https://doi.org/10.33271/nvngu/2026-3/184

O. Rozhenko[1],
orcid.org/0000-0002-9358-5436,
D. Labanauskaite[1],
orcid.org/0000-0002-3538-3991,
T. Beridze[*2],
orcid.org/0000-0003-2509-3242,
Z. Baranik[3],
orcid.org/0000-0002-9753-4572,
O. Galitsyna[3],
orcid.org/0000-0003-0560-755X,
A. Buhra[2],
orcid.org/0000-0003-3978-3404

1,– Klaipeda University, Klaipeda, Republic of Lithuania
2 – Kryvyi Rih National University, Kryvyi Rih Ukraine
3 – Kyiv National Economic University named after Vadym Hetman, Kyiv, Ukraine
* Corresponding author e-mail: beridzet2016@gmail.com

MODELING THE ETIOLOGY OF THE EFFECTS OF THE INFLUENCE OF THE ECOLOGICAL STATE OF THE REGION ON THE ACTIVITIES OF ENTERPRISES

Purpose. To investigate and analyze the impact of the environment on the functioning of enterprises in a regional context. To form an integral indicator of man-made pollution to assess in digital form the impact of environmental characteristics on the efficiency indicators of enterprise activity at the territorial level.

Methodology. The research was based on a systemic-synergistic approach, namely the formation of an integral indicator of technogenic pollution. Methods of statistical analysis were used for practical processing of the impact of the environment on the economic and social aspects of the activities of enterprises. Elements of analogies, comparisons were to determine the essence of assessing the effects of environmental impact from the point of view of the indicators of the enterprise's activities. Methodology of economic and mathematical modeling were used for developing a model for assessing and analyzing the impact of the state of the environment on the cost indicators of the enterprise's functioning and the formation of management decisions. Graphical method was applied for a visual presentation of the research carried out.

Findings. The feasibility and necessity of using mathematical modeling methods on the basis of environmental monitoring regarding the impact of technogenic components on the functioning of enterprises have been proven. It has been mathematically proven that there is an optimal amount of spending on the environmental component. Visualization and geometric interpretation of the obtained modeling results have confirmed their effectiveness.

Originality. An integral indicator of technogenic pollution is proposed, which allows assessing in digital form the simultaneous negative impact of pollutants on the performance of the enterprise and the social component of the region. The difference of the recommended indicator lies in the "collapsing" of information on each polluting substance that affects the characteristics of the environment. Methodological approaches to determining the dependence of the intensity of the disease of the relative number of workers in the region on the concentration of pollutants have been further developed.

Practical value. A study of the impact of pollutants on the health indicators of the population of the Kryvyi Rih region was conducted. It was shown that the activities of mining and processing enterprises in the region foresee costs for environmental protection. The analysis of the resulting mathematical model allowed us to obtain quantitative indicators of the mutual influence of the ecological state of the environment and the performance indicators of enterprises in the Kryvyi Rih region. The research demonstrated the prospects for using the results obtained when forming management decisions regarding costs for improving the state of the environment

Keywords: *enterprise, Kryvyi Rih region, ecology, mathematical model, integral indicator*

Received: 30 August 2025
Accepted: 24 March 2026
Available online: 27 June 2026

© Rozhenko O., Labanauskaite D., Beridze T., Baranik Z., Galitsyna O., Buhra A., 2026

Introduction. In modern conditions, the development of any enterprise is associated with a strategy that involves combining economic, social and environmental aspects of activity in order to ensure long-term stability. This means that the enterprise not only strives for profitability, but also cares about minimizing the negative impact on the environment and improving social well-being. The current stage of development of the national economy is based on regional components. The complexity of the development of regions under martial law poses a number of challenges for scientists. Given the ambiguity of the regionalization of the economic component, it makes sense to focus on regions with a developed industrial cluster. Operating industrial enterprises, the functioning of which is carried out in difficult conditions of martial law, require special attention from practicing scientists The genesis of enterprises involves a triune component that includes economic, social and environmental development plans. Accordingly, it is logical for managers to strive to optimize the selected aspects simultaneously. At the same time, a simple analysis shows that simultaneous optimization in three selected dimensions is an extremely difficult task. Moreover, improving one of them leads to a deterioration of the other two. Therefore, it is natural, according to the principles of economic and mathematical modeling, to formulate the task in such a way that optimization of one of the parameters is achieved, while the other two parameters are limited for certain reasons. It is relevant and appropriate to investigate the activities of industrial enterprises in the region from the point of view of the presence of sources of environmental pollution. The activities of these enterprises are associated with environmental problems. The desire to achieve maximum profit of enterprises leads to neglect of the ecological and social component. Technogenic pollution affects the health of the population. Failure to comply with the requirements for the safety component of the enterprise – dust concentration, violation of temperature regimes, etc., lead to occupational diseases. In turn, the violation of the ecological state causes an increase in chronic diseases of the most vulnerable segments of the population: children, disabled people, pensioners. The social component of the enterprise significantly depends on measures to minimize the negative consequences of technogenic impact. Existing methods for combating violations of life safety standards, to some extent, contribute to reducing technogenic pressure. At the same time, modernity requires the use of more radical measures that could not only contribute to the elimination of violations of the ecological state, but also predict their appearance in the future. This indicates the relevance and necessitates the further development of the scientific principles of the formation of economic and mathematical models for studying the impact of the ecological state of enterprises on its financial performance and human health. The development and implementation of such models creates a basis for making effective management decisions. This will allow preventing future risks and reducing the existing ones in the natural environment and society. It is proposed to use an integral characteristic of man-made pollution, which will allow to presenting qualitative concepts of man-made pollution in digital form. Analysis of modern criteria for assessing atmospheric pollution indicates their universality, which allows them to be used for a large number of conditions. At the same time, the task of constructing such a criterion arises, which would be adapted to the specific conditions of its application. To solve this problem, it seems advisable to "collapse" information on each of the harmful sources that cause man-made pollution, forming an integral characteristic of man-made pollution (ICMP).

Literature review. Today, new challenges are being created regarding the environmental state of the environment in general and the enterprises that form this environment. Scientists are not without reason paying attention to this issue. The influence of the environment on the economic and social component of the national economy in general and regions separately is difficult to overestimate. Thus, Poiasnyk H. devoted his study to the role of environmental entrepreneurship in the post-war reconstruction of Ukraine. The author emphasizes the terrible state of the environment. The need to apply advanced environmental protection technologies [1]. The team of authors led by Dzoban O.P. considers the sphere of national security of the state in combination with natural resources and the social component. Scientists have not ignored the peculiarities of human life and activity [2]. Authors Shvalb Yu. M., Vernik O. L., Vovchik-Blakytna O. O., Rudomino-Dusyatska O. V. investigated the problem of personality adaptation to the influence of the environmental component on its psychological state [3]. We consider the work by the authors Sokur M. I., Shmandii V. M., Babets E. K., Beletskyi V. S., Melnikova I. E. Kharlamova., O. V., Sheludchenko L. S. to be thorough in the direction of ecological and economic research. Scientists based their research on the development of empirical experiments on the technogenic impact on the ecological characteristics of the region. The authors identified further directions for solving economic and ecological problems of the industrial region [4]. Lashkun H. A., Pasichnyk N. V. focus on the regional aspect of ecological impact. The authors analyzed and assessed the ecological and economic consequences on the social component of the region. Scientists analyzed the objects with regard to significant negative impact on the environment [5]. The scientific work by the researcher Dudnik A. V. is devoted to environmental safety on the basis of economic and environmental monitoring. The author investigated the use of environmental investments in the context of sustainable development of the enterprise. A model is proposed for the analysis of the effective distribution of investments for the implementation of environmental measures. The scientific community considers environmental policy as an integral part of the strategic development of the enterprise [6]. The authors Savran V. V., Bohuslavskyi O. V., considering the economic strategy of the enterprise, identify the corresponding functions and factors that shape the direction of its development. Experts believe that thanks to an effective environmental policy, the enterprise increases its profits. Failure to comply with environmental measures creates the basis for negative social consequences. That is, environmental problems are reflected in the economic and social components of the strategic

