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Determining the economic sustainability reserve of economic entities in modern operating conditions

Abstract. In complex socio-economic and political conditions, economic entities must have a sufficient level of economic stability and its reserve for normal life activities. Therefore, the problems of assessment and analysis of economic stability and its reserve are urgent and require immediate solution. The purpose of the article was to study the determination of economic sustainability of economic entities, its reserve, substantiation of the logic of the stages of this determination, and the formation of an appropriate analytical tool. In the research process, general scientific and special research methods were used: abstract-logical method, systematic approach, methods of analysis and synthesis, graphic method, method of building an integral taxonomic indicator of development, multi-criteria optimisation, multi-factor regression analysis, genetic algorithm, marginal utility method, cluster analysis. The article presents the selection of a system of economic sustainability indicators for economic entities of the state sector of Ukraine across regions from the point of view of their legislative basis. In order to determine the reserve of economic sustainability of public sector economic entities across the regions, an economic-mathematical model of multi-criteria optimisation of economic sustainability indicators was developed and solved using a genetic algorithm, which is a new analytical support in economics in solving this problem. A new result in economic-mathematical modelling is the method of forming partial criteria in multi-criteria regression dependency optimisation. The article provides a procedure for implementing the marginal utility method for

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justifying the final single optimal solution of the multi-criteria optimal problem of determining the optimal values of economic sustainability indicators. It has been proven that it is advisable to determine the absolute value of economic sustainability reserve for economic entities in the regions by their clusters, which were obtained on the basis of the system of indicators of economic sustainability and regional gross product per person. The practical significance lies in the fact that such a scientific-methodical approach to determining economic sustainability and its reserve allows for the objective development of management decisions at industrial enterprises to ensure their normal life activities in difficult war and post-war conditions

Keywords: system of indicators; reserve of economic sustainability; multi-criteria optimisation; genetic algorithm; clusters of regions; deviation of indicators

INTRODUCTION

Wars, Covid-19 and other force majeure circumstances that have been taking place recently in the world and in Ukraine prompted the need to generalise and consider the conditions that limit the activities of business entities. Currently, the conditions that limit the activity of business entities include such conditions as war, post-war, natural disasters, social disasters (Covid-19), global world crises. In such conditions, the management of enterprises does not have time to react in time to the unexpected changes that are taking place and to immediately adapt to them. In this regard, the economic sustainability of economic entities, namely its reserve, ensures life activity, and constant monitoring provides the opportunity to maintain these values.

Various aspects of the problem of economic entities sustainability for all levels of management have been reflected in the works of many scientists both in the world and in Ukraine. Foreign scientists pay particular attention to ecological and economic sustainability. So famous scientist R.B. Howarth (2012), who addresses the challenges of ecological economics in his report, argued that accepting significant reductions in future economic growth rates may not be necessary to protect and sustain the biophysical systems that provide the basis and foundation for human existence and well-being. In the long run, growth in material production and consumption is constrained by natural resource constraints, and achieving a sustainable future will require policies and institutions that support the economy within the framework set by nature (Howarth, 2012). The concept of sustainability is closely related to the basic concepts of macroeconomics such as development and growth. This is very well and thoroughly substantiated in the fundamental monograph of V. Draskovic *et al*. (2017). This monograph contains recommendations for solving many conceptual problems, namely: the relationship between economic and environmental crises; contradictions of economic development and ecology; institutionalisation of relations between economy and ecology, interpretation of sustainable development; the importance of knowledge in sustainable development; the importance of social responsibility in ensuring sustainable development. This monograph is of great importance in the formation of the modern theory of sustainable development.

Regarding the determination of economic sustainability, the authors E. Stockhammer *et al*. (1997) in their work recommend using the index of sustainable economic well-being as an addition to GDP (Gross Domestic Product). They believe that a holistic reporting system for measuring economic sustainability should be developed. An interesting approach to modelling the sustainability of the corporation's activity is proposed by P. Ahi *et al*. (2018). They substantiated the sustainability model based on a probabilistic approach, taking into account environmental issues. L. Hassani *et al*. (2019) supports the idea of multi-criteria in the assessment of sustainability, connecting the process of its determination with the solution of optimisation problems. The problems of determining industrial sustainability remain relevant in many countries, as evidenced by the results of A. Trianni *et al*. (2019) research. J. Wang (2022) in his work used a regression model of Difference in differences (DID) to assess the impact on the sustainable development of resource cities, while he recommends measuring economic growth by the annual growth rate of GDP.

Thus, the existing current conditions of business entities and the numerous works of scientists, their studies, which differ in their approaches to the interpretation and definition of economic sustainability, testify to the need to determine the reserve of this sustainability. The purpose of this study was to justify a new approach to the interpretation of the reserve of economic stability to ensure the normal life of business entities in force majeure circumstances, its new analytical definition using recommended mathematical tools.

LITERATURE REVIEW

L. Zapata-Cantu & F. González (2021) analysed sustainable development in great detail as one of the vital challenges of the 21st century for humanity. They explored how mission-oriented policies have influenced sustainable regional development and innovation in Latin America, and argued for opportunities that could support the improvement of the national innovation system and, as a result, the development of sustainability.

Ukrainian scientists, such as P.P. Zakorko & V.E. Breus (2017), paid a lot of attention to solving the problems of economic stability. They considered the essence of understanding the economic sustainability of an enterprise as an adaptive response that would return the system to one of the acceptable stages, propose components, methods of ensuring and methods of evaluating economic sustainability. S. Kozlovskyi & G. Mazur (2017) considered the essence of the category "sustainability of the economic system", its types and proposed a definition of the stability of the economic system, analysed the importance of assessing economic stability, defined approaches to managing economic stability. T.V. Ponomarenko (2016) substantiated the methodical approach to the assessment of economic sustainability based on a value model, which is defined as an ana-

lytical innovation and will allow formalising the levels and states of economic sustainability in accordance with the needs of modern economic diagnostics and real business, which is oriented towards long-term economic growth. A.O. Kasych *et al*. (2019) justified the procedures for determining the type of sustainability, as well as modifying the algorithm of the main components of the method, which allows comparing the positions of companies in relation to competitors and quantifying achievements in the field of sustainable development. E.V. Mishuk (2018) investigated the relationship between economic sustainability and economic security of the enterprise in the conditions of multivariate external and internal environments. He gives definitions of economic security containing the term "sustainability" and its derivatives and, based on the comparison of definitions of economic sustainability with similar definitions of economic security, revealed their common characteristics. S. Dombrovska & M. Horbachenko (2021) in the study of the economic essence gives priority to financial sustainability; in the analysis and assessment of financial sustainability, they focus on influencing factors. The institutional basis of economic sustainability was substantiated by the members of the Council for the Study of Productive Forces of Ukraine of the National Academy of Sciences of Ukraine, State Institution "Institute of Economics and Forecasting of the National Academy of Sciences of Ukraine", National Institute for Strategic Studies, etc.

