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# THE ENTROPY APPROACH IN THE SYSTEM OF ASSESSING THE STATE OF ECONOMIC SECURITY OF THE COUNTRY

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**ЕНТРОПІЙНИЙ ПІДХІД В СИСТЕМІ ОЦІНКИ СТАНУ ЕКОНОМІЧНОЇ БЕЗПЕКИ КРАЇНИ**

***Currently, economic security is seen as a fundamental, but qualitative characteristic of the economic system, which determines its ability to provide a certain level of economic subjects, including a particular enterprise, industry, population, generally denotes sustainable resource provision of national economic development, as well as the ability to withstand economic crises of different scales. However, at the stage of society's development, security cannot be based solely on the postulates of a market or planned economy. A new concept is needed that would complement the fundamental theories and provide new mechanisms for ensuring economic security.***

***The article considers theoretical and conceptual issues of economic security analysis with the help of entropic approach. It is shown that economic security is connected with the identification and neutralization of internal and external threats in the sphere of economy to ensure social and political stability, sustainable and dynamic development of the economy, as well as with the creation of an effective and competitive system of the economic state system. The authors consider in detail the definition of the concept of "entropy", it is assumed that today it is promising to discuss economic security in the context of entropic analysis. The method of TOPSIS analysis is proposed for the development and decision-making of economic security problems, the result of which serves as a guide for practical economic actions. And also, to achieve the optimal synergistic effect it is necessary to eliminate the entropic threat of the system, on which the economic stability depends. In conclusion, the key stages of the application of entropic analysis in the system of economic security are characterized. The key aspect of further scientific works will be related to the selection and formation of a set of statistical indicators, such as demographic, resource, economic, etc., which provide a complete comprehensive picture of the existing relationships and patterns that have been established. Prospects for further research of this topic are seen in the development and justification of synergistic mechanisms for ensuring the economic security of the state.***

***У даний час економічна безпека країни розглядається як фундаментальна, але якісна характеристика економічної системи, яка визначає її здатність забезпечити певний рівень життєдіяльності економічних суб'єктів, включаючи конкретне підприємство, галузь, населення. Як правило, наявність економічної безпеки обумовлює стійке забезпечення ресурсами розвитку національної економіки, а також здатність протистояти економічним кризам різного масштабу. Однак на певному етапі розвитку суспільства безпека неспроможна базуватися виключно на постулатах ринкової чи планової економіки. Потрібна нова концепція, яка доповнювала б фундаментальні теорії та надавала нові механізми забезпечення економічної безпеки.***

***У статті розглядаються теоретичні та концептуальні питання аналізу економічної безпеки за допомогою ентропійного підходу. Показано, що економічна безпека пов'язана з виявленням і нейтралізацією внутрішніх і зовнішніх загроз у сфері економіки для забезпечення соціальної і політичної стабільності, стійкого та динамічного розвитку економіки, а також зі створенням ефективної й конкурентоспроможної системи економічної держави. Авторами аналізуються визначення поняття "ентропія", припускається, що на сьогоднішній день перспективним є обговорення економічної безпеки в контексті ентропійного аналізу. Для вироблення та прийняття рішень щодо економічної безпеки пропонується метод аналізу TOPSIS, результат застосування якого служить орієнтиром практичної дії. Для досягнення оптимального синергетичного ефекту необхідно усунути ентропійну загрозу системи, від якої залежить економічна стабільність. На завершення охарактеризовано ключові етапи застосування ентропійного аналізу в системі економічної безпеки. Напрями подальших наукових праць досліджень пов'язані з підбором і формуванням комплексу статистичних показників, таких як демографічних, ресурсних, економічних тощо, які дають описують цілісну вичерпну картину діючим взаємозв'язкам та закономірностям, що встановилися. Перспективи подальшого дослідження цієї теми вбачаються у розробці та обгрунтуванні синергетичних механізмів забезпечення економічної безпеки держави.***