development of the enterprise [7]. The modern period is characterized by a paroxysm of problems of ecological characteristics of regions. Scientists Rekova N. Yu., Rahulina N. V. in their research note the synergy of issues regarding the economic and ecological components of the functioning of the enterprise. The influence of ecological problems is reflected in the social component of the enterprise, namely on the support of the vital activity of employees. The authors conduct a thorough analysis of developments in the direction of economic and ecological analysis of the functioning of the enterprise. The importance of the study of sustainable development of the enterprise does not lose its relevance. The ecological state of the enterprise plays an important role in the formation of sustainable development [8]. Khakhaliev D. O. analyzes indicators that provide an assessment of the sustainable development of an enterprise. The author notes that sustainable development of an enterprise encompasses economic, environmental and social aspects. The highlighted components must be harmoniously integrated to achieve long-term stability and competitiveness [9]. Scientist Stepanenko T. O. forms his own concept of sustainable development. The author focuses on the growing importance of human potential and the impact of the external environment on it. An analysis of natural resources was conducted, highlighting their limitations [10]. Malyuk O. S. advises a system of indicators for the environmental characteristics of the region in which the enterprise operates. Analyzing the production potential of the enterprise, the author suggests creating a new institution within the enterprise. The proposed institution should take care of the environmental component of the enterprise [11]. In accordance with the environmental challenges of our time, scientists-practitioners pay attention to the formation of environmental management. Thus, Babchynska O. I. analyzes the role of environmental management in the management structure of an enterprise. The importance of using environmental management tools to ensure the competitiveness of an enterprise is emphasized [12]. The authors Mykhailova M. D., Kostenko O. K. pay attention to the implementation of an environmental management system, analyze its advantages and disadvantages. The environment directly affects human life and health [13]. In the scientific literature, reports about the negative impact of an external aggressive environment on human health are increasingly appearing. Scientists Berezutskyi V. V., Berezutska N. L., Bohodyst A. O. and others not without reason consider environmental monitoring necessary. Attention is focused on issues related to life safety [14]. Scientists Skopenko N. S., Kohut O. O. connect external and internal processes with the development of the enterprise. Determining the mechanism of sustainable development, the authors combine economic, social and environmental components [15]. A systems-logical approach is proposed by Komandrovska V. E. in the study of sustainable development of the enterprise. The scientist proposes a model of innovation-oriented transformation taking into account global technological trends. Accordingly, the ecological and economic component plays a certain role in the formation of such a model [16]. The scientist Nizhegolenko K. S. investigates the processes of modeling on the basis of the green economy. The author devoted his work to the formation of an ecologically balanced model. The formed model aims to study the economic development of the regions of the state in combination with environmental characteristics [17]. The parametric direction of research was proposed by Shashyna M. V. and Mosiichuk D. O. The scientists determined the effectiveness of the functioning of an enterprise through the prism of assessing the economic, social and environmental aspects of the parametric characteristics of sustainable development [18]. We draw attention to the research by the scientist Dubovyi O. V. The author reflects on the relationship between nature and man. He focuses on the negative impact of human resources on the natural environment [19]. The combination of economic characteristics and technogenic impact is studied by Kvitka T. The author proposes a model for assessing the technogenic impact on the economic indicators of an enterprise, namely profit and income [20]. The scientific work by researchers Vasenko O. G., Rybalova O. V., Artemiev S. R., Horban N. S., Korobkova G. V., Polozentseva V. O., Kozlovska O. V., Matsak A. O., Savichev A. A. is distinguished by its comprehensive research. The work presents the latest methods for assessing environmental characteristics. The scientists represent research in the field of environmental risks, as well as risks to public health. The main features of the methods and techniques of the formation of anthropogenic environmental factors, the degree of risk of the activities of an industrial enterprise in conditions of negative impact on the environment [21] have been determined. The authors Beridze T., Mishchuk E., Baranyk Z., Galitsyna O., Bugra A. considered the safety component on the basis of the system-parametric approach. The scientists have formed the main approaches to building economic and mathematical models in the safety field of the enterprise [22].

The analysis of scientific achievements in the field of research of environmental impact on the economic and social components of the activities of enterprises gives grounds to note the growing relevance of the issue. The peculiarity of the research is determined by the requirements of ecologization of the economy, its impact on the social component and the determination of the corresponding effects of the impact.

Unsolved aspects of the problem. Without belittling scientific achievements in the field of multifactorial impact of the environmental situation on the indicators of the enterprise's activity, its resource and social component, and human life, we can note the lack of attention to the implementation of methods for quantitative assessment of the impact of the environmental state on the economic components of the enterprise in general and social components separately. The analysis of modern scientific achievements gives grounds to state the lack of certainty of quantitative methods for assessing the multivector impact of the environment on the activities of the enterprise in general and in a regional context separately.

Purpose. To study and analyze the impact of the environment on the functioning of enterprises in a regional context. Formation of an integral indicator of technogenic pollution, in order to assess in a digital form the impact of the environment on the indicators of the enterprise's activity in the territorial plane.

Results. In mathematical modeling, which determines the impact of the environment on the activities of enterprises, it is necessary to translate qualitative concepts of pollution into a quantitative basis. Therefore, the question arises of presenting the concept of technogenic pollution in digital form. This can be done by introducing an integral characteristic of technogenic pollution. The analysis of modern criteria for assessing atmospheric pollution indicates their universality, which allows them to be used for a large number of conditions. At the same time, the task of constructing such a criterion arises, which would be adapted to the specific conditions of its application. To solve this problem, it seems advisable to "collapse" information on each of the harmful sources that cause man-made pollution, forming an ICMP.

Among the regions with increased technogenic load, the Kryvyi Rih region stands out. This necessitates further research, using, as an example, enterprises of the Kryvyi Rih region. Pollutants inherent in the activities of mining and processing enterprises include dust, gas pollution, etc. Assessing the impact of each of the harmful substances separately causes certain difficulties, which are primarily associated with the provision of information. The introduction of an appropriate integral characteristic allows you to avoid these difficulties. The social component of the impact of technogenicity is reflected in the occupational diseases of workers. First of all, to build an analytical definition that will characterize the dependence of the impact of harmful substances on the occupational morbidity of workers, it is necessary to choose its structure. The qualitative analysis of the dependence of the intensity of the disease of the relative number of workers on the concentrations of harmful substances allows you to determine the structure of the formula in the form

$$\gamma = \exp\left(-\sum_{k=1}^{n} \alpha_k \cdot c_k\right), \quad (1)$$

where γ is the value of ICMP, person/year; c_k is concentration of harmful substance of k-type, mg/m^3, α_k is parameters, (k = 1, 2, ..., n); n is the number of harmful substances.