For a detailed study of economic sustainability, its structure should be analysed. A socio-economic system has economic sustainability if its appropriate structure is preserved during the period of operation or flexibly changes under the influence of factors. But each state of the system is characterised by some separate structural norm, which is a ranked system of rates of changes in indicators that reflect meaningful economic sustainability. This structural dynamic standard takes into account the patterns of development of processes, phenomena and characteristics of socio-economic systems and reflects their current state (Malyarets *et al*., 2019).

Despite the significant development of the theoretical and practical principles of economic sustainability and its management, a number of unresolved problems remain. In particular, the informational-analytical, scientific-methodological support of the economic sustainability of industrial enterprises in modern conditions of limited activity, determination of the optimal levels of the criteria for this sustainability, and the size of its reserve need to be improved.

MATERIALS AND METHODS

The study considered the analytical task of determining the economic sustainability of economic entities of the state sector of the economy across the regions for 2021. In accordance with the Methodological recommendations for the application of criteria for determining the efficiency of state-owned objects' management, approved by the order of the Ministry of Economy and Development dated 15.03.2013 No. 253 (Order of the Ministry..., 2013), it is said that the evaluation of the results of the financial and economic activity of economic entities must be done according to the criteria, namely: the absence or reduction of arrears from the payment of wages, the rate of change in the size of the average monthly wage, the implementation of the financial plan, the degree depreciation of fixed assets, change in the size of net profit/loss, coverage ratio, financial stability ratio, solvency ratio, and the results of the audit opinion. Thus, the economic stability of economic entities of the state sector of the economy in the regional division was determined on the basis of the main indica-tors of their financial and economic activity, namely: net income (x_1, million UAH), net financial result (x_2, million UAH); receivables (x_3, million UAH), payables (x_4, million UAH), total value of assets (x_5, million UAH), equity (x_6, million UAH), average number of employees (x_7, thousands of people), arrears from the payment of wages (x_8, million UAH). In order to determine the level of economic sustainability of economic entities of the state sector of the economy in the regional section, the entire system of indicators was collapsed into one value, which is an integral indicator. Based on the advantages of calculating the integral indicator using the taxonomic indicator of development, namely the simplicity of the calculation algorithm of the method, the clear interpretation of the value of the integral indicator, it is recommended for determining the level of economic sustainability of entities of the economy state sector in a regional context. The graphic method was used to visualise the integral performance indicators of economic entities. Cluster analysis was used to calculate the values of the stock of economic sustainability of business entities in the studied regions.

RESULTS AND DISCUSSION

The analysis of the economic sustainability of economic entities of the economy state sector across the regions for 2021 shows that the highest level was observed in the Kyiv region, Kharkiv region, Odesa region, and Mykolaiv region; the lowest levels are in Kirovohrad, Luhansk, Kherson, and Chernivtsi regions. Figure 1 shows the calculated values of the integral indicator of economic sustainability of economic entities of the state sector of the economy across the regions.

In regions where there is a low level of economic entities' sustainability of the economy state sector, it is necessary to develop programs that would systematically solve the problems of their life activities. An important criteria of the economic sustainability of business entities in the region is the gross regional product per capita. Figure 2 shows the value of the GRP (Gross Regional Product) per capita in 2021.

According to Figure 2, the highest value of gross regional product per capita is in Poltava, Kyiv, and Dnipropetrovsk regions, and the lowest is in Luhansk region. But the analysis of the level of economic entities' sustainability of the state economy sector across the regions on the basis of the integral indicator of the efficiency of their activity or the gross regional product calculated per capita in the regions does not provide an opportunity to objectively talk about the reserve of this sustainability; a multi-criteria optimisation problem should be solved. But here it should also be noted that after obtaining a set of Pareto-optimal solutions in solving a multi-criteria optimisation problem, an important stage is the adoption of a final single solution. Many methods have been developed to determine the single optimal solution, but many of them have the disadvantage of requiring additional information and significant calculations.

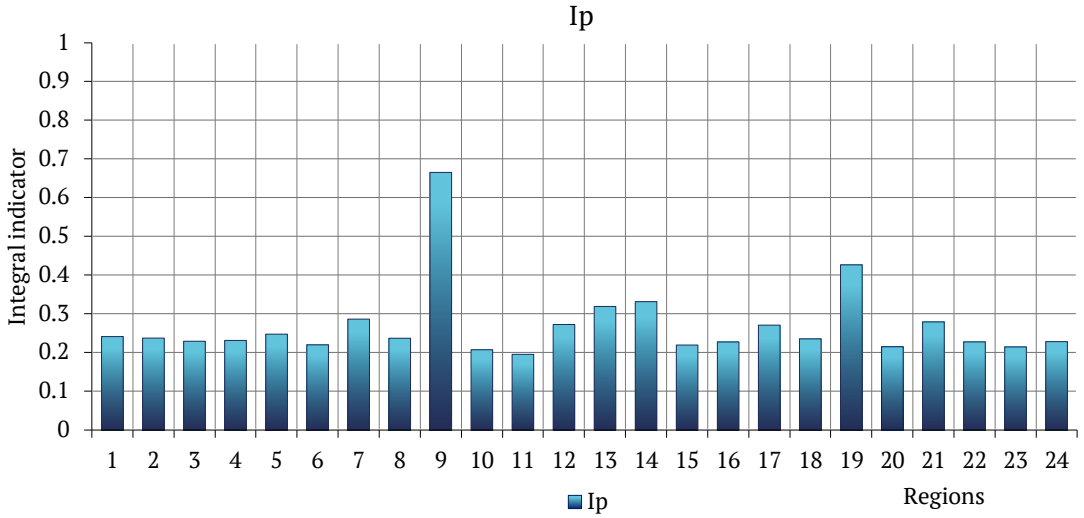

Figure 1. Integrated indicator of the efficiency of economic entities of the state sector of the economy across the regions for 2021