*Key words: economic security; economic development; entropy; structural entropy; entropic analysis; synergy.*
*Ключові слова: економічна безпека; економічний розвиток; ентропія; структурна ентропія; ентропійний аналіз; синергія.*

## INTRODUCTION

The problem of economic security is relevant for all countries of the world, any state, regardless of its level of economic development, political system and cultural way of life, is faced with it. The damage caused by the problem of economic security of the state is associated with a significant lack of various kinds of resources (land, energy, human, etc.) necessary for national production, excessive dependence of the national economy on the economy of other countries, low efficiency of national production, and the presence of corruption, as well as the uncontrolled shadow sector in the economic system etc. Thus causes the necessity of a clear analysis of the state of the national economy, search for possible measures and directions to overcome the problems.

The evolution of the economic theories and schools primarily indicates an attempt to solve the problems of economic growth. Representatives of those various theories and schools tend to attach more importance to the study of the behavior of economic systems economic subjects relative to economic development. Hence insufficient attention is paid to economic security, which is a prerequisite for the previous one. Moreover, traditional economic theories and methodologies, which dominate in the modern scientific thinking and activities of researchers of economic sciences, assume mainly a linear model of describing the state of economic systems and solving the problems arising in them. However, recurrent economic crises of different scales to a certain extent cause criticism concerning theories and methodologies of the traditional kind and cast doubt on their validity.

Thus, in the present era, economists and other scientists are increasingly interested in economics as one of the most important, comprehensive and distinctive systems of human civilization, borrowing and introducing from the natural to the social-human sphere a set of terms. They, on the one hand, have long been known to natural scientists and, on the other hand, appear so alien to human scientists that their borrowing often raises doubts about their logic and validity. The attempt to rethink modern economics as a field of science and as a sphere of human life dates back to the last century, at a time of accelerated technological progress.

## LITERATURE REVIEW

The application of the entropic approach in the study and description of the state of economic systems is a relatively new scientific trend, in spite of the fact that the term entropy emerged as far back as the XIX century.

The term "entropy" comes from the ancient Greek word entropia, which means "turning", "transformation". As a scientific category "entropy" emerged in the natural sciences, primarily in physics, and more specifically in thermodynamics as a measure of irreversible energy dissipation [1, p. 8]. Specifically, the concept of entropy goes back to the German physicist Rudolf Clausius (1865), then entropy was called thermodynamic used as one of the indicators to describe the state of physical systems consisting of a large number of elements and capable of exchanging energy and substance with the external environment.

Entropy formula was proposed by R. Clausius:

$$dS = \frac{\delta Q}{T} (1),$$

where $dS$ — is the entropy differential, $\delta Q$ — infinitesimal increment of heat. The term entropy allowed to go beyond the law of conservation of energy and denote

the fundamental difference between "useful" exchanges of energy and "dissipated" energy lost irreversibly [2, p.170]. According to Clausius's opinion, though energy can be transformed, but we can't use it 100%, the coefficient of useful energy is always less than 1. That is, E (energy) = $E_i$ (useful energy, i = 1,2,3...n) + $E_h$ (useless energy, understood as entropy).

Following R. Clausius, trying to clarify the meaning of entropy and the possibility of expanding its scope, Ludwig Boltzmann formulated entropy as statistical item in 1877, establishing the connection between entropy and the probability of a state of a system:

$$S = K \times \ln W \quad (2),$$

where S is the entropy of the thermodynamic state of the system, K is the Boltzmann constant (constants), and W is the statistical weight of the system state, which is equal to the number of possible microstates (ways) by which a given macroscopic state of the system can be composed. Thus, the greater the value of W denoting the number of possible microstates of the system, the greater the disorder in it.