Parameters α_k determine the relative sensitivity of ICMP to the concentration of harmful substance c_k, which is confirmed by the partial derivative with respect to the variable c_k.

Obviously, if any of the parameters α_k is zero, this means that there is no effect of the corresponding harmful substance on the ICMP.

It should be emphasized that the parameters $\alpha_k$must be non-negative, since they must negatively affect the ICMP. A feature of the proposed structure of formula (1) is that it allows it to be identified quite simply, that is, to find the values of the parameters that are included in it and are unknown. To do this, by logarithmizing formula (1) is reduced to a form in which the parameters are included linearly

$$\frac{1}{\gamma}\frac{\partial \gamma}{\partial c_k} = \alpha_k; \quad (2)$$

$$\lambda = -\sum_{(k=1)}^{n} \alpha_k \cdot c_k, \quad (3)$$

where $\lambda = \ln\gamma$. If there is statistical material, the parameters included in formula (3) are found using the least squares method (LSM) [2]. Indeed, let us have statistical material that characterizes the environmental state at the enterprise in the form of ordered sets of numbers

$$\langle \gamma_i, c_{i1}, c_{i2}, ..., c_{in} \rangle, (i = 1, 2, ..., N). \quad (4)$$

As a result of ICMP logarithmization, the set of numbers (4) forms the following relation

$$\langle \lambda_i, c_{i1}, c_{i2}, ..., c_{in} \rangle, (i = 1, 2, ..., N), \quad (5)$$

where $\lambda_i = \ln\gamma_i$.

Next, we need to find the parameters.

$$A = (\alpha_1, ..., \alpha_n). \quad (6)$$

Using the data (5), we substitute into (3). This analytical transformation allowed us to form a system containing N equations with n unknowns.

$$\begin{cases} \alpha_1 \cdot c_{1,1} + ... + \alpha_n \cdot c_{n,1} = \lambda_1 \\ ..... \\ \alpha_1 \cdot c_{1,N} + ... + \alpha_n \cdot c_{n,N} = \lambda_N \end{cases}. \quad (7)$$

Thus, to solve the identification problem (3), the system of linear equations (7) should be solved. The resulting system has a property inherent in certain difficulties of solution, namely – incompatibility. It is generally known that incompatibility is most often associated with the case when there are more equations than unknowns ($N > n$).

If the incompatibility occurs ($N > n$), then the least squares method is used to solve the corresponding system of equations (7). The minimization of the right and left parts of the complete residues is calculated. For this purpose, it is advisable to construct the corresponding function. Analytically, the sum of squares of the residues is formed from each of the equations.

$$F(A) = \sum_{i=1}^{N} \left(\alpha_1 \cdot c_{1,i} + ... + \alpha_n \cdot c_{n,i} - \lambda_i\right)^2. \quad (8)$$

The obtained function (8) is non-negative. In the case of coincidence of the right and left parts of (7), the function is equal to zero. It is logical to analyze the left and right parts of the residual function (8). The closeness of the left and right parts of (7) indicates the corresponding value of the residue function (8).

This creates the basis for determining the parameter values that represent the solution of system (7).

$$A^* = \left(\alpha_1^*, ..., \alpha_n^*\right). \quad (9)$$

Function (8) is minimal for the corresponding parameters, i.e.

$$F\left(A^*\right) = \min_A F\left(A\right).$$

Next, we can note that to solve the system of equations (7), which we have defined as inconsistent, it is sufficient to minimize the function of the total residue (8).

The obtained function (3) is the basis for solving the minimization problem (8). To do this, we set the partial derivatives with respect to the parameters of the obtained function (8) to zero, i.e.

$$\frac{\partial F(A)}{\partial \alpha_i} = 0, \quad i = 1,...,n. \tag{10}$$

The resulting system of equations is linear. This property is based on the property of function (8), which is quadratic.

In turn, it should be noted that function (3) is determined by linearity with respect to the parameters defined in (6). Applying the appropriate analytical transformations, namely, substituting the value (3) into (8), we differentiate. As a result, we obtain

$$\begin{cases} \dfrac{\partial F(A)}{\partial \alpha_1} = 2 \cdot \sum\limits_{i=1}^{N} \left(\alpha_1 \cdot c_{1,i} + ... + \alpha_n \cdot c_{n,i} - \lambda_i \right) \cdot c_{1,i} = 0 \\ \dfrac{\partial F(A)}{\partial \alpha_2} = 2 \cdot \sum\limits_{i=1}^{N} \left(\alpha_1 \cdot c_{1,i} + ... + \alpha_n \cdot c_{n,i} - \lambda_i \right) \cdot c_{2,i} = 0 \\ \dfrac{\partial F(A)}{\partial \alpha_N} = 2 \cdot \sum\limits_{i=1}^{N} \left(\alpha_1 \cdot c_{1,i} + ... + \alpha_n \cdot c_{n,i} - \lambda_i \right) \cdot c_{N,i} = 0 \end{cases}. \tag{11}$$

Using the linearity of the summation sign, we can represent system (11) in the following form.

$$\begin{cases} \alpha_1 \sum\limits_{i=1}^{N} c_{1,i}^2 + ... + \alpha_n \sum\limits_{i=1}^{N} c_{1,i} \cdot c_{n,i} = \sum\limits_{i=1}^{N} \lambda_i \cdot c_{1,i} \\ \alpha_1 \sum\limits_{i=1}^{N} c_{1,i} \cdot c_{2,i} + ... + \alpha_n \sum\limits_{i=1}^{N} c_{2,i} \cdot c_{n,i} = \sum\limits_{i=1}^{N} c_{2,i} \cdot \lambda_i \\ ..... \\ \alpha_1 \sum\limits_{i=1}^{N} c_{n,i} \cdot c_{1,i} + ... + \alpha_n \sum\limits_{i=1}^{N} c_{n,i}^2 = \sum\limits_{i=1}^{N} c_{n,i} \cdot \lambda_i \end{cases}. \tag{12}$$

If we use the notation of average values, then it is appropriate to represent system (12) as

$$\begin{cases} \overline{c_1^2} \cdot \alpha_1 + ... + \overline{c_1 c_n} \cdot \alpha_n = \overline{c_1 \lambda} \\ \overline{c_1 c_2} \cdot \alpha_1 + ... + \overline{c_2 c_n} \cdot \alpha_n = \overline{c_2 \lambda} \\ ..... \\ \overline{c_n c_1} \cdot \alpha_1 + ... + \overline{c_n^2} \cdot \alpha_n = \overline{c_n \lambda} \end{cases}, \tag{13}$$

where $\overline{\lambda} = \frac{1}{N} \sum\limits_{i=1}^{N} \lambda_i$; $\overline{c}_k = \frac{1}{N} \sum\limits_{i=1}^{N} c_{k,i}$;

$$\overline{c_k c_j} = \frac{1}{N} \sum_{i=1}^{N} c_{k,i} \cdot c_{j,i}; \quad \overline{c_k \lambda} = \frac{1}{N} \sum_{i=1}^{N} c_{k,i} \cdot \lambda_i;$$

$k = 1,2, ..., n, j = 1, 2, ..., n$.

