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A METHODOLOGICAL APPROACH TO ASSESSING THE PARAMETERS OF TECHNOLOGICAL CHANGE IMPACT ON THE ECONOMIC SUSTAINABILITY OF ENTERPRISES

Purpose. Creating a methodological basis for measuring the interrelation between the introduction of resource-saving technologies and the economic sustainability of enterprises.

Methodology. In the course of the study, the following methods were used: grouping and generalisation (in the classification of types of economic sustainability of companies), economic and mathematical modelling (in the development of indicators for assessing the economic sustainability of enterprises), system analysis (in the creation of methodological techniques for assessing the impact of resource-saving technologies on the economic sustainability of enterprises), methods of economic analysis and technical and economic calculations (in testing the methodological approach on a sample of industrial enterprises), a questionnaire method (in surveying business owners and managers about their implementation of energy-saving technologies), and methods of mathematical statistics (in processing the survey results).

Findings. Based on the allocation of types of economic sustainability of enterprises, the characteristics of high, moderate, low and unsatisfactory economic sustainability of enterprises are substantiated. The indicators for its assessment are proposed, their ability to serve as indicators of the ability of enterprises to ensure their sustainable functioning is demonstrated. A methodological approach has been developed to assess the impact of resource-saving technologies on the economic sustainability of enterprises. The analytical capabilities of this approach have been tested on a sample of 60 Ukrainian enterprises that have implemented resource-saving technologies in terms of replacing natural gas. The results showed that energy-saving technologies have a significant positive impact on the economic sustainability of companies.

Originality. An improved classification of the types of economic sustainability of enterprises is proposed based on the following features: method of calculation, realisation of reserves for increase, degree of generalisation and indicators whose values may deteriorate. Indicators for assessing the local sustainability of enterprises by product prices, variable costs, fixed costs, natural sales volumes, and costs of a certain type of production resources are formed. A methodological basis for assessing the impact of resource-saving technologies on the economic sustainability of enterprises has been created, which provides for obtaining information on the actual or expected improvement of various indicators of economic sustainability of companies as a result of increasing the level of resource-saving technologies. The article establishes the existence of a positive impact of energy-saving technologies on the economic sustainability of enterprises regarding technological modernisation, based on the use of natural gas.

Practical value. The obtained results can be used by enterprises in developing measures to improve economic sustainability, as well as in assessing the expected economic consequences of the introduction of resource-saving technologies by companies.

Keywords: *enterprise, economic sustainability, resource saving, innovations, technological change, production resource*

Introduction. The current stage of socio-economic development of society is characterised by fundamental shifts that radically change the environment of human activity. The existing technical and technological paradigm is being replaced by a new one, the main feature of which is the combination of real and virtual worlds, the massive introduction of cyber-physical systems into production processes. A powerful wave of discoveries is disrupting the usual ways of production, requiring the restructuring of technological and economic systems, and changing of the configuration of the institutional and geopolitical landscape. The main feature of these processes is the unprecedented speed of change, which does not allow the economy to fully exhaust the potential of its previous development. Therefore, it is in a state of constant turbulence. This requires rapid adaptation of all its components to changes and creation of conditions for a new technological "breakthrough" [1].

Against the backdrop of such revolutionary transformations, the ability of economic entities to sense such changes in advance and implement business models that will not only withstand the pressure of external factors, but also adapt to changes and remain successful is of great importance. Thus, in today's environment, the problem of increasing the level of economic sustainability of enterprises, i.e. their ability to conduct effective business activities even when the conditions for its im-

plementation become more complex and uncertain, is becoming more relevant.

The complexity of solving the problem of ensuring the economic sustainability of enterprises is due to the need to take into account a significant number of economic, social, political, legal and other factors that affect the conditions of business operation. These factors are characterised by interdependence and interrelationship, and multi-vector influence, which complicates the choice of indicators for diagnosing the current state of an enterprise in terms of its economic sustainability. Moreover, any enterprise is an open system – it operates in an environment that is subject to change under the influence of external factors (market prices for goods and resources, technological changes, government economic policy, global market conditions, and the activities of international supranational regulatory institutions). That is why the existing tools for managing economic sustainability should be constantly improved in the internal environment of companies. Feeling the pressure of external factors, the modern nature of which is associated with a change in the technical and technological paradigm, more and more companies are switching to resource-saving methods for manufacturing products. The latter significantly reduce both production and transaction costs, and thus can be seen as an important way to improve the economic sustainability of companies. This approach necessitates an assessment of the effect of resource-saving technologies on the economic sustainability of enterprises, which will increase the validity of measures aimed at improving its level.

Literature review. A significant number of scientific papers have been devoted to the study of the impact of resource-saving technologies on the functioning of enterprises. At the same time, scholars have considered various aspects of the process of implementing these changes. In particular, Chowdhury, J. I., at al. conducted a detailed review of the processes of introducing energy efficient technologies in the metallurgical and food industries in the UK and found that there is a significant potential for such implementation [2]. Bhandari, D., Singh, R. K. & Garg, S. K. examined the patterns of transition to clean technologies and developed methodological principles for assessing the obstacles faced by enterprises [3]. Scholars also point to the insufficient level of economic efficiency of investments [4], the lack of financial incentives for their investment [5], the insufficient level of rationality of the investment decision-making process [6], the lack of input information necessary for making decisions on technological modernisation [7], the low competence of company managers in processing it [8], institutional restrictions on the realisation of economic interests of business entities [9], etc.

At present, there is also a significant number of scientific works on the impact of technological innovations, including resource-saving technologies, on the final indicators of economic activity. For example, in [10], the author investigates the links between technological innovation, financial efficiency and environmental quality. At the same time, [11] considers technological innovations as an intermediate link that ensures the impact of the digital economy on the value of firms. Various researchers have also identified the multifaceted effects of technological upgrading, which is reflected in its impact on environmental efficiency [12], competitiveness of enterprises [13], financial development [14], corporate investment and labour force engagement [15].