The next breakthrough in the interpretation of the concept of entropy is Claude Shannon's nomination of information entropy. In his scientific article "Mathematical Theory of Communication," published in 1948, he developed the theory of entropy as a measure of randomness and introduced a measure of discrete p-probability distribution on the set of alternative states of message transmitter and receiver [3, p. 243]:

$$H = -\sum_{i=1}^{n} \boldsymbol{p}_i \log_2 p_i \quad (3).$$

Here n is the number of characters of which a message (alphabet) can be composed, is the probability of the i-th outcome, — information entropy.

It should be noted that there are other representatives of entropy theory and their interpretations, but together with the above mentioned they are generally aimed at the description and investigation of the state of physical systems. Nevertheless, the development of physical-thermodynamic theories and their practical implementation were not limited to the natural-natural sphere of science, and accordingly, traces of these theories were also observed in the social-humanitarian scientific field. And further events developed according to the already known scheme: methodological achievements of natural science disciplines acted as a basis for reforming social sciences [4, p. 20]. In general, there is an alternative tradition or tendency in economics, which uses the proven natural-natural principle as a general principle of rational inference when faced with some incomplete, uncertain problem.

Back in the 1920s, Nobel laureate in chemistry Frederick Soddy (1926) criticized the traditional model of economic development, offering an economic perspective based on physics-the laws of thermodynamics; moreover, in his view, "... debt was growing at an exacerbated rate of geometric progress, but the real economy was based on inexhaustible reserves of fossil fuels. It was impossible to reuse energy from fossil fuels" [5]. In his book titled "Wealth, Virtual Wealth, and Debt: A Solution to the Economic Paradox" [6] Soddy divided property into those that have real wealth and those that do not (that is, have only virtual wealth), arguing that real wealth was obtained by using energy to convert materials into physical goods and services. It is obvious that the situations described in this statement partially hide the root of the problems of fluctuations and depressions in the economy that occurred in subsequent years, and thus one of the causes of the manifestation of the cyclical economic crisis can be correlated with non-compliance of economic activity with objective physical laws, in particular, the rule of limited resources for social production.

The Austrian theoretical physicist Erwin Schr?dinger, Nobel Laureate in Physics in 1933, one of the founders of quantum mechanics, in his book "What is life?" (1944) borrowed the concept of entropy and introduced the concept of negative entropy in analyzing the nature of life, noting that living organisms must obtain from the world around them to compensate for the growth of entropy leading them to thermodynamic equilibrium and hence to death [7]. In accordance with this the question is raised about the property of the social and economic system formed and created by people as a living organism, more specifically, about resources as a kind of negative entropy for the social and economic system.

In 1971 the Romanian economist, mathematician and statistician Nicolas Georgescu-Regen in his published book "The Law of Entropy and the Economic Process" [8] noted that production as the use of a limited stock of materials, energy and other resources, must obey the law of entropy, which operates in all systems: entropy or the amount of matter and energy not available for use tends to increase continuously, while the amount of matter and energy available tends to decrease continuously. According to Regen, the author of the article proposes a division at the micro-level of goods and services into those whose production directly increases more than a fraction of entropy and those whose production increases less than a fraction of entropy or allows for negative entropy.

## PURPOSE AND OBJECTIVE

Taking into account the cyclically occurring economic crises, the complexity of explaining their causes and the results of studies concerning the synthesis and integration of entropy theory in economic science, as well as the statement that the physical-thermodynamic foundations of modern economy are not to be ignored, the authors of the article consider appropriate to study the application of entropy theory and methodology in the analysis of problems concerning economic security. Thus, the purpose and objective of the article is to determine how to conduct entropy analysis in the general case and in the study of economic security, and by the results of the analysis to propose ways of structural reform of economic systems in order to obtain the synergistic potential, which is considered capable of obtaining negative entropy and eliminating the entropic threat in the economic system.