The resulting system (13) is a system of linear algebraic equations. The specified system (13) is determined by parameters (6).

It should be emphasized that the number of equations of the system is equal to the number of its parameters, therefore this system is solved by standard methods.

Let the optimal values of parameters (9) be obtained as a result of solving system (13). Then formula (3) takes the form

$$\lambda_0 = -\sum_{k=1}^{n} \alpha_k^* \cdot c_k,$$

or taking into account the substitution in (1), takes the form

$$\gamma_0 = \exp\left(-\sum_{k=1}^{n} \alpha_k^* \cdot c_k \right). \tag{14}$$

In turn, it is necessary to emphasize that the issues related to the reliability of the found formula (14) relate to correlation-regression analysis. It is based on the study of the properties of statistical material. Thus, thanks to the introduction of ICMP, it became possible to compactly assess the harmfulness of technogenic pollution in digital form. In addition, it is advisable to note that formula (14) is "open", that is, if necessary, information about new pollutants can be added to it or unnecessary ones can be eliminated. This approach allows us, in further modeling, to understand the corresponding value of ICMP under the value of technogenic pollution of the enterprise. The introduction of the ICMP variable allows us to consider the dependence of the ecological state of mining and processing plants (MPP) in general and technogenic pollution of mining and processing plants (MPP) in particular on this variable.

It should be noted that mining enterprises are a source of environmental pollution. The operation of mining and quarrying enterprises leads to man-made pollution of the environment [5]. With the growth of production volumes, man-made pollution also increases. Currently, the increase in man-made pollution leads to a decrease in income. The implementation of environmental protection measures requires appropriate investments. Analytically, we can determine the amount of income in the event of man-made pollution of the enterprise as a differential equation with respect to the ICMP under the initial condition, which is equal to the maximum possible amount of income. Mathematically, this is formulated as a Cauchy problem

$$\frac{dD}{d\lambda} = -\alpha \cdot D; \tag{15}$$

$$D(\lambda = 0) = D_0, \tag{16}$$

where D is income, conditional units; D_0 is income that can be earned by the enterprise at $\lambda = 0$, conditional units; α is a parameter that determines the rate of decline in income from technogenic pollution, year/person.

The initial condition means that in the absence of technogenic pollution, when $\lambda = 0$, income will be maximum. To solve the Cauchy problem (15, 16), we first find the general solution of the differential equation (15). The differential equation (15) is a first-order differential equation with variables that are separable. We solve equation (15) according to the classification of the equation

$$\begin{gathered} \frac{dD}{d\lambda} = -\alpha \cdot D; \quad \frac{dD}{D} = -\alpha \cdot d\lambda; \\ \int \frac{dD}{D} = -\alpha \cdot \int d\lambda; \quad \ln D = -\alpha \cdot \lambda + C, \end{gathered} \tag{17}$$

where C is an arbitrary constant.

According to the initial condition (16), in the general solution (17) we find the constant C

$$C = \ln D_0. \tag{18}$$

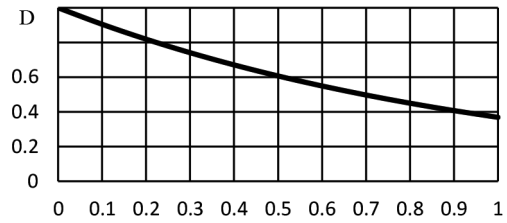

Fig. 1. Dependence of income on ICMP ($D_0 = 1$, $\alpha = 1$)

We substitute (18) into (17) and after transformations we obtain the solution of the Cauchy problem (15, 16)

$$D = D_0 \cdot e^{-\alpha \cdot \lambda}. \quad (19)$$

Fig. 1 shows the graph of function (19).

The analysis of the graph shown in Fig. 1 shows that it meets the requirements for the dependence of the amount of income on man-made pollution, which are formulated above. A feature of formula (19) is that it can be reduced to a form that is convenient for finding the unknown parameter α using OLS. To do this, we will successively transform formula (19) to the form

$$D = D_0 \cdot e^{-\alpha \cdot \lambda}; \quad e^{\alpha \cdot \lambda} = \frac{D_0}{D}; \quad \alpha \cdot \lambda = \ln\left(\frac{D_0}{D}\right); \quad \alpha = \frac{1}{\lambda}\ln\left(\frac{D_0}{D}\right). \quad (20)$$

If there is appropriate statistical material, using the Least Squares method, according to formula (20), we find the estimate of the parameter α

$$\alpha^* = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{\lambda_i}\ln\left(\frac{D_{0i}}{D_i}\right), \quad (21)$$

where $\lambda_i, \frac{D_{0i}}{D_i}$, $i = 1, 2, ..., n$ are statistical data.

The reliability of the found value of the parameter α^* using formula (21) can be proven by statistical analysis.

Next, we will consider the mathematical modeling of costs aimed at reducing technogenic pollution. Reducing technogenic pollution of the mining and quarrying industry requires corresponding costs. At the same time, even a superficial qualitative analysis shows that without taking into account the impact of technogenic pollution on the mining and quarrying industry's activities, it is impossible to achieve significant achievements. For mathematical modeling of costs for reducing technogenic pollution, it is necessary to determine the properties of the function that characterizes the dependence of costs on the ICMP. First of all, when reducing costs for combating technogenic pollution, the ICMP value should increase. Secondly, the rate of decline of this function should be proportional to the value of the function itself. And, finally, with a zero value of the ICMP, the costs for reducing technogenic pollution should be equal to some maximum permissible value, which is determined by the features of the operation of the mining and quarrying industry. To summarize, from a mathematical point of view, the sought-after function must satisfy a first-order differential equation with respect to the ICMP with an initial condition that corresponds to the largest value of the costs of reducing technogenic pollution, which corresponds to the Cauchy problem.

$$\frac{dV}{d\lambda} = -\beta \cdot V; \quad (22)$$

$$V(\lambda = 0) = V_0, \quad (23)$$

where V is the value of economic costs for reducing technogenic pollution, standard units; V_0 is the value of economic costs when $\lambda = 0$, standard units; β is a parameter that characterizes the rate of decline in economic costs with increasing technogenic pollution, year/person.

Considering that the Cauchy problem (22, 23) coincides with the Cauchy problem (15, 16) solved above, the solution of this Cauchy problem will have the form

$$V = V_0 \cdot e^{-\beta \cdot \lambda}. \quad (24)$$

Fig. 2 shows the graph of function (24).

Analysis of the graph shown in Fig. 2 shows that the nature of its change meets the requirements that were formed for the function of the dependence of economic costs on the reduction of technogenic pollution from ICMP.

As was noted, if there is appropriate statistical material, using the OLS, according to formula (24) one can find an estimate of the parameter β

$$\beta^* = -\frac{1}{n}\sum_{i=1}^{n}\frac{1}{\lambda_i}\ln\left(\frac{V_{0i}}{V_i}\right), \quad (25)$$

where $\left\langle \lambda_i, \frac{V_{0i}}{V_i} \right\rangle$, $i = 1, 2, ..., n$ is statistical data

The reliability of the found value of the parameter β^* using formula (25) can be proven using the appropriate statistical analysis.