Despite the significant progress in studying the impact of resource-saving technologies, the vast majority of scientific works focus on the impact of the latter on various aspects of economic entities. However, the relationship between the introduction of resource-saving technologies and the economic sustainability of enterprises is still an under-researched area of economic science. Moreover, there is no consensus among scholars on methodological approaches to assessing the impact of new technologies on economic sustainability. For example, Stanitsas M., Kirytopoulos K. and Leopoulos V. propose to evaluate the economic sustainability of enterprises using three groups of indicators, namely: indicators of economic, social and environmental sustainability [16]. At the same time, Maynard D., at al. also distinguish a fourth group of indicators, which includes indicators of the level of institutional sustainability [17]. There are also scientific publications that propose different approaches to calculating generalised sustainability assessment indicators by a certain combination of partial indicators. At the same time, different researchers have proposed different methods for such a combination, in particular, the use of the weighting method, multi-criteria decision-making models, fuzzy logic models, the Saaty hierarchy method, the Mamdani algorithm, etc. for this purpose [18, 19].

At the same time, there are works devoted to assessing the impact of certain factors on the economic sustainability of companies. For example, Chowdhury S. at. al. showed that organisational factors, primarily organisational leadership, improvement of competences, in particular on the basis of knowledge sharing, development of information systems, etc. have a significant impact on them [20]. The importance of organisational factors is also noted by the authors of [21, 22]. At the same time, Hernita H., at al. convincingly prove the importance of optimising the use and strengthening the potential of their human resources for ensuring the economic sustainability of enterprises [23]. A similar point of view is held, in particular, by the authors of [24, 25]. At the same time, Lutfi, A., at al. have shown that business sustainability is largely related to the introduction of advanced information systems, and, above all, accounting systems [26]. The same opinion regarding diagnostic systems was expressed, in particular, by the authors of [27]. It is worth noting that there are also studies on the impact of certain types of technological innovations on certain aspects of economic sustainability of companies. In this context, scholars have considered such progressive technological changes as digitalisation [28], introduction of financial technologies [29], transition to a circular economy [30], etc. These technological changes are largely related to resource conservation.

As the analysis of the most well-known publications has shown, the issue of assessing the direct impact of resource-saving technologies on the overall economic sustainability of companies and its individual types still cannot be considered fully resolved. This necessitates further research aimed at creating an effective toolkit for assessing the impact of resource-saving technologies on the economic sustainability of business entities.

The purpose of this article is to develop a methodological approach to assessing the parameters of the impact of technological changes on the economic sustainability of enterprises. Achievement of this goal requires solving a number of tasks, the main of which are: identifying the types of economic sustainability of enterprises; developing indicators for assessing this sustainability; forming a methodological basis for assessing the impact of resource-saving technologies on the economic sustainability of enterprises; testing the proposed methodological approach on a sample of industrial enterprises.

Methods. The creation of a methodological approach to assessing the impact of technological change on the economic sustainability of enterprises was carried out through the gradual application of a clearly defined toolkit of scientific knowledge. In order to obtain indicators for assessing the economic sustainability of enterprises, the classification of its types was initially carried out using the methods of grouping and generalisation. In order to develop an instrumentarium for assessing the impact of resource-saving technological changes on the economic sustainability of companies, the method of system analysis is used. In carrying out empirical research on a sample of industrial enterprises, the methods of economic analysis and technical and economic calculations were applied. The questionnaire survey method was used to conduct a survey of owners and managers of enterprises on the implementation of energy-saving technologies. To process the obtained results, the mathematical statistics apparatus was used.

Results. Assessing the impact of resource-saving technologies on the economic sustainability of enterprises requires a preliminary determination of the level of this sustainability. It is necessary to take into account the presence of different types of economic sustainability of companies, which requires their grouping. This allows distributing sustainability by common features, obtaining homogeneous groups and, on this basis, fixing the natural connections between the elements. As criteria for classifying the economic sustainability of enterprises, we consider it necessary to choose the following features: method of calculation (reporting, forecast); realisation of reserves for increase (current, prospective (strategic)); degree of generalisation (general, local); indicators whose values may deteriorate (by prices for the enterprise's products, by variable costs of production and sales, by fixed costs of production and sales, by natural sales volumes, by other indicators, in particular, by costs. This grouping is presented in Table 1.

As Table 1 shows, there are many types of economic sustainability of enterprises based on the indicators of their performance, the values of which may deteriorate. In fact, each of them characterises a certain local level of economic sustainability of companies. Assessment of each of these levels requires preliminary modelling of the existing relationships between them. In order to implement it, it is advisable to present the amount of profit of an enterprise from its operating activities in the following form

$$P = R - C_1 - C_2 - C_3, \quad (1)$$

where P is the reported or planned (forecast) amount of the company's profit from its operating activities; R is the reported or planned (forecast) amount of the company's net income; $C_{(1)}$ is the reported or planned (forecast) amount of variable costs of production and sales, except for the costs of a certain type of production resources; C_2 is the reported or planned (forecast) amount of variable costs for this type of production resources; C_3 is the reported or planned (forecast) amount of fixed costs for production and sales of products.

It should be noted that the allocation in expression (1) of variable costs for a certain type of production resources is determined by the purpose of this study, i.e. such allocation is necessary to assess the impact of resource-saving technological changes on the economic sustainability of enterprises.

Taking into account equation (1), the condition of economic sustainability of an enterprise can be described by the following inequality

$$R \cdot ((1-a_1) - c_1 \cdot (1+a_2) - c_2 \cdot (1+a_3)) \cdot (1-a_5) - C_3 \cdot (1+a_4) \geq \frac{O \cdot n}{(1-c)}, \quad (2)$$

where a_1, a_2, a_3, a_4, $a_{(5)}$ are the reported or planned (forecast) relative values of the decrease in product prices, increase in variable costs of production and sales, except for the costs of a certain type of production resources, increase in variable costs of this type of production resources, decrease in natural sales volumes and increase in fixed costs of production and sales, unit shares; c_1 is the ratio of variable costs of production and sales, except for the costs of a certain type of production resources, to the net income of the enterprise ($c_1 = C_1/R$); $c_{(2)}$ is the ratio of variable costs of a certain type of production resources to the net income of the enterprise ($c_2 = C_2/R$); O is the reported or planned (forecast) value of the enterprise's equity capital; n is the rate of return on the enterprise's equity capital, fractions of a unit; c is the corporate income tax rate, fractions of a unit.