Note: 1 – Vinnytsia region; 2 – Volyn region; 3 – Dnipropetrovsk region; 4 – Donetsk region; 5 – Zhytomyr region; 6 – Zakarpattia region; 7 – Zaporizhzhia region; 8 – Ivano-Frankivsk region; 9 – Kyiv region; 10 – Kirovohrad region; 11 – Luhansk region; 12 – Lviv region; 13 – Mykolaiv region; 14 – Odesa region; 15 – Poltava region; 16 – Rivne region; 17 – Sumy region; 18 – Ternopil region; 19 – Kharkiv region; 20 – Kherson region; 21 – Khmelnytskyi region; 22 – Cherkasy region; 23 – Chernivtsi region; 24 – Chernihiv region

Source: compiled by the authors based on O.S. Budarin (2022)

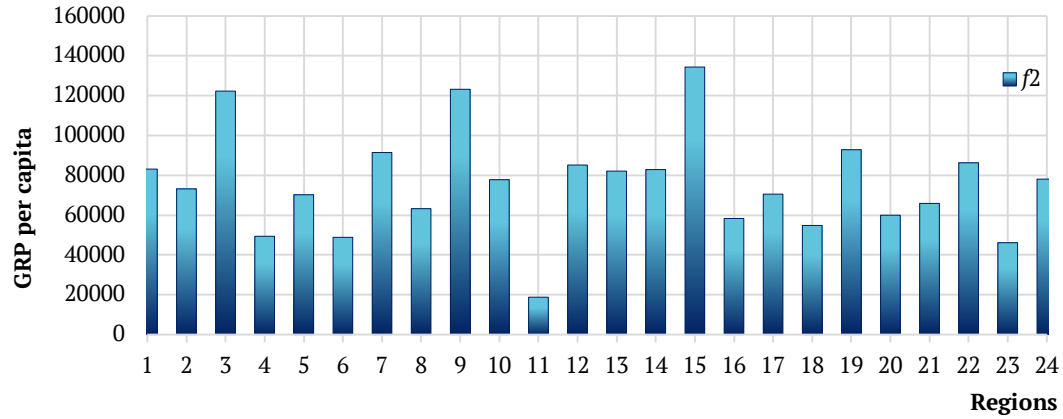

Figure 2. Gross regional product per capita in Ukraine in 2021

Source: compiled by the authors based on Regional Statistics (2022)

These methods include the method of decision-making based on the analysis of hierarchies, the method of decision-making based on network analysis (Saaty, 2008), the method of the best and worst criteria (Rezaei, 2015) and others. However, they all reflect the so-called fundamental paradox of the theory of decision-making based on multiple criteria, namely, when using different methods to solve the same problem, different solutions can be obtained (Triantaphyllou, 1989). One of the methods that is not affected by the stated paradox is the method of marginal utility (Zhao *et al*., 2006), according to which the optimal final solution is obtained based on the determination of the smallest value of affinity between the nearest vectors in the space of values of the objective vectors of the solutions. In the task of determining the optimal level of economic sustainability of business entities, which contains two partial criteria, it is necessary to analyse all vectors in terms of their affinity with the two nearest neighbouring solution vectors (Butko *et al*., 2018). It should also be noted that solving the multi-criteria optimisation problem of determining the optimal values of indicators of economic entities' sustainability using a genetic algorithm is expedient in the MatLab software environment.

The approaches of scientists and practitioners allow us to outline the principles of ensuring economic sustainability: 1) the principle of multidimensionality and multicriteria – economic sustainability is a system that has a structure and elements, their properties, which are expressed through features and criteria; 2) the principle of dynamism – economic sustainability as a system changes over time; 3) the principle of institutionality – the obligation of business entities in the process of ensuring economic

stability to comply with the current legislation. Most often, sustainability is understood as a certain "state" of the enterprise, during which its stable functioning is ensured. Less often, sustainability is highlighted as the ability or capacity of the enterprise to resist the influence of negative factors of the external environment. In this study, economic sustainability is considered as a complex integral characteristic of business entities to maintain homeostasis with the external environment in various conditions of their activity, in particular, in conditions of its limitations, to counteract the negative impact of destabilising force majeure factors. According to the types of activities, financial, production, marketing, investment and innovation, as well as market, organisational sustainability are distinguished.

In a multi-criteria optimisation problem, the comparison of solutions based on their merits is not carried out directly, but with the help of set of X numerical functions f_1, f_2, ..., f_k, which are called criteria that form a vector criterion $f=(f_1, f_2, ..., f_k)$. The set of criteria can be presented in the form of a vector objective function: $F(X)=\{f_1(X), ..., f_k(X)\}$, where $X=\{x_1, ..., x_n\}$ $(i=\overline{1,n})$ is a vector of variables, usually $X \geqslant 0$. The functional interrelationship between variables is established by relations, on which restrictions $g_i(X) \leqslant b_i$ $(i=\overline{1,m})$ are imposed.

Since there are many methods of solving multi-criteria optimisation problems, the problem lies in its choice. Multi-criteria problems are classified according to many features: according to optimisation options, according to the number of criteria, according to types of criteria, according to the ratio between criteria, according to the level of structuring, according to the presence of the uncertainty factor (Voronin, 2018). It is believed that the most important of the classification features of multi-criteria optimisation methods is the feature based on the functions of the person who makes the decision, namely: 1) methods of finding the optimal solution without the participation of decision maker; 2) a posteriori methods; 3) a priori methods; 4) interactive methods.