The analysis of the dependence of the ecological state of the mining industry on man-made pollution allows us to draw certain conclusions. The conclusions obtained are appropriate and necessary to be taken into account when forming development plans for enterprises. It should be borne in mind that the desire to completely get rid of man-made pollution, for example, by closing enterprises, also leads to negative consequences. Therefore, the question arises of determining the most rational ecological indicators of the mining and quarrying industry in the presence of technogenic pollution. Analysis of mathematical models of reducing income from technogenic pollution (19) and economic costs of reducing technogenic pollution (24)

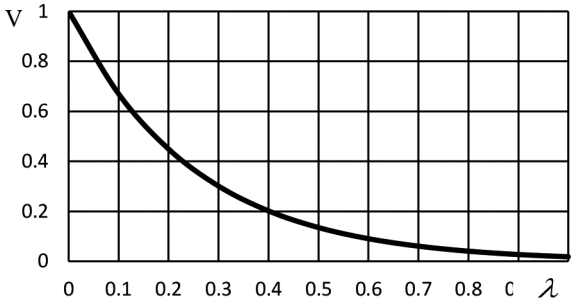

Fig. 2. Dependence of costs for reducing technogenic pollution on ICMP ($V_0 = 1$, $\beta = 4$)

shows that there is such an acceptable level of technogenic pollution that provides optimal profit. It is known that "profit is the difference between income and expenses (in monetary terms" [20]. Using the appropriate notations, we can write

$$P = D - V, \tag{26}$$

where P is profit, conditional unit.

Taking into account (19) and (24), formula (26) takes the form

$$P = D_0 \cdot e^{-\alpha \cdot \lambda} - V_0 \cdot e^{-\beta \cdot \lambda}. \tag{27}$$

Fig. 3 presents the graphs of functions (19, 24) and (27).

The analysis of the graphs in Fig. 3 shows that profit (27) does indeed reach a maximum at some (optimal) value of ICMP.

Taking into account the content of formulas (19) and (24), the problem is to maximize criterion (27) in the variable λ, i.e.

$$\max_{\lambda}\left[D_0 \cdot e^{-\alpha \cdot \lambda} - V_0 \cdot e^{-\beta \cdot \lambda} \right]. \tag{28}$$

The general condition for the existence of an extremum of a function is that the derivative is zero. Thus, the derivative of the function (27) with respect to the variable λ must be zero, i.e.

$$P'(\lambda) = [D_0 \cdot e^{-\alpha \cdot \lambda} - V_0 \cdot e^{-\beta \cdot \lambda})]' = 0. \tag{29}$$

We calculate the derivative

$$P'(\lambda) = -\alpha \cdot D_0 \cdot e^{-\alpha \cdot \lambda} + \beta \cdot V_0 \cdot e^{-\beta \cdot \lambda} = 0,$$

and successively solve the obtained equation with respect to λ

$$\alpha \cdot D_0 \cdot e^{-\alpha \cdot \lambda} = \beta \cdot V_0 \cdot e^{-\beta \cdot \lambda}; \quad e^{(\beta-\alpha)\cdot\lambda} = \frac{\beta \cdot V_0}{\alpha \cdot D_0}; \qquad \lambda_0 = \frac{1}{\beta - \alpha} \ln\left(\frac{\beta \cdot V_0}{\alpha \cdot D_0} \right). \tag{30}$$

Let us find under what conditions the formula (30) determines the maximum of the criterion (28). To do this, we will use the sufficient condition of the existence of an extremum of the function using the second-order derivative. According to this condition, the function reaches a maximum if the second-order derivative at the point of the extremum is negative. We calculate the second-order derivative as the derivative of the first-order derivative

$$P''(\lambda) = \alpha^2 \cdot D_0 \cdot e^{-\alpha \cdot \lambda} - \beta^2 \cdot V_0 \cdot e^{-\beta \cdot \lambda}. \tag{31}$$

Let us find under what conditions the formula (31) determines the maximum of the criterion (28). To do this, we will use the sufficient condition of the existence of an extremum of the function using the second-order derivative. According to this condition, the function reaches a maximum if the second-order derivative at the point of the extremum is negative.

Next, we substitute (30) into equation (31) and sequentially find

$$P''(\lambda_0) = \alpha \cdot D_0 \cdot \left(\frac{\beta \cdot V_0}{\alpha \cdot D_0} \right)^{\frac{\alpha}{\alpha - \beta}} (\alpha - \beta). \tag{32}$$

According to (32), the second order derivative will be negative when

$$\alpha < \beta, \tag{33}$$

given that the parameters α and β are positive.

Thus, if condition (33) is satisfied, function (27) reaches its maximum value at the optimal value (30). Let us find this value

$$P_{opt} = P(\lambda_0) = D_0 \cdot \left(\frac{\beta \cdot V_0}{\alpha \cdot D_0} \right)^{\frac{\alpha}{\alpha - \beta}} \left(1 - \frac{\alpha}{\beta} \right). \tag{34}$$

Using the obtained formulas (19, 24 and 30), we can find the optimal values of income and expenses for reducing technogenic pollution. Indeed, substituting (30) into formula (19), we consistently find the optimal value of income

Using the obtained formulas (19, 24 and 30)

$$D_{opt} = D_0 \cdot e^{-\alpha \cdot \lambda_0}; \quad D_{opt} = D_0 \cdot e^{-\frac{\alpha}{\beta - \alpha} \ln\left(\frac{\beta \cdot V_0}{\alpha \cdot D_0} \right)}; \qquad D_{opt} = D_0 \cdot e^{\ln\left(\frac{\beta \cdot V_0}{\alpha \cdot D_0} \right)^{\frac{\alpha}{\alpha - \beta}}}; \quad D_{opt} = D_0 \cdot \left(\frac{\beta \cdot V_0}{\alpha \cdot D_0} \right)^{\frac{\alpha}{\alpha - \beta}}. \tag{35}$$

Similarly, by substituting (30) into formula (24), we find the optimal cost of reducing man-made pollution

$$V_{opt} = V_0 \cdot e^{-\beta \cdot \lambda_0}; \quad V_{opt} = V_0 \cdot e^{\frac{\beta}{\alpha - \beta} \ln\left(\frac{\beta \cdot V_0}{\alpha \cdot D_0} \right)}; \qquad V_{opt} = V_0 \left(\frac{\beta \cdot V_0}{\alpha \cdot D_0} \right)^{\frac{\beta}{\alpha - \beta}}. \tag{36}$$

Formulas (30, 34–36) provide a solution to the problem of optimal choice of the value of ICMP to achieve the greatest profit of the mining and quarrying company.

Let us consider the obtained modeling results in practice.

First, let us consider the construction of a mathematical model of ICMP according to the data presented in Table 1.