Using equation (2), it is possible to establish the levels of local types of economic sustainability of a particular enterprise. To this end, in the vector (a_1, a_2, a_3, a_4, a_5), we need to consistently take the values of all its elements, except one, to zero, transform inequality (2) into an equation and express this element from it. Under such conditions, we obtain the following expressions for determining the levels of local types of economic sustainability of a company

$$s_1 = 1 - c_1 - c_2 - \frac{O \cdot n}{R \cdot (1-c)} - \frac{C_3}{R}; \quad (3)$$

$$s_2 = 1 - \frac{1}{c_1} \cdot \left(1 - c_2 - \frac{O \cdot n}{R \cdot (1-c)} - \frac{C_3}{R}\right); \quad (4)$$

$$s_3 = 1 - \frac{1}{c_2} \cdot \left(1 - c_1 - \frac{O \cdot n}{R \cdot (1-c)} - \frac{C_3}{R}\right); \quad (5)$$

$$s_4 = 1 - \frac{R}{C_3} \cdot \left(\frac{O \cdot n}{R \cdot (1-c)} + c_1 + c_2\right); \quad (6)$$

$$s_5 = 1 - \frac{1}{1 - c_1 - c_2} \cdot \left(\frac{O \cdot n}{R \cdot (1-c)} + \frac{C_3}{R}\right), \quad (7)$$

where s_1, s_2, s_3, s_4, $s_{(5)}$ is the reported or planned (forecast) level of economic sustainability of the enterprise in question in accordance with the decrease in product prices, increase in variable costs of production and sales, except

Table 1

Types of economic sustainability of an enterprise

Criterion	Types of economic sustainability	Characteristics of types of economic sustainability
1. By the method of calculation	1.1. Reporting	Calculated based on actual data of the reporting period
	1.2. Forecast	Calculated on the basis of forecast estimates
2. Depending on the implementation of resilience reserves	2.1. Current	Corresponds to the current capabilities of the enterprise to ensure its sustainable operation
	2.2. Prospective (strategic)	Meets the condition of realisation of the enterprise's reserves for improving its current economic sustainability
3. By the degree of generality	3.1. General	Characterises the impact of the entire set of factors
	3.2. Local	Characterises the impact of only certain factors
4. By indicators whose values may deteriorate	4.1 By prices for the enterprise's products	The ability of an enterprise to conduct effective business activities in the face of declining prices for its products
	4.2. By variable costs of production and sales	The ability of the enterprise to conduct effective economic activity in the face of increasing variable costs of production and sales of its products
	4.3. By fixed costs of production and sales of products	The ability of the enterprise to conduct effective economic activity in the face of increasing fixed costs of production and marketing of its products
	4.4. By natural volumes of sales of products	The ability of the enterprise to conduct effective economic activity in the face of a decrease in the natural volume of sales of its products
	4.5. By other indicators, in particular, by the cost of a certain type of resources	The ability of the enterprise to conduct effective economic activity in the face of deterioration of other indicators, in particular, in the face of increased costs for a certain type of resources
5. By the level of sustainability	5.1. High	The ability of the enterprise to ensure return on equity at a level not lower than the average in the economy under certain deterioration of its operating conditions
	5.2. Moderate	The ability of an enterprise to ensure return on equity at a level not lower than the credit interest under certain deterioration of its operating conditions
	5.3. Low	The ability of the enterprise to ensure a positive return on equity under certain deterioration of its operating conditions
	5.4. Unsatisfactory	The inability of the enterprise to ensure positive return on equity under certain deterioration of its operating conditions
6. By type of activity	6.1. Production	The ability of the enterprise to ensure normal operation of its production activities under certain deterioration of its operating conditions
	6.2. Sales	The ability of an enterprise to ensure normal operation of its sales activities under certain deterioration of its operating conditions
	6.3. Investment	The ability of an enterprise to ensure normal operation of its investment activity under certain deterioration of its operating conditions
	6.4. Financial	The ability of an enterprise to ensure normal conduct of its financial activities under certain deterioration of its operating conditions

for the costs of a certain type of production resources, increase in variable costs of this type of production resources, decrease in natural sales volumes and increase in fixed costs of production and sales, unit share.

In order to determine the overall level of economic sustainability of an enterprise, the following sequence of actions should be performed:

1. In the vector $(a_{(1)}, a_2, a_3, a_4, a_5)$, select a certain element as the base element. This choice can be arbitrary. Therefore, in the following, we will consider the first element to be the base.

2. Estimate the possible values of the elements of the vector $(a_1, a_2, a_3, a_4, a_5)$ under moderately unfavourable conditions of the enterprise.

3. Divide each of the values of the elements of the vector $(a_1, a_2, a_3, a_4, a_5)$, established at the previous stage, by the value of the element a_1 determined at the same stage. Then a new vector $(1, b_2, b_3, b_4, b_5)$ is obtained.

4. Convert equation (2) to equality and replace $a_{(i)}$ with $b_{(i)}$ for all $a_{(i)}$ $(2 \le i \le 5)$.

5. Substitute the numerical values of all indicators (except for the desired indicator a_1) into the resulting equation.

6. Solve the resulting quadratic equation with respect to a_1. In this way, the numerical value of the level of overall economic sustainability of the business entity can be obtained.

The above approaches to assessing the local and overall levels of economic sustainability of enterprises can be considered as a basis for determining the extent to which resource-saving technologies influence these levels. In order to make such a determination, it is necessary, first of all, to form a sample of enterprises of a certain industry (type of economic activity) and divide them into classes according to the level of resource-saving technologies. In particular, such a division opens up the possibility of applying the criteria listed in Table 2.