To compile the objective function of the multi-criteria optimisation problem, we will use the dependence of the levels of economic sustainability of business entities and the gross regional product per person on the main indicators of financial and economic activity:

$$F(X)=\{f_1(X), f_2(X)\}, \quad (1)$$

where $f_1(X)$ is the criterion of the gross regional product level per capita; $f_2(X)$ is the criterion of the level of economic sustainability of economic entities of the state sector of the economy; $X=\{x_1, ..., x_8\}$ is a vector of variables, which are the main indicators of financial and economic activity.

At the same time, the limitations in the problem are the numerical characteristics of variables X, which are defined for the totality of regions in 2021.

As a result of the calculations performed in the MatLab environment, the economic-mathematical model of the multi-criteria optimisation problem of determining the optimal values of indicators of economic stability of economic entities of the public sector of the economy has the form:

$$f_1=71.9842-10.0189x_1+26.6956x_2+17.0093x_3-0.5111x_4-1.2117x_5+2.382x_6+3.9764x_7+0.42x_8 \rightarrow \max;$$

$$f_2=0.2075-0.0038x_1+0.016x_2+0.024x_3-0.0042x_4+0.0025x_5+0.0063x_7-0.0004x_8 \rightarrow \max.$$

subject to restrictions:

$$0.5818 \leqslant x_1 \leqslant 47.2707;\ -3.358 \leqslant x_2 \leqslant 10.9404;$$
$$0.0328 \leqslant x_3 \leqslant 8.7242;\ 0.1269 \leqslant x_4 \leqslant 59.0309;$$
$$0.9583 \leqslant x_5 \leqslant 126.8385;\ -11.145 \leqslant x_6 \leqslant 61.1503;$$
$$1.6 \leqslant x_7 \leqslant 29.6;\ 0.0 \leqslant x_8 \leqslant 248.0.$$

To solve this multi-criteria problem, it is recommended to use a genetic algorithm, which is based on the principles of the evolutionary theory of living organisms. Evolutionary methods are new methods of solving multi-criteria optimisation problems, which are successfully applied in various fields of science and practice. The essence of multi-criteria optimisation problems and their practical implementation in the MatLab environment are detailed in the work of L.M. Malyarets *et al.* (2013). This paper not only describes well the capabilities of the Matlab environment for solving optimisation problems, but also demonstrates examples of solving different types of optimisation problems, especially multi-criteria ones.

Therefore, solving the multi-criteria optimisation problem of determining the optimal values of indicators of economic entities' sustainability of the state sector of the economy across the regions for 2021, based on the genetic algorithm, is recommended to be carried out in the following logic of its stages (Malyarets & Minenkova, 2017): 1) form non-dominant vectors X_j $j \in [1:s]$ on the set D_X of admissible values; 2) make an initial population; 3) find the fitness function for the individuals of the population (estimates); 4) calculate the fitness of each individual in the population, and then the average fitness of the entire population; 5) make a choice of individuals from the current population as two parents for the implementation of the crossing over operator; 6) form the genotype of offspring; 7) implement a mutation operator with given probabilities and obtain the offspring genotype; 8) determine the number of individuals to exclude them from the population so that its size remains constant; 9) determine fitness (estimate the value of the objective function) and list the average fitness (calculate the value of the corresponding vector optimality criterion $f_j=f(X_j)$, $j \in [1:s]$; 10) to analyse the obtained solutions. If they satisfy the decision maker, then the process should be stopped and thus the optimal solution of the problem should be obtained. If it does not satisfy, then you should continue the computational algorithm and return to stage 3 (if the stopping conditions are met, the loop ends, otherwise you should go to the beginning of the loop, that is, to stage 3).

So, in order to find a set of Pareto solutions, it is necessary to use the MatLab software environment, namely, to implement the procedure Multiobjective optimisation using Genetic Algorithm. The genetic algorithm does not put forward any requirements for the form of the objective function and restrictions.

The calculation procedure takes into account the population type as a double vector with a population size of 120, and the selection function is implemented as a random selection of two people with reproduction parameters of 0.3 and 0.5. The mutation function depends on the

restrictions, and the crossing is average, the direction of migration is forward, that is, along the last subpopulation and every 20 generations. Figure 3 shows the results of the calculations described above.

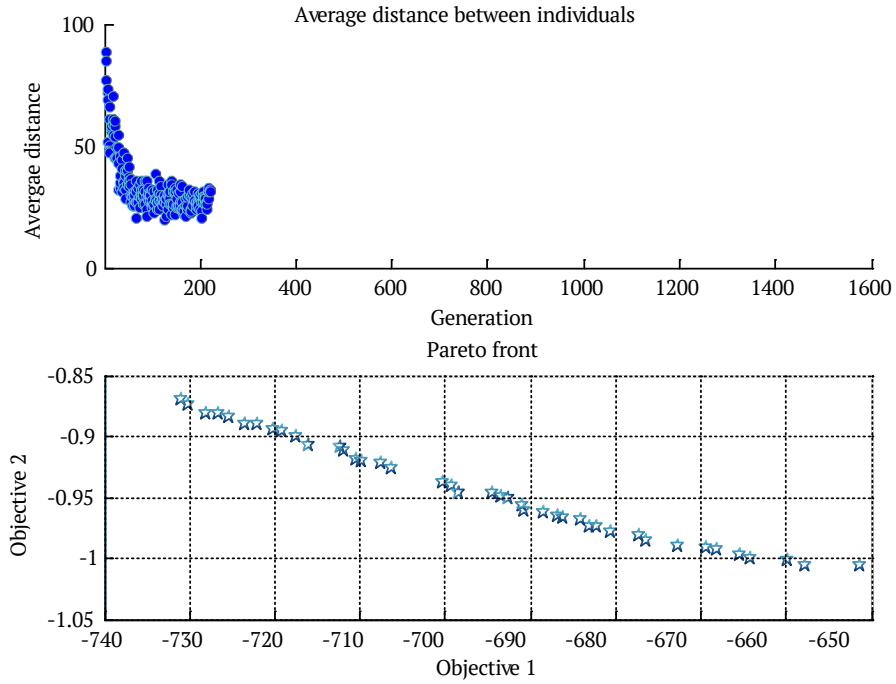

Figure 3. Results of calculations of Pareto-optimal solutions using genetic algorithm
Source: developed by the authors