## RESULTS

Entropy of any system is a measure of its disorganization and disorderliness, respectively, one of the methods for assessing this measure is entropic analysis based on Shannon information entropy. Structural entropy is used when measuring disordered structure of a system [9]. Structural entropy in systems is characterized by structural imbalance, loss of system integrity and synergetic capabilities. Currently, against the background of economic globalization entropic processes may be intensified by the transboundary spread of adverse situations in a global crisis [10]. In [11] a fundamental difference between structural and thermodynamic entropy of the system is noted, pointing out that in closed systems thermodynamic entropy steadily increases over time, while structural entropy can both increase and decrease. In other words, it is structural entropy that is more characteristic of an open system, such as social and economic in most countries of the world. And while the science of thermodynamics directly associates thermal energy with entropy, the science of economics associates resources, which include not only natural resources in the form of thermal energy, but also others, for example, human and informational resources.

If the fundamental problem of macroeconomics is considered to be the relationship between supply and demand, the following hypothesis is put forward with the help of entropy theory, which reflects the entropy of demand and the entropy of supply:

(1) It is assumed that there are n numbers of consumers in a country whose demand is $x_1, x_2, x_3, x_4, \ldots x_n$, then the

**Table 1. Methodology for assessing economic security using the TOPSIS method**

| Sustainability assessment methodology stage | Indicator and formula for its calculation | Used map legend |
|---|---|---|
| 1. The procedure for processing statistical data by linear scaling to bring the values of indicators to a single unit of measurement (standardization of data). | $Z_{ij} = \frac{(x_{ij} - x_j^{min})}{(x_j^{max} - x_j^{min})}$ | the initial value of the indicator for a particular object of research; $Z_{ij}$ the reduced value of the indicator. |
| 2. Standardization procedure relative to the sum of values on the number of objects of research (includes subjects of economic security or periods). | $S_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{m} Z_{ij}}$ | $S_{ij}$ standardized value of the index. The values of which fall within the range [0,1]. |
| 3. Procedure for determining the entropy values of the indicators. | $E_j = -\frac{1}{\ln m}\sum_{i=1}^{m} S_{ij} \ln S_{ij}$ | $E_j$ is a measure of indicator entropy. |
| 4. Calculation of the weight coefficient of the indicator. | $V_j = \frac{1 - E_j}{\sum_{j=1}^{n}(1 - E_j)}$ | $V_j$ - weight coefficient of the indicator. |
| 5. Calculation of the weighted indicator weight coefficient. | $\Delta i_j = V_j * Z_{ij}$ | |
| 6. Finding the best estimates of indicators $\Delta^+$ (positive decision) and the worst estimates of indicators $\Delta^-$ (negative decision). | $\Delta^+ = \max_j \Delta_{ij}$ $\Delta^- = \min_j \Delta_{ij}$ | |
| 7. Ranking and evaluation of indicators. Evaluation of the state of the system. | | |

Source: the table was compiled by the authors.

total amount of demand of consumers in this country $D_x = \sum_{i=1}^{n} x_i$, the average demand of each consumer $\overline{D_x} = \frac{D_x}{n}$, the set of distribution of consumer demand $X = (\frac{x_1}{D_x}, \frac{x_2}{D_x}, \frac{x_3}{D_x} \ldots \frac{x_n}{D_x})$, then the entropy of demand distribution $H(X) = -\sum_{i=1}^{n} \frac{x_i}{D_x} \log \frac{x_i}{D_x}$;

(2) Similarly, if a country has m numbers of producers whose supply is $y_1, y_2, y_3, y_4, \ldots y_n$, then the total supply of producers in the country $S_y = \sum_{i=1}^{m} y_i$, the average supply of each producer $\overline{s_y} = \frac{S_y}{m}$, the set of distribution of the producers' supply $Y = (\frac{y_1}{S_y}, \frac{y_2}{S_y}, \frac{y_3}{S_y} \ldots \frac{y_m}{S_y})$, then the entropy of the supply distribution $H(Y) = -\sum_{i=1}^{n} \frac{y_i}{S_y} \log \frac{y_i}{S_y}$.