The following main methods for assessing the impact of resource-saving technological changes on the economic sustainability of enterprises can be identified:

1) studying the distribution of enterprises by the level of their local economic sustainability, depending on which of the classes described in Table 2 these enterprises belong to. Then, if the share of economically sustainable enterprises increases with the transition from a class with a lower level of resource-saving technologies to a class of companies with a higher level of resource-saving technologies, this may be an argument in favour of the fact that resource-saving technologies have a positive impact on the local economic sustainability of enterprises;

2) studying the distribution of enterprises by the level of their overall economic sustainability depending on which of the classes described in Table 2 they belong to. Similarly to the previous case, if the overall economic sustainability increases when moving from a class of companies with a lower level of resource-saving technologies to a class of companies with a higher level of resource-saving technologies, this will indicate a positive impact of these changes on the overall economic sustainability of enterprises;

3) assessing the statistical significance of the impact of the level of resource-saving technologies on the economic sustainability of enterprises. The disadvantage of the two previous methods for assessing the impact of resource-saving technologies on the economic sustainability of companies is that these methods do not allow one to establish whether the impact of the level of resource-saving technologies on the economic sustainability of enterprises is statistically significant. To eliminate this drawback, it is necessary to use the method of analysis of variance. It allows us to determine how significant are the differences between the average values of economic sustainability indicators of companies belonging to different classes in terms of the level of influence of resource-saving technologies (Figure);

4) analysis of the relationship between the share of costs for a given type of production resources at the stud-

Table 2

Classification of companies by the level of energy saving technologies use

Names of classes of companies	Signs of companies belonging to the classes
Companies with low level of energy saving technologies use	The share of goods produced using energy-saving technologies in the total volume of output does not exceed 30 %
Companies with an average level of energy saving technologies use	The share of goods produced with the use of energy-saving technologies in the total volume of output ranges from 30 to 70 %
Companies with a high level of energy saving technologies use	The share of production volumes using energy-saving technologies in the total volume of production is more than 70 %

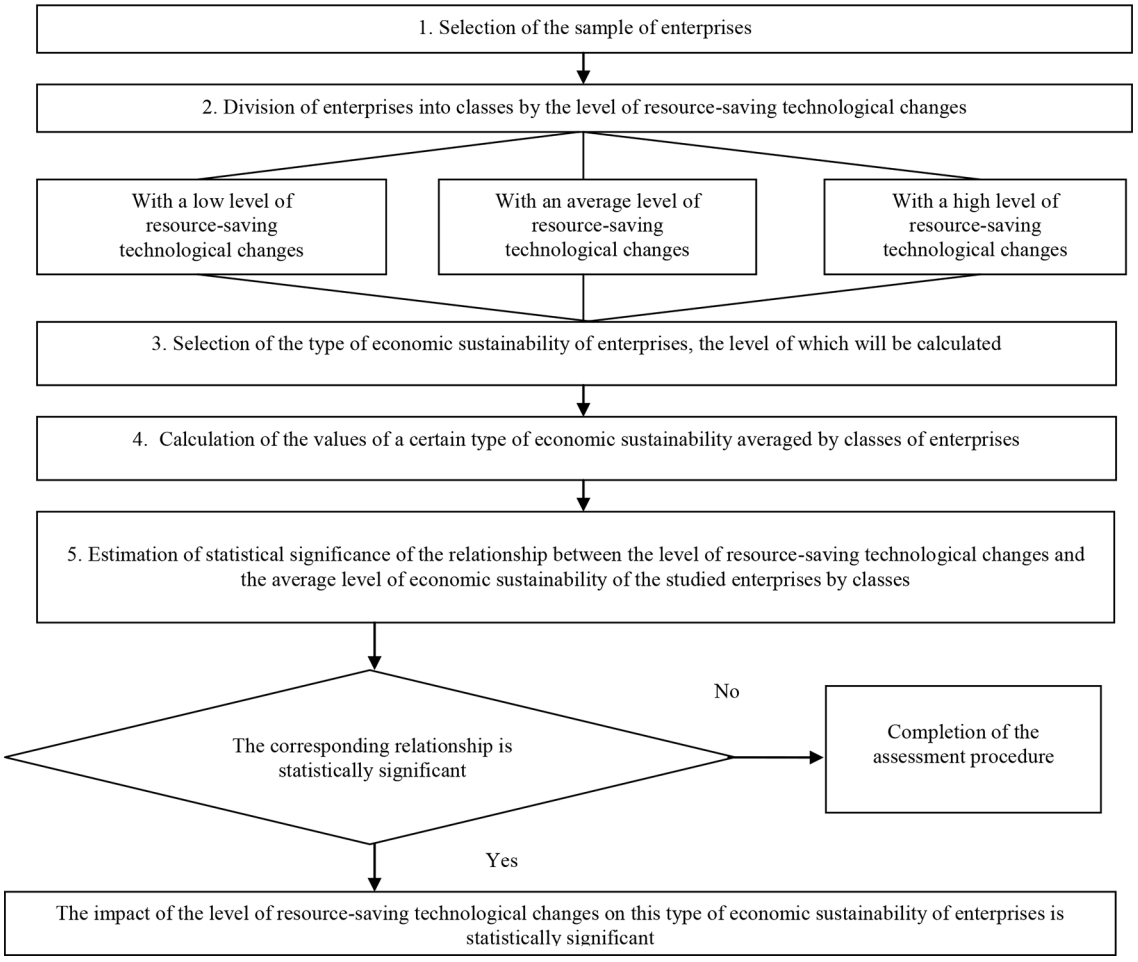

Fig. Sequence of assessing the impact of the level of resource-saving technologies on the economic sustainability of enterprises using the method of analysis of variance

Table 3

Distribution of the studied enterprises by the level of energy-saving (natural gas) technological changes in 2023