The idea of the method of analysis of all vectors regarding their relationship with the two nearest neighboring solution vectors in the marginal utility method (Butko *et al.*, 2018) is as follows: consider an arbitrary vector V^0 belonging to the set of Pareto-optimal non-dominated solution vectors and whose coordinates are the values of the target functions $(\overline{f_1^0}, \overline{f_2^0})$. First, it is necessary to determine two nearest neighboring vectors V^1 and V^2, and with coordinates $(\overline{f_1^2}, \overline{f_2^2})$ and $(\overline{f_1^2}, \overline{f_2^2})$ such that $f_1^1 \leqslant f_1^0 \leqslant f_1^2$ and $f_2^1 \geqslant f_2^0 \geqslant f_2^2$. These vectors are defined as those that are the least distant from the centroids of the k nearest vectors, the first coordinate of which is first less than and then greater than f_1^0. After defining these vectors for each V^0 vector, the affinity function is determined:

$$A_{V^0} = max\left(\frac{f_1^0 - f_1^1}{f_2^1 - f_2^0}, \frac{f_1^2 - f_1^0}{f_2^0 - f_2^2}\right). \quad (2)$$

The value of the affinity function is determined for all vectors, but for k extreme vectors at both ends of the Pareto front, it may not be determined because it is considered that for these vectors it is a priori the smallest. The value k represents the resolution at which the affinity function is calculated and the compromise solution is determined. It can be taken depending on the power of the Pareto set or based on other considerations. In this study, the value k=2. The optimal compromise solution according to the marginal utility method is the solution corresponding to the target vector with the minimum value of the affinity function. Calculation data are summarised in Table 1.

Table 1. Calculations in the selection of a compromise solution from a set of Pareto-optimal solutions of a two-criteria optimisation problem using the marginal utility method

№	f_1^0	f_2^0	f_1^1	f_2^1	f_1^2	f_2^2	$\frac{f_1^0 - f_1^1}{f_2^1 - f_2^0}$	$\frac{f_1^2 - f_1^0}{f_2^0 - f_2^2}$	A_{V0}
1	651.4317	1.0056							
2	657.7353	1.0054							
3	659.8921	1.0015							
4	664.2009	1.0005	651.4317	1.0056	669.3590	0.9913	2530.0879	558.6891	2530.0879
5	665.4446	0.9971	657.7353	1.0054	672.6504	0.9902	936.0701	1044.6900	1044.6900
6	668.1918	0.9934	659.8921	1.0015	676.3993	0.9860	1024.6586	1117.5453	1117.5453
7	669.3590	0.9913	664.2009	1.0005	677.2780	0.9814	558.6891	799.0367	799.0367
8	672.6504	0.9902	665.4446	0.9971	680.5138	0.9781	1044.6900	649.0885	1044.6900

Table 1. Continued

9	676.3993	0.9860	668.1918	0.9934	682.3406	0.9739	1117.5453	488.3715	1117.5453
10	677.2780	0.9814	669.3590	0.9913	683.0007	0.9733	799.0367	705.0897	799.0367
11	680.5138	0.9781	672.6504	0.9902	684.1725	0.9677	649.0885	350.5624	649.0885
12	682.3406	0.9739	676.3993	0.9860	686.1608	0.9667	488.3715	533.7049	533.7049
13	683.0007	0.9733	677.2780	0.9814	686.8695	0.9645	705.0897	443.6640	705.0897
14	684.1725	0.9677	680.5138	0.9781	688.4105	0.9617	350.5624	705.5195	705.5195
15	686.1608	0.9667	682.3406	0.9739	690.8516	0.9610	533.7049	816.4393	816.4393
16	686.8695	0.9645	683.0007	0.9733	691.0280	0.9562	443.6640	496.7672	496.7672
17	688.4105	0.9617	684.1725	0.9677	692.5800	0.9514	705.5195	407.6462	705.5195
18	690.8516	0.9610	686.1608	0.9667	693.4751	0.9486	816.4393	212.7469	816.4393
19	691.0280	0.9562	686.8695	0.9645	694.4002	0.9465	496.7672	350.2855	496.7672
20	692.5800	0.9514	688.4105	0.9617	698.3822	0.9457	407.6462	1013.2754	1013.2754
21	693.4751	0.9486	690.8516	0.9610	699.3173	0.9403	212.7469	704.2144	704.2144
22	694.4002	0.9465	691.0280	0.9562	700.2764	0.9375	350.2855	650.9500	650.9500
23	698.3822	0.9457	692.5800	0.9514	706.2697	0.9266	1013.2754	413.8178	1013.2754
24	699.3173	0.9403	693.4751	0.9486	707.5909	0.9216	704.2144	442.5537	704.2144
25	700.2764	0.9375	694.4002	0.9465	709.8845	0.9202	650.9500	554.5301	650.9500
26	706.2697	0.9266	698.3822	0.9457	710.4499	0.9184	413.8178	505.3807	505.3807
27	**707.590**9	**0.9216**	**699.3173**	**0.9403**	**711.9941**	**0.9119**	**442.5537**	**451.4612**	**451.4612**
28	709.8845	0.9202	700.2764	0.9375	712.2732	0.9093	554.5301	220.1037	554.5301
29	710.4499	0.9184	706.2697	0.9266	715.9753	0.9078	505.3807	520.7159	520.7159
30	711.9941	0.9119	707.5909	0.9216	717.5621	0.9007	451.4612	496.0977	496.0977
31	712.2732	0.9093	709.8845	0.9202	719.2526	0.8961	220.1037	525.9404	525.9404
32	715.9753	0.9078	710.4499	0.9184	720.2399	0.8941	520.7159	311.6084	520.7159
33	717.5621	0.9007	711.9941	0.9119	722.0964	0.8902	496.0977	435.2888	496.0977
34	719.2526	0.8961	712.2732	0.9093	723.5078	0.8892	525.9404	617.3222	617.3222
35	720.2399	0.8941	715.9753	0.9078	725.3999	0.8843	311.6084	529.3199	529.3199
36	722.0964	0.8902	717.5621	0.9007	726.6732	0.8816	435.2888	526.1333	526.1333
37	723.5078	0.8892	719.2526	0.8961	728.0760	0.8806	617.3222	530.6680	617.3222
38	725.3999	0.8843	720.2399	0.8941	730.0688	0.8736	529.3199	434.3125	529.3199
39	726.6732	0.8816	722.0964	0.8902	730.9788	0.8689	526.1333	340.3245	526.1333
40	728.0760	0.8806							
41	730.0688	0.8736							
42	730.9788	0.8689							