According to formula (1), the ICMP for the data in Table 1 will be written as

$$\gamma = e^{-(\alpha_1 \cdot c_1 + \alpha_2 \cdot c_2)}. \tag{37}$$

Then, as a result of logarithmization, we have

$$\lambda = -\ln \gamma = \alpha_1 \cdot c_1 + \alpha_2. \tag{38}$$

Using Least Squares, we obtain a system of two equations with two unknowns to determine the parameters

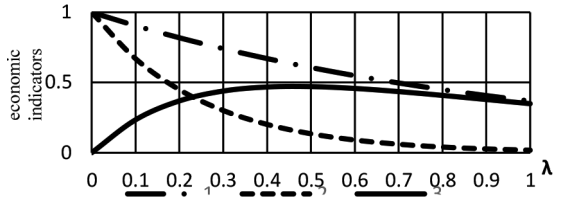

Fig. 3. Graphs of economic indicators depending on the ICMP (1 – D (D_0 = 1, α = 1), 2 – V (V_0 = 1, β = 4), 3 –P)

Table 1

ICMP and corresponding intensities of emissions of harmful substances into the air of mining and quarrying plants [23]

No.	ICMPγ	λ	Dust (c1), tons/day	Sulfur dioxide (C_2), tons/day	λ_m
1	0.95	0.05	121.42	25	0.49
2	0.91	0.09	133.41	28	0.54
3	0.85	0.16	140.1	29	0.57
4	0.71	0.34	146.1	25	0.58
5	0.65	0.43	150.1	31	0.61
6	0.54	0.63	161.1	35	0.66
7	0.45	0.79	172.1	36	0.70
8	0.41	0.89	173	38	0.71
9	0.310	1.172	175.2	32	0.71
10	0.26	1.34	180.1	38	0.75

$$\begin{cases} 24{,}467.59\cdot\alpha_1 + 4{,}768.85\cdot\alpha_2 = 100.49 \\ 4{,}768.85\cdot\alpha_1 + 930.22\cdot\alpha_2 = 19.42 \end{cases}. \quad (39)$$

Let us solve system (39) using Cramer's formula

$$\alpha_1 = \frac{\Delta_1}{\Delta}; \quad \alpha_2 = \frac{\Delta_2}{\Delta}; \quad (40)$$

$$\Delta = \begin{vmatrix} 24{,}467.59 & 4{,}999.778 \\ 4{,}999.778 & 1{,}026.9 \end{vmatrix} = 127{,}992.7;$$

$$\Delta_1 = \begin{vmatrix} 99.50 & 4{,}999.78 \\ 20.34 & 1{,}026.9 \end{vmatrix} = 476.08; \quad (41)$$

$$\Delta_2 = \begin{vmatrix} 24{,}467.59 & 99.50 \\ 4{,}999.78 & 20.34 \end{vmatrix} = 217.37.$$

According to (41), we find by formula (40)

$$\alpha_1 = 0.00372; \quad \alpha_2 = 0.001698. \quad (42)$$

Taking into account (42), formula (38) takes the form

$$\lambda_m = 0.00372 \cdot c_1 + 0.001698 \cdot c_2. \quad (43)$$

In this case, taking into account (43), the mathematical model of the ICMP will be written in the form

$$\gamma_m = e^{-0.00372\tilde{n}_1 - 0.001698\tilde{n}_2}. \quad (44)$$

The last two columns of Table 1 present the results of calculations using formulas (44) and (45), i.e., using mathematical models. The correlation coefficient calculated between λ and λ_m was

$$r = 0.871. \quad (45)$$

Since the quantity (45) is within the limits

$$0.7 < r < 0.9,$$

then according to the Chaddock scale, the relationship between the variables is "high".

Let us use the data given in Table 2 to build a mathematical model of the dependence of income on ICMP.

Using formula (21) and the data in Table 2, we find the optimal value of the parameter

$$\alpha^* = \frac{1}{5}\sum_{i=1}^{5}\frac{1}{\lambda_i}\ln\left(\frac{D_0}{D}\right)_i = 0.483. \quad (46)$$

Table 2

Initial data for building a mathematical model (44)

No.	λ_i	$\left(\frac{D}{D_0}\right)_i$	$\left(\frac{D_0}{D}\right)_i$	α_i	Revenue model $\left(\frac{D}{D_0}\right)_m$
1	0.5	0.800	1.250	0.446	0.787
2	0.6	0.750	1.333	0.479	0.750
3	0.7	0.700	1.429	0.510	0.715
4	0.8	0.680	1.471	0.482	0.681
5	0.9	0.640	1.563	0.496	0.649

Using formula (21) and the data in Table 2, we find the optimal value of the parameter

$$\left(\frac{D}{D_0}\right)_m = e^{-0.483\cdot\lambda}. \quad (47)$$

The correlation coefficient between the real data (3 columns of Table 2) and those calculated using the mathematical model (last column of Table 2) was

$$r = 0.993. \quad (48)$$

Since the correlation coefficient (48) is greater than 0.99, according to the Chaddock scale, the relationship between the variables is "very strong".

Let us use the data presented in Table 3 to construct a mathematical model of the dependence of economic costs on the reduction of man-made pollution from ICMP.

Using formula (21) and the data in Table 3, we find the optimal value of the parameter

$$\beta^* = \frac{1}{5}\sum_{i=1}^{5}\frac{1}{\lambda_i}\ln\left(\frac{V_0}{V}\right)_i = 1.765. \quad (49)$$

The last column of Table 2 presents the results of calculations based on the found mathematical model.

$$\left(\frac{V}{V_0}\right)_m = e^{-1.765\cdot\lambda}. \quad (50)$$

The correlation coefficient between real data (3 columns of Table 3) and those calculated using the mathematical model (last column of Table 3) was

$$r = 0.995. \quad (51)$$

Since the correlation coefficient (48) is greater than 0.99, according to the Chaddock scale, the relationship between the variables is "very strong".

Profit, according to formula (27), will be written as

$$P(\lambda) = D_0 \cdot e^{-0.483\cdot\lambda} - V_0 \cdot e^{-1.765\cdot\lambda}. \quad (52)$$

Table 3

Input data for building a mathematical model (47)

No.	λ_i	$\left(\frac{V}{V_0}\right)_i$	$\left(\frac{V_0}{V}\right)_i$	β_i	Expense model $\left(\frac{V}{V_0}\right)_m$
1	0.5	0.40	2.5	1.83	0.41
2	0.6	0.35	2.86	1.75	0.35
3	0.7	0.30	3.33	1.72	0.29
4	0.8	0.25	4	1.73	0.24
5	0.9	0.20	5	1.78	0.20

In the following, we will conditionally assume that

$$D_0 = 1{,}000; \quad V_0 = 600. \tag{53}$$

Taking into account (53), formula (52) can be written as

$$P(\lambda) = 1{,}000 \cdot e^{-0.483 \cdot \lambda} - 100 \cdot e^{-1.765 \cdot \lambda}. \tag{54}$$

Fig. 4 shows graphs of the values of economic indicators of the mining and quarrying industry depending on the ICMP.

The analysis of the profit graph shows that this indicator reaches a maximum. The calculation according to formulas (30 and 34) gave the following results

$$\lambda_0 = 0.612, \quad P0_{\max}. \tag{55}$$

The obtained results (55) are confirmed by the location of these values on the graph (Fig. 4).