Classes of enterprises	Number of nterprises	Share of enterprises in their total number, %
Enterprises with a low level of energy-saving technological changes	32	53.33
Enterprises with an average level of energy-saving technological changes	17	28.33
Enterprises with a high level of energy-saving technological changes	11	18.33
Total	60	100.00

Table 4

Distribution of the surveyed enterprises by the level of their local economic sustainability

Types of local economic sustainability of enterprises	Estimated number of surveyed enterprises that will remain sustainable if the relevant indicator deteriorates by							
	2 %	4 %	6 %	8 %	10 %	12 %	14 %	16 %
Enterprises with a low level of energy-saving (natural gas) technological changes								
1. By prices for enterprise products	17	14	12	11	10	7	6	4
2. By variable production and distribution costs	18	16	15	14	12	10	8	6
3. By fixed costs of production and sales	19	17	16	14	13	11	10	7
4. By volume of sales of products	17	14	11	10	8	6	5	3
5. Expenses for the purchase of natural gas	21	20	20	18	17	15	14	13
Enterprises with an average level of energy-saving (by natural gas) technological changes								
1. By prices for the enterprises' products	11	9	8	7	6	4	4	3
2. By variable production and distribution costs	11	10	9	9	8	7	5	4
3. By fixed costs of production and sales	12	11	10	9	8	7	6	4
4. By volume of sales of products	10	9	7	7	5	4	3	2
5. Expenses for the purchase of natural gas	14	13	12	12	11	10	9	8
Enterprises with a high level of energy-saving (natural gas) technological changes								
1. By prices for the enterprises' products	8	7	6	6	5	3	3	2
2. By variable production and distribution costs	9	8	7	7	6	5	4	3
3. By fixed costs of production and sales	9	9	8	7	6	6	5	3
4. By volume of sales of products	8	7	6	5	4	3	2	1
5. Expenses for the purchase of natural gas	11	10	10	9	8	8	7	6

ied enterprises and the level of their economic sustainability. If the differences between this share in different companies are mainly due to differences in the level of impact of resource-saving technologies, and the dependence is clearly downward, this will serve as another confirmation of the positive impact of resource-saving technologies on the economic sustainability of enterprises.

It should be noted that many countries around the world are currently facing the issue of reducing the consumption of non-renewable energy resources. In particular, this applies to such an energy source as natural gas. The problem of reducing its use is also quite relevant for many Ukrainian companies. Therefore, given the objective of this study, the impact of technologies aimed at saving natural gas on the level of economic sustainability of Ukrainian enterprises consuming this type of energy resources was assessed. To perform the empirical analysis, a sample of 60 enterprises engaged in the production of bricks and other building materials from clay was formed. The sample included only those companies that showed a positive net financial result in the reporting period (2023).

At the first stage of the empirical analysis, the studied enterprises were divided into three classes according to the level of energy-saving (natural gas) technologies, using the distribution criteria listed in Table 2 above. As follows from the results of such a division, shown in Table 3, the majority of the surveyed companies (53.33 % of the total number) belong to enterprises with a low level of energy-saving (natural gas) technologies. At the same time, the share of enterprises with medium and high levels of these changes was 28.33 and 18.33 %, respectively.

Having collected the input data and processed them, the resilience of the studied companies to a possible deterioration of certain indicators characterising the conditions and results of economic activity was assessed using formulas (3–7). This assessment, the results of which are presented in Tables 4 and 5, was carried out separately for the three classes of the studied enterprises by the level of energy-saving (natural gas) technological changes at them. The moderate degree of economic sustainability was assessed, i. e. the ability of firms to ensure

the return on their equity capital at least at a level not lower than the credit interest rate (Table 1). As can be seen from the data in Tables 4 and 5, the number and share of economically sustainable firms increase with the transition from a class with a lower level of energy-saving technological change to a class of firms with a higher level of such change. This may indicate that energy-saving technological changes generally have a positive impact on the local economic sustainability of the enterprises under study.

At the next stage of the empirical analysis, the studied enterprises were divided by the level of their overall economic sustainability. The calculation of this sustainability was performed according to the sequence proposed above, which consists of six steps. As follows from the results of this calculation, shown in Tables 6 and 7, when moving from the class of companies with a lower level of energy-saving technologies to the class of companies with a higher level, their overall economic sustainability increases. This indicates a positive impact of these changes on the overall economic sustainability of the companies under consideration.

Also, using the sequence of assessing the impact of the level of resource-saving technologies on the economic sustainability of enterprises shown in the figure above, the indicators for assessing the impact of the level of energy-saving technologies on the economic sustainability of the studied enterprises were calculated.

Table 5

Indicators of the structure of the studied enterprises by levels of their local economic sustainability

Types of local economic sustainability of enterprises	The estimated percentage of the studied enterprises in the total number of enterprises of a certain class that will remain stable if the respective indicator deteriorates by							
	2 %	4 %	6 %	8 %	10 %	12 %	14 %	16 %
Enterprises with a low level of energy-saving (natural gas) technological changes								
1. By prices for the enterprises' products	53	45	38	35	30	22	18	13
2. By variable production and distribution costs	56	51	46	44	38	32	25	18
3. By fixed costs of production and sales	59	54	49	45	40	36	30	22
4. By volume of sales of products	53	44	36	32	26	20	15	9
5. Expenses for the purchase of natural gas	66	63	61	58	53	47	44	40
Enterprises with an average level of energy-saving (natural gas) technological changes								
1. By prices for enterprise products	65	53	45	41	36	26	22	15
2. By variable production and distribution costs	65	60	55	52	45	38	30	22
3. By fixed costs of production and sales	71	64	59	53	48	42	36	26
4. By volume of sales of products	59	52	42	38	31	23	18	11
5. Expenses for the purchase of natural gas	82	75	72	68	63	56	52	48
Enterprises with a high level of energy-saving (natural gas) technological changes								
1. By prices for the enterprises' products	73	65	55	50	43	32	27	18
2. By variable production and distribution costs	82	73	67	63	55	47	37	27
3. By fixed costs of production and sales	82	78	72	65	58	52	43	32
4. By volume of sales of products	73	63	52	47	38	28	22	13
5. Expenses for the purchase of natural gas	100	92	88	83	77	68	63	58