Source: developed by the authors

Thus, the minimum value of the affinity function is equal to 451.4612 for point number 27, which corresponds to the value of the first criterion – the gross regional product per capita – 707.5909 UAH/person, and the second criterion – the level of economic entities' sustainability of public sector economy -0.921643, which is taken as the final compromise solution. At the same time, the optimal values of the indicators: net income 611.25 million UAH, net financial result 10834.34 million UAH, receivables 8713.881 million UAH, payables 4825.442 million UAH, total value of assets UAH 92,527.6 million, equity capital UAH 56,546.94 million, average number of employees 29,576 thousand, salary arrears UAH 158.4911 million. To determine the reserve of economic sustainability of economic entities of the regions, it is necessary to distinguish clusters according to its system of indicators and gross regional product per person (Fig. 4).

It is appropriate to distinguish 7 clusters of economic entities of the regions of Ukraine according to the system of indicators of economic sustainability and gross regional product per person and then calculate the average values of all these indicators in each cluster (Table 2).

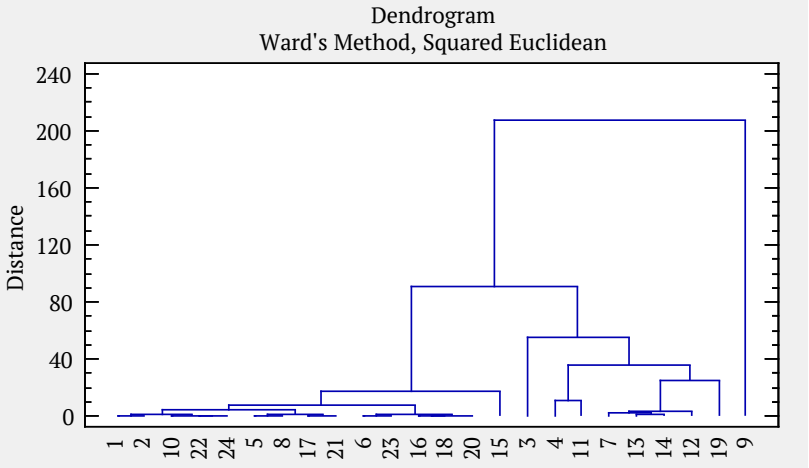

Figure 4. Dendrogram of clustering of economic entities of the regions of Ukraine in 2021 according to the system of indicators of economic sustainability and gross regional product per capita

Source: developed by the authors

Table 2. Average values of indicators of economic sustainability and gross regional product per capita in each cluster of economic entities of the regions

Cluster	*x1*	*x2*	*x3*	*x4*	*x5*	*x6*	*x7*	*x8*	*Y1*
1	2615.94	41.06	267.96	960.55	2647.72	1040.44	4.66	3.66	66.89
2	7233.70	-3358.00	3041.10	19976.90	34831.20	10823.80	20.30	248.00	122.30
3	3896.15	-1776.25	1476.75	17516.20	9420.50	-10688.30	14.35	63.35	34.09
4	7251.62	-27.83	2078.57	12108.60	13703.50	142.68	15.25	20.93	85.41
5	47270.70	10940.40	8724.20	59030.90	126839.00	61150.30	29.60	14.30	123.22
6	1023.40	19.20	32.80	1914.40	2621.80	666.20	2.60	1.40	134.38
7	19504.40	-126.70	7887.10	11230.90	27398.30	13778.70	17.60	66.00	92.84

Source: developed by the authors

The final determination of the reserve of economic sustainability of economic entities of the regions in each cluster is determined by the deviation of each achieved average value of the indicator (x_i) from the optimal value (x_o), i.e; $\Delta_i=x_i-x_o$. If $\Delta_i \geqslant 0$, there is a reserve of economic sustainability according to this indicator; if $\Delta_i<0$, there is no reserve of sustainability and urgent measures should be taken to increase it. Table 3 shows the calculated values of the reserve of economic sustainability of economic entities across the regions in each cluster.

Table 3. Values of the reserve of economic sustainability of business entities across the regions in each cluster

Cluster	*x1*	*x2*	*x3*	*x4*	*x5*	*x6*	*x7*	*x8*	*Y1*
1	2004.6900	-10793.28	-8445.92	-3864.89	-95175.32	-55506.50	-24.91	-154.83	-640.70
2	6622.4500	-14192.34	-5672.78	15151.46	-127358.80	-45723.14	-9.28	89.51	-585.29
3	3284.9000	-12610.59	-7237.13	12690.76	-101948.10	-67235.24	-15.23	-95.14	-673.50
4	6640.3700	-10862.17	-6635.31	7283.16	-106231.10	-56404.27	-14.33	-137.57	-622.18
5	46659.4500	106.06	10.32	54205.46	-219366.60	4603.36	0.02	-144.19	-584.37
6	412.1500	-10815.14	-8681.08	-2911.04	-95149.40	-55880.74	-26.98	-157.09	-573.21
7	18893.1500	-10961.04	-826.78	6405.46	-119925.90	-42768.24	-11.98	-92.49	-614.75

Source: developed by the authors

The analysis of Table 3 shows that only economic entities of region 5 of the cluster, which is the Kyiv region, have positive deviations on 6 indicators of economic sustainability, for economic entities of the rest of the regions, programs of urgent management measures to strengthen their sustainability should be developed.

As it was already mentioned above, in order to determine the real parameters of the reserve of economic

sustainability of economic entities in the regions, it is necessary to find the optimal values of the indicators that characterise it by solving a multi-criteria optimisation problem. L. Hassani *et al*. (2019), A. Trianni *et al*. (2019), J. Wang (2022) talked about this in their works, but they did not state the problem itself, and even more so did not say how to solve it.