In turn, the ICMP is the optimal value

$$\gamma_0 = e^{-0.612} = 0.542. \tag{56}$$

The obtained formula (54) allows us to solve the problem of stabilization of the ICMP, that is, stabilization of the level of technogenic pollution relative to the indicators given in Table 1.

Indeed, let the given level of stabilization of the ICMP be

$$\gamma_1 = 0.7, \tag{57}$$

then

$$\lambda_1 = -\ln(\gamma_1) = 0.357. \tag{58}$$

At the same time, the value (58) is determined by the formula (43), that is, it depends on two variables and can take many values. Therefore, the question arises of finding, in a certain sense, the best value of ICMP, that is, a problem arises of the optimal values of the variables that make up ICMP.

To solve this problem, it is necessary to specify a functional whose extreme value will allow determining the best solution. As such a functional, it is assumed to choose a linear functional of the form

$$L = l_1 \cdot c_1 + l_2 \cdot c_2,$$

where l_1, l_2 are "weight" coefficients.

The "weight" coefficients characterize the contribution to the functional of each of the positive ones.

In the considered problem, it is assumed that dust impurities are twice as harmful as sulfur oxide, that is, it is assumed that

$$l_1 = 2, \quad l_2 = 1.$$

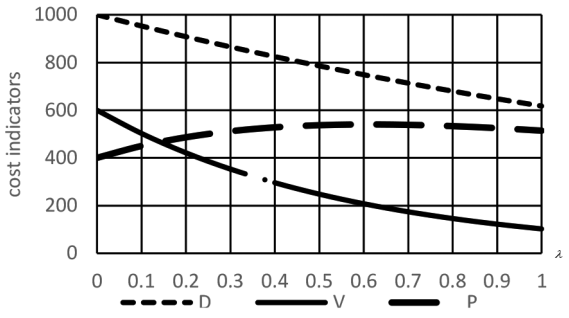

Fig. 4. Graph of dependence of cost indicators on ICMP

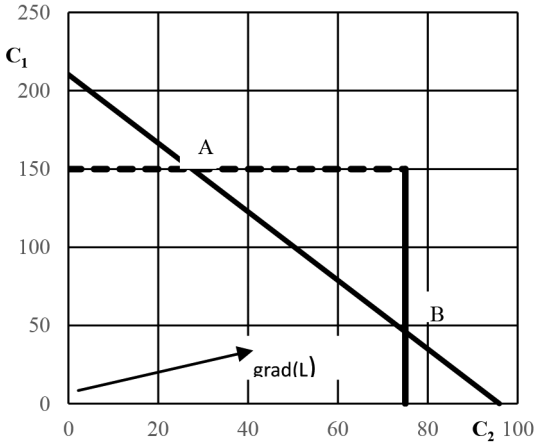

Fig. 5. Geometric solution of the linear programming problem (59)

As a result, the problem is mathematically formulated as a linear programming problem [24].

$$\begin{cases} L = 2 \cdot c_1 + 1 \cdot c_2 \to \min\limits_{c_1, c_2} \\ 0.00372 \cdot \tilde{n}_1 + 0.001698 \cdot \tilde{n}_2 = 0.357 \\ 0 \le c_1 \le 75 \\ 0 \le c_2 \le 150 \end{cases}. \tag{59}$$

The last two conditions determine the limits on the concentrations of dust and sulfur dioxide.

Problem (59) can be solved geometrically on the plane (Fig. 5), since we have two variables. To do this, in the coordinates (c_1, c_2) we construct a straight line (the second equation in the system (59)), then we select a rectangle according to the inequalities in (59).

The extreme values of the functional are located on the segment that cuts off the corner of the rectangle, that is, on the segment [A; B]

Then we select the gradient of the functional L

$$grad(L) = \left(\frac{\partial L}{\partial c_1}; \frac{\partial L}{\partial c_2} \right) = (2;1).$$

Moving in the direction opposite to the gradient, we reach the extreme point, the coordinates of which are found by solving the system of equations

$$\begin{cases} c_1 = 75 \\ 0.00372 \cdot c_1 + 0.001698 \cdot c_2 = 0.357 \end{cases}.$$

Solving the system of equations, we find the coordinates of the point (75; 45.9).

In this case, the functional reaches its minimum value

$$L_{\min} = L(75{:}45.9) = 336.6.$$

Thus, the obtained analytical dependencies provide an opportunity to assess the mutual influence of the ecological state of the region on the performance indicators of the enterprise

Conclusions. The results obtained as a result of the analysis of the environmental characteristics during the operation of mining and processing plants confirmed the negative impact of pollutants. As one of the possible ways to solve the problem of reducing their impact, the

use of the method of mathematical modeling based on modern information technologies was proposed. It was proven that the activities of mining and processing plants are impossible without spending on protecting the environmental situation in the region. It was mathematically proven that there is an optimal amount of spending on environmental characteristics, at which the profit of mining and processing plants will be maximum. What is new in the study is the introduction of an integral indicator of technogenic pollution, which allows us to assess in digital form the simultaneous negative impact of pollutants on the performance indicators of the enterprise and the social component. The study on a practical example showed the prospects of using the results obtained.

References.

1. Poiasnyk, H. (2023). The role of ecological entrepreneurship in the post-war reconstruction. *Ekonomika ta suspil'stvo*, 47. https://doi.org/10.32782/2524-0072/2023-47-11

2. Dzoban, O. P. (Eds) (2021). *National Security: Worldview and Theoretical and Methodological Principles: monograph*. Kharkiv. https://doi.org/10.31359/9789669980885

3. Shvalb, Yu. M., Vernik, O. L., Vovchyk-Blakytna, O. O., Kyrpenko, T. M., Rudomino-Dusiatska, O. V., & Matviienko, O. V. (2018). *Personal determinants of ecologically oriented life activity: monograph*. (Shvalba, Yu. M. Eds.). Kyiv: Instytut psykholohii imeni H. S. Kostiuka NAPN Ukrainy. ISBN 978-966-97846-4-3.

4. Sokur, M. I., Shmandii, V. M., Babets, Ye. K., Biletskyi, V. S., Melnikova, I. Ye., Kharlamova, O. V., & Sheludchenko, L. S. (2020). *Environmental safety and economy: monograph*. Kremenchuk. ISBN: 978-617-639-255-2.