Table 6

Distribution of the studied companies by the level of their overall economic sustainability

Types of overall economic sustainability	Number of enterprises by the level of energy-saving (natural gas) technological changes		
	With a low level	With an average level	With a high level
1. High	0	3	4
2. Moderate	5	6	4
3. Low	25	7	3
4. Unsatisfactory	2	0	0
Total	32	17	11

Table 7

Indicators of the structure of the studied enterprises by the level of their overall economic sustainability

Types of general economic sustainability	Share of enterprises (in per cent) with the level of energy-saving (by natural gas) technological changes		
	With a low level	With an average level	With a high level
1. High	0.00	17.65	36.36
2. Moderate	15.63	35.29	36.36
3. Low	78.13	41.18	27.27
4. Unsatisfactory	6.25	0.00	0.00
Total	100.00	100.00	100.00

As the results of such calculations show in Table 8, for all types of economic sustainability under consideration, an increase in the level of energy-saving (natural gas) technologies leads to an increase in the degree of each type of sustainability. The analysis of variance showed that all these dependencies are statistically significant, based on the actual values of the F-criterion.

Finally, we analysed the relationship between the share of natural gas costs at the studied enterprises and the level of their economic sustainability. The numerical values of this dependence are presented in Table 9. Additional research has shown that differences between the share of natural gas costs in the companies under study are largely due to differences in the level of energy-saving (natural gas) technologies. At the same time, the dependence described in Table 9 has a clearly expressed downward linear character (the coefficient of determination exceeds 0.8). This circumstance is another strong confirmation of the positive impact that energy-saving (natural gas) technologies will have on the economic sustainability of the studied enterprises.

Conclusions. In the current conditions of changes in technical and technological paradigms, enterprises must maintain their economic sustainability, the types of which can be classified according to such new features as: method of calculation; realisation of reserves for growth; degree of generalisation; indicators whose values may deteriorate, etc. It is advisable to distinguish between the concepts of high, moderate, low and unsatisfactory economic resilience. High sustainability should be understood as the ability of an enterprise to ensure the return on equity at a level not lower than the average in the economy in the face of a certain deterioration in its operating conditions. At the same time, moderate sustainability is the ability of an enterprise to ensure the return on equity at a level not lower than the average in the economy in the face of a certain deterioration in its operating conditions. The application of the proposed group-

Table 8

Indicators for assessing the impact of the level of energy-saving technological changes on the economic sustainability of the studied enterprises

Types of economic sustainability	Levels of energy-saving (natural gas) technological changes	Number of enterprises	Average level of financial sustainability by enterprises	The value of the F-criterion
1. By prices for enterprises' products	1.1. Low	32	0.06	5.76
	1.2. Medium	17	0.11	
	1.3. High	11	0.15	
2. By variable costs of production and sales	2.1. Low	32	0.08	6.12
	2.2. Medium	17	0.13	
	2.3 High	11	0.17	
3. By fixed costs of production and sales	3.1. Low	32	0.09	6.48
	3.2. Medium	17	0.14	
	3.3 High	11	0.19	
4. By volume of sales of products	4.1 Low	32	0.05	5.39
	4.2. Medium	17	0.10	
	4.3. High	11	0.14	
5. By the cost of purchasing natural gas	5.1. Low	32	0.10	7.75
	5.2. Medium	17	0.17	
	5.3. High	11	0.28	
6. Overall economic sustainability	6.1. Low	32	0.08	5.19
	6.2. Medium	17	0.13	
	6.3. High	11	0.17	

Table 9

Indicators of the relationship between the share of costs for the purchase of natural gas at the studied enterprises and the level of their overall economic sustainability

Ranges of the share of natural gas purchase costs in the net income of the researched enterprises, %	<1	1–1.5	1.5–2	2–2.5	2.5–3	3–3.5	3.5–4	>4
Average level of overall economic sustainability of enterprises	0.187	0.171	0.146	0.125	0.110	0.093	0.068	0.051

ing of types of economic sustainability of enterprises allowed forming a system of indicators for assessing the local sustainability of companies by product prices, variable costs, fixed costs, natural sales volumes, and costs of a certain type of production resources.

The study developed a methodological approach to assessing the impact of resource-saving technologies on the economic sustainability of enterprises, which provides for obtaining detailed information on the actual or expected improvement of various indicators of economic sustainability of companies as a result of increasing the level of application of resource-saving technologies. The article allocates the following main methods for assessing the impact of resource-saving technologies on the economic sustainability of enterprises, namely: 1) studying the distribution of enterprises by the level of their local economic sustainability depending on which of the classes by the level of resource-saving technologies these enterprises belong to; 2) studying the distribution of enterprises by the level of their overall economic sustainability depending on which of the classes these enterprises belong to; 3) assessing the statistical significance of the impact of the level of resource-saving technologies on the economic sustainability of enterprises; 4) analysing the relationship between the share of costs for a given type of production resources in the studied enterprises.

Testing of these approaches on a sample of 60 industrial enterprises in Ukraine showed that the number and share of economically sustainable enterprises increase with the transition from a class with a lower level of energy-saving technologies to a class of companies with a higher level of energy-saving technologies. This may indicate that energy-saving technologies generally have a positive impact on the local economic sustainability of the studied enterprises. At the same time, for all types of economic sustainability under consideration, an increase in the level of energy-saving (natural gas) technologies leads to an increase in the degree of each type of sustainability. The application of analysis of variance showed that all these dependencies, based on the actual values of the F-criterion, are statistically significant. It was also found that the relationship between the share of natural gas costs at the studied enterprises and the level of their economic sustainability has a clearly expressed downward linear character (the coefficient of determination exceeds 0.8). This circumstance is another strong confirmation of the positive impact that energy-saving (natural gas) technologies will have on the economic sustainability of the studied enterprises. Further research on the topic of the article should include the development of a mechanism for improving the economic sustainability of enterprises on the basis of their implementation of resource-saving technological processes.