N.E. Kondruk & M.M. Malyar (2019) in their work discuss in sufficient detail the problem of methods of constructing and solving multi-criteria optimisation problems, but they do not indicate the disadvantages and advantages of each of the methods, and consider the implementation of these methods on simplified problems, not on real data.

Authors fully agree with J. Branke *et al*. (2008) that research and application of multi-objective optimisation require optimisation experience, as well as decision support, and it can also be added that knowledge of the research object, laws and regularities of its functioning and development is needed as well.

The well-known scientist M. Ehrgott (2005) speaking on the problems of multi-criteria optimisation admits that there is a lot of heuristics in the formulation of the most multi-criteria problems and methods of solving them, and this, in our opinion, does not reduce their value, but increases the effectiveness of both the methods themselves and their usefulness tasks in practical activity.

Modern multi-criteria optimisation methods in various spheres of human activity are interactive methods, in particular genetic algorithms; this is described in detail in the work of L.M. Malyarets *et al*. (2013). But the listed methods of multi-criteria optimisation were not used in determining the economic sustainability reserve of business entities; these methods were used to solve other problems in the economics.

Many scientists, including S.C. Chiam *et al*. (2008), talk about the unconditional advantage of such iterative methods for solving multi-criteria optimisation problems due to their computational algorithm in dialog mode and constant control of the calculation parameters by the person who makes the decision.

As for the logic of the stages of the genetic algorithm, it is described in the works of many scientists, in particular K.V. Kolesnikov *et al*. (2013), which not only provides the content of these stages, but also establishes that the convergence time of these algorithms depends on the accuracy and dynamics of the network change.

So, from the analysis of the works, it can be concluded that the topic of estimating the reserve of economic sustainability has been studied by many scientists. However, certain aspects, such as the application of certain methods to determine the reserve of economic sustainability in practice, the advantages and disadvantages of problem-solving methods, and specific ways of solving problems, have not been sufficiently considered.

CONCLUSIONS

Summarising the presented results of the study, it is necessary to emphasise once again on the specified new approach in the study of economic sustainability of economic entities, which involves not only determining its level according to the appropriate system of partial indicators, but also its reserve. The study recommends an improved logic of the analysis stages of the economic entities' sustainability across the regions. The novelty of the research results is the formalisation of the economic-mathematical model of multi-criteria optimisation of indicators of economic entities' sustainability, which involves the formation of partial criteria in multi-criteria optimisation based on regression dependencies. To solve the multi-criteria optimisation problem of determining the reserve of economic sustainability of economic entities, the feasibility of using the genetic algorithm and the marginal utility method, which increases the efficiency and objectivity of the obtained optimal solution, is substantiated.

Further research of the authors will be the formulation and solution of the problem of the sensitivity of the reserve of economic sustainability of economic entities, which allows to determine the intervals of permissible change of economic sustainability and its reserve.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Ahi, P., Searcy, C., & Jaber, M.Y. (2018). A quantitative approach for assessing sustainability performance of corporations. *Ecological Economics*, 152, 336-346. doi: 10.1016/j.ecolecon.2018.06.012.

[2] Branke, J., Deb, K., Miettinen, K., & Slowinski, R. (2008). *Multiobjective optimization, interactive and evolutionary approaches*. Heidelberg: Springer Berlin. doi: 10.1007/978-3-540-88908-3.

[3] Budarin, O.S. (2022). The features of assessment of the efficiency of industrial enterprises in the current conditions. *Business-Inform*, 10, 126-131. doi: 10.32983/2222-4459-2022-10-126-131.

[4] Butko, T.V., Prokhorov, V.M., & Chekhunov, D.M. (2018). The technology of intelligent control of the switchyard station on the basis of multi-objective optimization using genetic algorithms. *Information and Control Systems at Railway Transport*, 4, 45-55. doi: 10.18664/ikszt.v0i4.142016.

[5] Chiam, S.C., Tan, K.C., & Mamum, A.A. (2008). Evolutionary multi-objective portfolio optimization in practical context. *International Journal of Automation and Computing*, 5(1), 67-80. doi: 10.1007/s11633-008-0067-2.

[6] Dombrovska, S., & Horbachenko, M. (2021). Financial stability of the enterprise: Evaluation and ways of improvement. *Collection of scientific works of Odessa National University of Economics*, 3-4, 28-34.

[7] Draskovic, M., Streimikiene, D., Baldesku, E., Baležentis, T., Bauk, S., Bilan, Y., Delibašić, M., Delijić, K., Drašković, D., Drašković, V., Ilysheva, N., Jasinskas, E., Jereb, B., Jovović, R., Lakić, S., Lojpur, A., Osipov, Y., Popov, E., Pupavac, D., & Erznkyan, B. (2017). Sustainable development: Crisis or regulation? Podgorica: Scientific Publishing Hub.

[8] Ehrgott, M. (2005). *Multicriteria optimization*. Heidelberg: Springer Berlin. doi: 10.1007/3-540-27659-9.

