the limited access to data on the consumption of different types of fuel. Incompleteness or unreliability of information can negatively affect the accuracy of calculations of entropy indicators. Methodological limitations must also be taken into account: Using only a few methods (Shannon, Renyi, Kullback-Leibler) for entropy analysis can reduce the depth of the study. Incorporating additional assessment methods can provide a more comprehensive overview. External factors such as political change, economic instability, and environmental constraints can significantly affect energy security, but are difficult to accurately integrate into the analysis. The dynamics of the energy market can lead to the rapid obsolescence of the obtained results, which requires regular updating of research to adapt to new conditions.

Martial law is often accompanied by economic difficulties, which can lead to an increase in energy prices and a decrease in investments in the modernization of energy infrastructure, as well as in providing the necessary volumes of fuel (coal, gas, oil). This complicates the accuracy of the data for analysis.

During a military conflict, the demand for electricity for the needs of the military and the population may increase, which changes the structure of consumption. Attacks on energy infrastructure can lead to a change in the operational indicators of enterprises, which will affect the assessment of their stability and energy security.

Martial law may lead to the introduction of new rules and regulations that may affect the energy sector, particularly the diversification of energy sources. Under the conditions of martial law, new requirements and expectations from the government regarding energy security may appear.

As a *perspective for further studies* of entropy as a factor influencing energy security, there may be studies that are supplemented with new mathematical and statistical models for a more accurate analysis of entropy in the context of energy security.

In addition, entropy analysis can be integrated with other economic, social and environmental indicators to create comprehensive energy security assessment models.

Research into new technologies, such as renewable energy sources and energy-saving solutions, can affect the structure of energy resources and, accordingly, entropy indicators.

Attention should be paid to the study of the impact of crisis situations, which will help analyze changes in entropy indicators during crises (military conflicts, natural disasters), as well as help identify vulnerabilities of energy systems and find ways to strengthen them.

4. Conclusions

The theoretical research results show that entropy, as a measure of the uncertainty and diversity of energy resources, is an important theoretical approach and tool for assessing the state of energy security of enterprises.

The study confirms that energy systems with high entropy scores, which indicate a diversity of energy sources, show less vulnerability to price fluctuations, supply disruptions and other external threats. This is important for the formation of theoretical models that combine energy policy with risks. The study of entropy indicators in dynamics (in particular, for the period 2012÷2022) demonstrates how changes in the consumption of energy resources affect energy security. This highlights the importance of real-time monitoring of energy systems to identify risks.

Practical application of the obtained results, taking into account the obtained entropy indicators, enterprises can develop specific strategies to diversify their energy sources, which may include investments in renewable energy sources, which will reduce dependence on traditional types of fuel.

The use of entropy indicators in the monitoring system allows timely detection of changes in the structure of consumption and response to them, which will help prevent potential crises in ensuring energy security.

Practical application of research results may include adaptation of energy systems to changes in the external environment (political, economic, environmental factors). This will contribute to increasing resilience to the crisis, especially in the conditions of martial law. In this context, further research can help reveal new aspects and mechanisms affecting energy security, contributing to the formation of effective energy strategies.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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The manuscript has no associated data.

Use of artificial intelligence

The authors confirm they did not use artificial intelligence technologies when creating the presented work.

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