References.

1. Pylypenko, H., Fedorova, N., Lytvynenko, N., & Pylypenko, Yu. (2025). Breakthrough technologies of social transformations: devising an identification methodology. *Eastern-European Journal of Enterprise Technologies*, *2*(13(134)), 15-27. https://doi.org/10.15587/1729-4061.2025.326555

2. Chowdhury, J., Hu, Y., Haltas, I., Balta-Ozkan, N., & Varga, L. (2018). Reducing industrial energy demand in the UK: A review of energy efficiency technologies and energy saving potential in selected sectors. *Renewable and Sustainable Energy Reviews*, *94*, 1153-1178. https://doi.org/10.1016/j.rser.2018.06.040

3. Bhandari, D., Singh, R. K., & Garg, S. K. (2019). Prioritization and evaluation of barriers intensity for implementation of cleaner technologies: A framework for sustainable production. *Resources, Conservation and Recycling, 146*, 156-167. https://doi.org/10.1016/j.resconrec.2019.02.038

4. Trianni, A., Cagno, E., Worrell, E., & Pugliese, G. (2013). An empirical investigation of energy efficiency barriers in Italian manufacturing SMEs. *Energy*, *49*, 444-458. https://doi.org/10.1016/j.energy.2012.10.012

5. Zhang, Z., Jin, X., Yang, Q., & Zhang, Y. (2013). An empirical study on the institutional factors of energy conservation and emissions reduction: Evidence from listed companies in China. *Energy Policy*, *57*, 36-42. https://doi.org/10.1016/j.enpol.2012.07.011

6. Backman, F. (2017). Barriers to Energy Efficiency in Swedish Non-Energy-Intensive Micro- and Small-Sized Enterprises-A Case Study of a Local Energy Programme. *Energies, 10*(1), 1-13. https://doi.org/10.3390/en10010100

7. Giraudet, L. (2020). Energy efficiency as a credence good: A review of informational barriers to energy savings in the building sector. *Energy Economics, 87*, 104698. https://doi.org/10.1016/j.eneco.2020.104698

8. Smiesova, V., Ivanova, M., Faizova, S., Zolotukhina, L., & Karpenko, R. (2020). Strengthening of the Power-property Tendencies and Forecasting their Impact on the Implementation of Interests of Households, Enterprises and the State. *Scientific Papers of the University of Pardubice, Series D: Faculty of Economics and Administration*, *28*(2), 113-125. https://doi.org/10.46585/sp28020113

9. Palm, J., & Backman, F. (2020). Energy efficiency in SMEs: overcoming the communication barrier. *Energy Efficiency*, *13*(5), 809-821. https://doi.org/10.1007/s12053-020-09839-7

10. Alvarado, R., Tillaguango, B., Toledo, E., Murshed, M., & Işık, C. (2024). Links between technological innovation, financial efficiency and environmental quality using quantile regressions: The role of foreign direct investment, institutional quality and natural resources. *Journal of Open Innovation, 10*(3), 1-15. https://doi.org/10.1016/j.joitmc.2024.100360

11. Pan, X., Wang, Y., Zhang, C., Shen, Z., & Song, M. (2023). The impact of platform economy on enterprise value mediated by technological innovation. *Journal of Business Research, 165*, 114051. https://doi.org/10.1016/j.jbusres.2023.114051

12. Chen, Y., & Jiang, Z. (2024). The Impact of Enterprise Technological Innovation on Environmental Performance – An Industry Perspective. *Sustainability, 16*, 6457. https://doi.org/10.3390/su16156457

13. Nagdiev, O. (2023). Evaluation of the innovation-investment factor for augmenting the competitiveness of construction enterprises. *Economics of the transport complex*, *42*, 143-154. Retrieved from https://dspace.khadi.kharkov.ua/handle/123456789/17706

14. Andrew, A., Adebayo, T., Lasisi, T., & Muoneke, O. (2024). Moderating roles of technological innovation and economic complexity in financial development-environmental quality nexus of the BRICS economies. *Technology in Society, 78*, 102581. https://doi.org/10.1016/j.techsoc.2024.102581

15. Liu, Y., Liu, S., Wu, Z., & Xiao, Y. (2022). How do technological innovations affect corporate investment and hiring? *The North American Journal of Economics and Finance, 62*, 101759. https://doi.org/10.1016/j.najef.2022.101759

16. Stanitsas, M., Kirytopoulos, K., & Leopoulos, V. (2020). Integrating sustainability indicators into project management: The case of the construction industry. *Journal of Cleaner Production, 279*, 123774. https://doi.org/10.1016/j.jclepro.2020.123774

17. Maynard, D., Vidigal, M., Farage, P., Zandonadi, R., Nakano, E., & Botelho, R. (2020). Environmental, Social and Economic Sustainability Indicators Applied to Food Services: A Systematic Review. *Sustainability, 12*, 1804.

18. Tian, N., Tang, S., Che, A., & Wu, P. (2020). Measuring regional transport sustainability using super-efficiency SBM-DEA with weighting preference. *Journal of Cleaner Production, 242*, 118474. https://doi.org/10.1016/j.jclepro.2019.118474

19. Ghenai, C., Albawab, M., & Bettayeb, M. (2020). Sustainability indicators for renewable energy systems using multi-criteria decision-making model and extended SWARA/ARAS hybrid method. *Renewable Energy, 146*, 580-597. https://doi.org/10.1016/j.renene.2019.06.157

20. Chowdhury, S., Dey, P., Rodríguez-Espíndola, O., Parkes, G., Tuyet, N., Long, D., & Ha, T. (2022). Impact of organizational factors on the circular economy practices and sustainable performance of small and medium-sized enterprises in Vietnam. *Journal of Business Research*, *147*, 362-378. https://doi.org/10.1016/j.jbusres.2022.03.077