[9] Hassani, L., Daneshvar kakhki, M., Sabouhi sabouni, M., & Ghanbari, R. (2019). The optimization of resilience and sustainability using mathematical programming models and metaheuristic algorithms. *Journal of Cleaner Production*, 228, 1062-1072. doi: 10.1016/j.jclepro.2019.04.324.
[10] Howarth, R.B. (2012). Sustainability, well-being, and economic growth. *Minding Nature*, 5(2), 32-39.
[11] Kasych, A., Vochozka, M., & Yakovenko, Y. (2019). Diagnostic of the stability states of enterprises and the limits of their tolerance. *Quality Access to Success*, 20(172), 3-12.
[12] Kolesnikov, K.V., Karapetyan, A.R., & Tsarenko, T.A. (2013). Genetic algorithms for multiobjective optimization problems in networks adaptive routing data. *Bulletin of the National Technical University "KhPI". Series: New solutions in modern technologies*, 56, 44-50.
[13] Kondruk, N.E., & Malyar, M.M. (2019). Multi-criteria optimisation of linear systems. Uzhhorod: Outdoor Shark.
[14] Kozlovskyi, S., & Mazur, G. (2017). Ensuring the sustainability of modern economic system – The basis economic development. *Investytsiyi: Praktyka ta Dosvid*, 1, 5-12.
[15] Malyarets, L.M., & Minenkova, O.V. (2017). Solving problems multicriteria optimization efficiency of enterprises based on genetic algorithm. *Business Inform*, 4, 119-125.
[16] Malyarets, L.M., Barannik, I.O., Sabadash, L.O., & Grynko, P.O. (2019). Modeling the economic sustainability of the macro system (for example Ukraine). *Montenegrin Journal of Economics*, 15(3), 23-35. doi: 10.14254/1800-5845/2019.15-3.2.
[17] Malyarets, L.M., Reznik, E.V., & Sinkevuch, B.V. (2013). Modern optimization methods in the MatLab environment. Kharkiv: KhNEU.
[18] Mishuk, E.V. (2018). Research of economic stability and economic security of the enterprise in the conditions of the variety of external and internal environment. *Scientific notes of Taurida National V.I. Vernadsky University. Series: Economy and Management*, 29(68), 67-71.
[19] Order of the Ministry of Economic Development and Trade of Ukraine No. 253 "On the Approval of Methodological Recommendations for the Application of Criteria for Determining the Efficiency of Management of State-Owned Objects". (2013, March). Retrieved from https://ips.ligazakon.net/document/view/ME130426?an=1.
[20] Ponomarenko, T.V. (2016). Evaluation of economic stability of the enterprise on the basis of value approach. *Ekonomichnyy analiz*, 24(2), 106-113.
[21] Regional Statistics. (2022). Retrieved from https://ukrstat.gov.ua/druk/publicat/kat_u/publ2_u.htm.
[22] Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, 53, 49-57. doi: 10.1016/j.omega.2014.11.009.
[23] Saaty, T. (2008). Relative measurement and its generalization in decision making: Why pairwise comparisons are central in mathematics for the measurement of intangible factors. *Physical and Natural Sciences, Series A: Mathematics*, 102(2), 251-318.
[24] Stockhammer, E., Hochreiter, H., Obermayr, B., & Steiner, K. (1997). The index of sustainable economic welfare (ISEW) as an alternative to GDP in measuring economic welfare. *Ecological Economics*, 21(1), 19-34. doi: 10.1016/S0921-8009(96)00088-2.
[25] Trianni, A., Cagno, E., Neri, A., & Howard, M. (2019). Measuring industrial sustainability performance: Empirical evidence from Italian and German manufacturing small and medium enterprises. *Journal of Cleaner Production*, 229, 1355-1376. doi: 10.1016/j.jclepro.2019.05.076.
[26] Triantaphyllou, E. (1989). An examination of the effectiveness of multi-dimensional decision-making methods: A decision-making paradox. *International Journal of Decision Support Systems*, 5, 303-312. doi: 10.1016/0167-9236(89)90037-7.
[27] Voronin, A.M., Ziatdinov, Y., & Varlamov, I. (2018). A multi-criteria approach to the resource distribution. *International Journal Information Theories and Applications*, 25(2), 103-116.
[28] Wang, J. (2022). Did China's "national sustainable development plan of resource-based cities" promote economic growth? *Sustainability*, 14, article number 8222. doi: 10.3390/su14138222.
[29] Zakorko, P.P., & Breus, V.E. (2017). Estimation of economic sustainability of the enterprise. *Economy and Society*, 13, 464-467.
[30] Zapata-Cantu, L., & González, F. (2021). Challenges for innovation and sustainable development in Latin America: The significance of institutions and human capital. *Sustainability*, 13(7), article number 4077. doi: 10.3390/su13074077.
[31] Zhao, J., He, L., Liu, W., & Bian, H. (2006). Optimization of part-building orientation for rapid prototyping manufacturing. *Journal of Computer-Aided Design and Computer Graphics*, 18(3), 456-463.

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Визначення запасу економічної стійкості суб'єктів господарювання в сучасних умовах діяльності

Анотація. В складних соціально-економічних, політичних умовах для нормальної життєдіяльності суб'єкти господарювання повинні мати достатній рівень економічної стійкості та її запасу. Тому проблеми оцінки та аналізу економічної стійкості, її запасу є актуальними й потребують свого негайного вирішення. Метою статті було дослідження визначення економічної стійкості суб'єктів господарювання, її запасу, обґрунтування логіки етапів цього визначення, формування відповідного аналітичного інструменту. В процесі дослідження були використані загальнонаукові та спеціальні методи дослідження: абстрактно-логічний метод, системний підхід, методи аналізу і синтезу, графічний метод, метод побудови інтегрального таксономічного показника розвитку, багатокритеріальна оптимізація, багатофакторний регресійний аналіз, генетичний алгоритм, метод граничної корисності, кластерний аналіз. В статті наводиться вибір системи показників економічної стійкості суб'єктів господарювання державного сектору України в регіональному розрізі з огляду їх законодавчої основи. Для визначення запасу економічної стійкості суб'єктів господарювання державного сектору в регіональному розрізі була розроблена та вирішена економіко-математична модель багатокритеріальної оптимізації показників економічної стійкості з використанням генетичного алгоритму, що є новим аналітичним забезпеченням в економіці у вирішенні цієї проблеми. Новим результатом в економіко-математичному моделюванні є метод формування частинних критеріїв в багатокритеріальній оптимізації на основі регресійних залежностей. В статті наводиться процедура реалізації методу граничної корисності для обґрунтування кінцевого єдиного оптимального розв'язку багатокритеріальної оптимальної задачі визначення оптимальних значень показників економічної стійкості. Доведено, що визначення абсолютної величини запасу економічної стійкості суб'єктів господарювання в регіонах доцільно зробити за їх кластерами, які були отримані на основі системи показників економічної стійкості та валового регіонального продукту розрахунку на одну особу. Практичне значення полягає в тому, що такий науково-методичний підхід визначення економічної стійкості та її запасу дозволяє об'єктивно розробляти управлінські рішення на промислових підприємствах щодо забезпечення нормальної їх життєдіяльності в складних воєнних та повоєнних умовах

Ключові слова: система показників; запас економічної стійкості; багатокритеріальна оптимізація; генетичний алгоритм; кластери регіонів; відхилення показників