5. Lashkun, H. A., & Pasichnyk, N. V. (2018). Environmental and economic assessment and social consequences of mining activities. *Ekonomika i suspil'stvo*, *17*, 454-460. https://doi.org/10.32782/2524-0072/2018-17-67

6. Dudnyk, A. V. (2020). Principles of ensuring the environmental safety of industrial-urban agglomerations in the context of their sustainable development. *Ekonomichnyi Visnyk Dniprovskoii politekhniky: nauk. zhurn. Nats. tekhn. un-t "Dniprovska politekhnika"*, *2*(70), 202-213. https://doi.org/10.33271/ev/70.202

7. Savran, V. V., & Bohuslavskyi, O. V. The environmental policy of an enterprise as a main component of its economic strategy. *Kyivs'kyj natsional'nyj universytet imeni Tarasa Shevchenka*. Retrieved from https://fileserver-az.core.ac.uk/download/14043680.pdf

8. Rekova, N. Yu., & Rahulina, N. V. (2021). Eco-economic analysis as an element of the system of operational activities of the enterprise. *Efektyvna ekonomika*, (1). https://doi.org/10.32702/2307-2105-2021.1.22

9. Khakhaliev, D. O. (2024). Assessment of the sustainability of the enterprise. *Biznes Inform*, *5*, 338-344. https://doi.org/10.32983/2222-4459-2024-5-338-344

10. Stepanenko, T. O. (2020). Theoretical and methodological principles of sustainable enterprise development. *Vcheni zapysky TNU imeni V. I. Vernads'koho. Seriia: Ekonomika i upravlinnia, 31*((40)6), 136-141. https://doi.org/10.32838/2523-4803/70-6-23

11. Maliuk, O. S. (2017). Formation of a system of indicators for assessing the environmental potential of a manufacturing enterprise. *Ekonomika i suspilstvo, 9, 853-858.*

12. Babchynska, O. I. (2020). Tools for forming an environmental management mechanism in modern conditions. *Efektyvna ekonomika*, (10). https://doi.org/10.32702/2307-2105-2020.10.52

13. Mykhailova, M. D., & Kostenko, O. K. (2016). Advantages and disadvantages of implementing an environmental management and certification system at industrial enterprises. *Ahrosvit*, *7*, 57-60.

14. Berezutskyi, V. V., Berezutska, N. L, Bohodyst, A. O., Vaskovets, L. A., Varekhovska, M., Horbenko, V. V., ..., & Chelstovska, A. (2018). *Human safety in modern conditions: monograph*. (Berezutskyi, V.V. Ed.). Kharkiv: FOP Mezina V.V. ISBN: 978-617-7577-60-6.

15. Skopenko, N. S., & Kohut, O. O. (2022). Theoretical and practical aspects of ensuring sustainable development of enterprises in modern conditions. *Efektyvna ekonomika*, (1). https://doi.org/10.32702/2307-2105-2022.1.5

16. Komandrovska, V. Ye. (2023). Theoretical and methodological foundations of the concept of sustainable enterprise development. *Ekonomichnyi Visnyk*, (4), 157-166. https://doi.org/10.33271/ebdut/84.157

17. Nyzheholenko, K. S. (2020). Theoretical and methodological approach to the development and formation of an ecologically balanced model of economic development of the agricultural sector. *Naukovyj pohliad: ekonomika ta upravlinnia*, (4), 72-78. https://doi.org/10.32836/2521-666X/2020-70-12

18. Shashyna, M. V., & Mosiichuk, D. O. (2022). Parametric characteristics of sustainable development of an enterprise. *Efektyvna ekonomika*, *3*. https://doi.org/10.32702/2307-2105-2022.3.2

19. Dubovyi, O. V. (2015). Ecology as a new philosophy in the relationship between man and nature. *Pytannia kulturolohii*, *31*, 43-48.

20. Kvitka, T. (2020). Modeling profit under conditions of man-made pollution. *Zbirnyk naukovykh prats' ChDTU. Seriia: Ekonomichni nauky*, *57*, 35-44. https://doi.org/10.24025/2306-4420.0.57.2020.206256

21. Vasenko O. H., Rybalova, O. V., Artemiev, S. R., Horban, N. S., Korobkova, H. V., Polozentsieva, V. O., Kozlovska, O. V., & Matsak, A. O. (2015. *Integral and complex assessments of the state of the natural environment: monograph*. Retrieved from http://elib.chdtu.edu.ua/e-books/4116

22. Beridze, T., Mishchuk, Ie., Baranik, Z., Galitsyna, O., & Buhra, A. (2024). Assessment of the economic security of an industrial enterprisein the paradigm of the systemic and synergetic approach. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 169-178. https://doi.org/10.33271/nvngu/2023-6/169

23. *Ecological passport* (2023). Retrieved from https://mepr.gov.ua/diyalnist/napryamky/ekologichnyj-monitoryng/ekologichni-pasporty/

24. Pedchenko, N., Birta, H., Karpenko, N., Strilets, V., & Ivannikova, M. (2024). Mathematical methods and methods of statistical information processing in scientific research methodology. *Naukovyj visnyk Poltavskoho Universytetu Ekonomiky i Torhivli. Seriia "Ekonomichni nauky"*, *3*(113), 89-95. https://doi.org/10.37734/2409-6873-2024-3-12

Моделювання етіології ефектів впливу екологічного стану регіону на діяльність підприємств

О. В. Роженко[1], *Д. Лабанаускайте*[1], *Т. М. Берідзе*[*2], *З. П. Бараник*[3], *О. В. Галіцина*[3], *А.В. Бугра*[2]

1 – Клайпедський університет, м. Клайпеда, Литовська Республіка

2 – Криворізький національний університет, м. Кривий Ріг, Україна

3 – Київський національний економічний університет імені Вадима Гетьмана, м. Київ, Україна

[*] Автор-кореспондент e-mail: beridzet2016@gmail.com

Мета. Дослідити й проаналізувати вплив довкілля на функціонування підприємств у регіональному розрізі. Сформувати інтегральний показник техногенної забрудненості задля оцінювання у цифровій формі впливу характеристик навколишнього середовища на показники діяльності підприємства на територіальному рівні.

Методика. Дослідження ґрунтувалися на системно-синергетичному підході, а саме формуванні інтегрального показника техногенної забрудненості. Методи статистичного аналізу – для практичного опрацювання впливу навколишнього середовища на економічні й соціальні аспекти діяльності підприємств. Елементи аналогій, порівняння – для визначення сутності оцінювання ефектів впливу довкілля з точки зору показників діяльності підприємства. Методологія економіко-математичного моделювання – для розробки моделі оцінювання й аналізу впливу стану довкілля на вартісні показники функціонування підприємства й формування

управлінських рішень. Графічний метод – для наочного подання опрацьованого дослідження.

Результати. Доведена доцільність і необхідність на засадах моніторингу стану довкілля застосовувати методи математичного моделювання щодо впливу техногенних складових на функціонування підприємств. Математично доведено, що існує оптимальна величина витрат на природоохоронну складову. Візуалізація й геометрична інтерпретація отриманих результатів моделювання підтвердили їхню дієвість.

Наукова новизна. Запропоновано інтегральний показник техногенної забрудненості, що дозволяє у цифровій формі оцінити одночасний негативний вплив забруднюючих речовини на показники діяльності підприємства й соціальну складову регіону. Відмінність рекомендованого показника полягає в «згортанні» інформації щодо кожної забруднюючої речовини, яка впливає на характеристики навколишнього середовища. Набули подальшого розвитку методичні підходи щодо визначення залежності інтенсивності захворювання відносної кількості робітників регіону від концентрації забруднюючих речовин.

Практична значимість. Проведене дослідження впливу забруднюючих речовини на показники здоров'я населення Криворізького регіону. Показано, що діяльність гірничозбагачувальних підприємств регіону передбачає витрати на захист довкілля. Аналіз отриманої математичної моделі дозволив отримати кількісні показники взаємного впливу екологічного стану довкілля й показників діяльності підприємств Криворізького регіону. Дослідження засвідчили перспективність використання одержаних результатів під час формування управлінських рішень щодо витрат на покращення стану навколишнього середовища.

Ключові слова: *підприємство, Криворізький регіон, екологія, математична модель, інтегральний показник*