21. Shibaeva, N., Baban, T., Prokhorova V., Karlova O., Girzheva O., & Krutko, M. (2019). Methodological bases of estimating the efficiency of organisational and economic mechanism of regulatory policy in agriculture. *Global Journal of Environmental Science and Management*, *5*, 160-171. https://doi.org/10.22034/gjesm.2019.05.SI.18
22. Prokhorova, V., Protsenko, V., Bezuglaya, Y., & Us, J. (2018). The optimisation algorithm for the directions of influence of risk factors on the system that manages the potential of machine-building enterprises. *Eastern-European Journal of Enterprise Technologies*, *4*(1(94)), 6-13. https://doi.org/10.15587/1729-4061.2018.139513
23. Hernita, H., Surya, B., Perwira, I., Abubakar, H., & Idris, M. (2021). Economic business sustainability and strengthening human resource capacity based on increasing the productivity of small and medium enterprises (SMES) in Makassar city, Indonesia. *Sustainability*, *13*(6), 3177. https://doi.org/10.3390/su13063177
24. Babenko, V., Baksalova, O., Prokhorova, V., Dykan, V., Ovchynnikova, V., & Chobitok, V. (2021). Information and Consulting Service Using in the Organization of Personnel Management. *Estudios de Economía Aplicada*, *38-3*(1), 1-10. https://doi.org/10.25115/eea.v38i4.3999
25. Pylypenko, Yu., Prokhorova, V., Halkiv, L., Koleshchuk, O., & Dubiei, Yu. (2022). Innovative intellectual capital in the system of factors of technical and technological development. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 181-186. https://doi.org/10.33271/nvngu/2022-6/181
26. Lutfi, A., Al-Khasawneh, A. L., Almaiah, M. A., Alsyouf, A., & Alrawad, M. (2022). Business sustainability of small and medium enterprises during the COVID-19 pandemic: The role of AIS implementation. *Sustainability*, *14*(9), 5362. https://doi.org/10.3390/su14095362
27. Smerichevskyi, S., Kryvovyazyuk, I., Prokhorova, V., Usarek, W., & Ivashchenko, A. (2021). Expediency of symptomatic diagnostics application of enterprise export-import activity in the disruption conditions of world economy sustainable development. *IOP Conference Series: Earth and Environmental Science, 628,* 012040. https://doi.org/10.1088/1755-1315/628/1/012040
28. Broccardo, L., Zicari, A., Jabeen, F., & Bhatti, Z. A. (2023). How digitalisation supports a sustainable business model: A literature review. *Technological Forecasting and Social Change*, *187*, 122146. https://doi.org/10.1016/j.techfore.2022.122146
29. Pizzi, S., Corbo, L., & Caputo, A. (2021). Fintech and SMEs sustainable business models: Reflections and considerations for a circular economy. *Journal of Cleaner Production*, *281*, 125217. https://doi.org/10.1016/j.jclepro.2020.125217
30. Nudurupati, S., Budhwar, P., Pappu, R., Chowdhury, S., Kondala, M., Chakraborty, A., & Ghosh, S. (2022). Transforming sustainability of Indian small and medium-sized enterprises through circular economy adoption. *Journal of Business Research*, *149*, 250-269. https://doi.org/10.1016/j.jbusres.2022.05.036

Методологічний підхід до оцінювання параметрів впливу технологічних змін на економічну стійкість підприємств

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Мета. Створення методологічного підґрунтя виміру взаємозв'язку між запровадженням ресурсозберігаючих технологій та економічною стійкістю підприємств.

Методика. У процесі дослідження використані методи: групування й узагальнення (при здійсненні класифікації видів економічної стійкості компаній), економіко-математичного моделювання (при розробленні показників оцінювання економічної стійкості підприємств), системного аналізу (при створенні методичних прийомів оцінювання впливу ресурсозберігаючих технологій на економічну стійкість підприємств), методи економічного аналізу й техніко-економічних розрахунків (при апробації методологічного підходу за вибіркою промислових підприємств), метод анкетування (при опитуванні власників і менеджерів підприємств щодо впровадження ними енергозберігаючих технологій), методи математичної статистики (при обробці результатів опитування).

Результати. На основі виокремлення видів економічної стійкості підприємств обґрунтовані характеристики високої, помірної, низької й незадовільної економічної стійкості підприємств. Запропоновані показники її оцінювання, продемонстрована їхня здатність слугувати індикаторами можливості підприємств забезпечувати своє стійке функціонування. Розроблено методологічний підхід, що дозволяє оцінити вплив ресурсозберігаючих технологій на економічну стійкість підприємств. Аналітичні можливості такого підходу апробовані на вибірці 60 українських підприємств, що запроваджували ресурсозберігаючі технології у частині заміщення природного газу. Результати показали, що енергозберігаючі технології здійснюють відчутний позитивний вплив на економічну стійкість компаній.

Наукова новизна. Запропонована удосконалена класифікація видів економічної стійкості підприємств за такими ознаками, як: спосіб обчислення, реалізованість резервів підвищення, ступінь узагальненості й індикатори, значення яких можуть погіршитися. Сформовані показники оцінювання локальної стійкості підприємств за: цінами на продукцію, змінними витратами, постійними витратами, натуральними обсягами збуту продукції, витратами на певний вид виробничих ресурсів. Створене методологічне підґрунтя оцінювання впливу ресурсозберігаючих технологій на економічну стійкість підприємств, що передбачає отримання інформації щодо фактичного або очікуваного покращення різних індикаторів економічної стійкості компаній унаслідок підвищення рівня ресурсозберігаючих технологій. Встановлена наявність позитивного впливу, що справлять енергозберігаючі технології на економічну стійкість підприємств, щодо технологічної модернізації виробництв, які базувалися на використанні природного газу.

Практична значимість. Отримані результати можуть бути використані підприємствами при розробці заходів із підвищення економічної стійкості, а також оцінюванні очікуваних економічних наслідків упровадження компаніями ресурсозберігаючих технологій.

Ключові слова: *підприємство, економічна стійкість, ресурсозбереження, інновації, технологічна зміна, виробничий ресурс*

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