From this we can conclude that the greater the values of entropy $H(X)$ и $H(Y)$, the more complex will be the country's economic system, the more uncertainty and disorder in it. The state of the population's income, life expectancy, gross domestic product (GDP) of the countries and GDP of the country's regions can be described in this way. To build a model of entropic analysis of the state of economic systems, including the system of economic security, let us connect the entropy index and economic indicators.

The authors propose to use in this article the entropic method "TOPSIS" (The Technique for Order Preference by Similarity to the Ideal Solution) to assess the state of the economic security system. The method was specially developed for the comparative evaluation of objects in order to maintain objectivity with a large number of indicators and indexes (private criteria) [12, 13]. The main concept of the method consists in the fact that the greatest integral assessment among the compared objects gets the one of them, the values of private indicators of which are as close as possible to the best values and as far as possible from the worst ones. From the side of this article, the basis for calculating integral assessments of compared objects is the indicator of economic security. And the result of this method of analysis, as a rule, allows to find out and explain the increase and decrease of entropy in the system and its structure, on the basis of this to show the positive and negative value of the result itself, and to serve as a practical orientation for taking measures and decisions.

And so, let's consider the system of economic security as a stochastic system in the form of a multidimensional continuous random variable with the density of the distribution of weights (significance). For calculation we use the data of stability indicators in the form of matrix m-n, where m — the number of evaluation objects (countries, regions, enterprises and other subjects of economic security, or evaluation periods), n — the number of indicators (criteria or indicators):

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$$

where $x_{ij}$ is the initial value of the economic security indicator, including i = 1, 2, 3,... m, j = 1, 2, 3,... n.

After considering the method of entropic analysis, the task is to select and determine the indicators of economic security. Subsequently, on the basis of these indicators will be carried out a practical calculation of the entropic value of a separate part of the system of economic security and the value of the system as a whole. In this article the authors offer a summary table of indicators from the "Economic Security Strategy of Ukraine until 2025" [14].

It is noteworthy that the above table did not include items on energy and human security, which are no less important components of a state's economic security system, since it is the volume and state of resource possession and, accordingly, the effective use of the latter that is the essence of economic security, much less economic growth. A country with a huge amount of resources, but no effective management mechanism, and a country that knows how to manage economic activity, but suffers from a lack of

**Table 2. Indexes and indicators of economic security of Ukraine**

| |
|---|
| **1. Financial security** |
| 1) Ratio of state budget deficit to GDP, % |
| 2) Ratio of public debt and publicly guaranteed debt to GDP, % |
| 3) Gross external debt, % of GDP |
| 4) Change in the exchange rate of the hryvnia to the U.S. dollar (average for the period), % against the previous year |
| 5) Gross international reserves of Ukraine, months of imports |
| 6) Share of long-term loans in the total volume of loans granted, % |
| 7) Share of non-performing loans, % |
| **2. Occupational Safety and Health** |
| 1) Degree of depreciation of fixed assets in industry, % |
| 2) Degree of depreciation of fixed assets in construction, % |
| 3) Degree of depreciation of fixed assets in transport and communications, % |
| 4) Share of high-tech products in the total volume of industrial products sold, % |
| 5) Energy intensity of GDP (primary energy expenditures per unit of GDP), kg eq.<br>6) internationalise PCC dollar 2011 |
| 7) Material intensity of GDP, % of the 2015 level |
| 8) ..... |
| **3. Foreign economic security** |
| 1) Share of the leading partner country in total exports of goods, % |
| 2) Share of the leading partner country in total imports of goods, %3 |
| 3) Specific weight of the leading commodity (commodity group) in the total volume of exports, % |
| 4) Share of raw and low value added exports of industry in total exports of goods, % |
| 5) Share of exports of goods using high and medium level technologies in the total volume of goods exports, % |
| **Investment and innovation security** |
| 1) Net growth of foreign direct investment, % of GDP |
| 2) Gross fixed capital formation, % of GDP |
| 3) Share of enterprises that implemented innovations from the total number of industrial enterprises, % |
| 4) Share of sold innovative products in the volume of sold products in the industry, % |
| 5) Total expenditure on research and development at the expense of the state budget, % of GDP |
| 6) Ukraine's place in the Global Innovation Index ranking |
| **5. Macroeconomic security.** |
| 1) The excess of the index of real average monthly wages and the index of labor productivity in Ukraine, p.p. |
| 2) Index of physical volume of GDP, % |
| 3) Labor productivity index, % |
| 4) Consumer price index for goods and services (to December of the previous year), % |
| 5) Unemployment rate (ILO methodology), % |
| 6) Population's propensity to save, % |

Source: Strategy of economic security of Ukraine until 2025 [14].

resources (or no reliable access to them) are the same in terms of vulnerability to potential threats and crises [15, p. 76].

Nevertheless, another official document of the Government of Ukraine [16] gives a full and detailed description of the method of recommending indicators for calculating the level of economic security, but the authors do not consider it relevant to give its full content, arguing that from the point of view of the entropy theory, the more particles and components of the system, the more probable and degree of disorder and chaos in this system, the more uncertainty and confusion, thus the accuracy of assessing the state of economic security largely depends on the names.

For example, the level of openness of one region of the country determines its ability to receive resources from the outside world, i.e. negative entropy to maintain economic stability in the region. For a comprehensive assessment of the level of openness of each region of the country, the following sample table is proposed as a database for further mathematical calculation:

**Table 3. Indicators of economic openness of the country's provinces**

| Indicators / Provinces | GDP | Volume of direct foreign investment | ... | Foreign trade volume |
|---|---|---|---|---|
| Province 1 | $x_{11}$ | $x_{12}$ | $x_{1...}$ | $x_{1n}$ |
| Province 2 | $x_{21}$ | $x_{22}$ | $x_{2...}$ | $x_{2n}$ |
| Province 3 | $x_{31}$ | $x_{32}$ | $x_{3...}$ | $x_{3n}$ |
| Province ... | $x_{...1}$ | $x_{...2}$ | $x_{.....}$ | $x_{...n}$ |
| Province m | $x_{m1}$ | $x_{m2}$ | $x_{m...}$ | $x_{mn}$ |

Source: the table was compiled by the authors.

The next stage of the analysis is the practical calculation of the values of entropy of economic indicators, as a result of which a general picture of the circumstances of the economic system is constructed. To eliminate the identified structural entropy and threat it is necessary to be guided by the principles of the theory of systems and the theory of synergy, which will determine the development of specific measures, the adoption of economic policy and the quality of the result — getting economic synergy, improving economic security and optimizing the economic state.

## CONCLUSIONS

In the course of the research in the article the authors considered the issues of entropy theory and its application to assess the state of danger of the economic system. In the authors' opinion, the limitedness and exhaustibility of most types of resources (primarily natural resources) determine the state of economic security of the country, thereby predetermining the boundary of the height of its economic development. Moreover, it is fairly assumed that based on the process of extraction, processing, transformation and use of different types of resources, the modern economy of the traditional model is not released from the entropic constraint, the reason for which is the fact that at each stage of the marked economic process the law of entropy dominates.

Thus, the solution of entropic problems in the economic system of the country is determined by ensuring its economic security. It should be noted

that innovative technology, known as one of the found ways out of the predicament, increasing the efficiency of production, contributes to the reduction of entropy in the economic system.

In addition, the TOPSIS entropic analysis method proposed in the article not only makes it possible to carry out a multi-criteria evaluation on a sufficiently objective basis, but also to propose appropriate solutions based on the analysis, developing targeted programs to support the economic security of the country and its regions. The collection and processing of economic indicator data are necessary for further research.

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