UDC 338.2: 330.42: 504.03

https://doi.org/10.33271/nvngu/2021-5/118

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ECOLOGICAL AND ECONOMIC MANAGEMENT OF INNOVATION ACTIVITY OF ENTERPRISES

Purpose. To analyze the current state of innovation and environmental projects, to develop management strategies and algorithms for project environmental and economic management in subsoil use, to propose a mathematical model of the system of perception and support of solutions for effective environmental and economic management.

Methodology. Different methods of cognition were used for scientific research – both general and special. Analytical study on the state and realities of innovation in Ukraine in general and in particular in the mining industry, identification of trends in world practice were conducted based on using the methods of content analysis, quantitative and qualitative comparison. Methods of scientific abstraction and systematization were used to develop strategies and basic algorithm of project environmental and economic management in subsoil use. Mathematical methods were used to develop a mathematical model and coordinate it with the developed algorithm of project environmental and economic management for subsequent use in the system of perception and support of decisions.

Findings. A systematic approach to the definition of management strategies and an algorithm of project environmental and economic management for the implementation of effective economic and environmental management of mining enterprises is proposed. A mathematical model designed for use in the system of perception and support of decisions for effective environmental and economic management has been developed. An analytical study on the state of innovation in Ukraine in general and in particular in the extractive industry has been conducted. This provided an opportunity to identify trends in the dynamics of change regarding the introduction of innovations and identify the causes of existing trends.

Originality. The study identified threatening trends in the practice of introducing innovation. To solve production and scientific problems in the presence of significant challenges, new tools for finding optimal solutions in the environmental and economic management of subsoil use were proposed. Using a systematic approach, a mechanism for selecting strategies, an algorithm of project environmental and economic management and an original mathematical model have been proposed.

Practical value. The results of the study can be used both to create new tools for information support of environmental and economic management, and by scientists and practitioners to develop effective solutions for the management and implementation of innovative projects in subsoil use.

Keywords: *innovations, economic efficiency, environmental and economic management, mining enterprises*

Introduction. The urgency of the topic is due to the fact that Ukraine is among the top ten countries in terms of mineral reserves, and in terms of explored resources of iron-containing minerals it ranks first.

Today, the number of deposits under development is ~ 5,000. The share of iron ore export in total exports is more than six percent. Revenues to the state budget for subsoil use account for more than 5 % of the country's revenues (State Statistics Service of Ukraine, 2020). But the use of outdated technologies of the extractive industry causes an increase in the man-made load on the environment, due attention to which has not been paid for more than a century of intensive development of minerals in Ukraine.

The use of outdated methods leads to the fact that ≥ 50 % of salts, ≥ 40 % of coal, ≥ 25 % of metal-bearing ores are not extracted from deposits (State Statistics Service of Ukraine, 2020), ~ 2/3 of the extracted minerals are delivered to dumps [1].

This results not only in direct economic losses but also in long-term environmental threats, raising the cost of production with increasing environmental fines.

Literature review. In Pavlychenko's article [2] methodological approaches to an estimation of technogenic influence of accumulation of wastes of the mining industry are offered. Shmygol, et al. [3] created a mathematical model for predicting environmental pollution by sulfur-containing emissions, taking into account the condensation and evaporation of liquid sulfuric acid by energy and mining companies, which is a significant innovative breakthrough in this area. Popovych and Voloshchyshyn [4] studied the economic and environmental consequences of man-made impact of ash components and their sulfur content on the environment. Chetveryk, et al. [5] created a mathematical model that predicts geomechanical processes under man-made load which allows estimating the land area under the accumulated waste and thus indicating the required rate of their formation and enrichment. Arsawan, et al. [6] studied innovative approaches to optimizing the sealing of mine dumps with different layers of soil for further land recultivation and prevention of salinization. Tulaydan, et al. [7] analyzed the mechanisms of pollution of wastewater with nitrogen and phosphorus dumps and proposed methods for removing harmful substances. Melnyk [8], Yadav and Jamal [9] point out that the most noticeable impact of the mining industry on the environment is air pollution, in particular, suspended particles of dumps, which requires innovative approaches to control and management of pollution processes. Yadav and Jamal [9] modeled the risk of inhalation of solid particles from open mines and thermal power plants which is studied in detail in [10]. Gautam, et al. [11], in this regard, points out that increasing the depth of mines leads to increased damage to miners by inhaling solids, due to improper ventilation and insufficient attention to modeling air flows. Shirin, et al. [12] and Carvalho [13] study the degree of propagation with air flows of solid particles depending on the reduction in size and slope of the dumps. Krichevsky and Levchenko [14] and Hutsaliuk, et al. [15] studied the impact of technology on reducing the man-made impact of the industry.

Thus, the cited references indicate the presence of certain trends, namely the increase in modern methods of mathematical modeling of the formation and impact on humans and the environment of harmful substances, solid fine particles, undesirable geomechanical processes in mining and subsequent use of minerals; accumulation of waste in energy, metallurgy and other industries.

There is also a tendency to algorithmize these processes and use modern information technologies to optimize them.

Unsolved aspects of the problem. The review of literature sources indicates a thorough study on environmental and economic management (EEM) by the scientific community.

At the same time, a review of recent research proves the need for Ukraine to implement algorithm management, create and use new mathematical models to optimize and find optimal solutions, implement new approaches to automated decision-making systems and support in difficult economic conditions. The urgency of the introduction of digital technologies in mining is indicated by the experience of mining companies in developed countries in this direction.

In addition, the present is characterized by rapid changes in business conditions. Economic, political, and military threats pose new challenges. Therefore, the task is to update the analytical study on the state and realities of innovation in Ukraine in general and in particular in the mining industry. Especially, since there is a tendency to reduce primarily environmental innovation projects in difficult circumstances in the economy.

The purpose of the article is to analyze the current state of innovation and environmental projects, to develop management strategies and algorithms for project environmental management in subsoil use, to propose a mathematical model of the system of perception and support of solutions for effective environmental management.

Methods. Different methods of cognition were used for scientific research – both general and special.

Analytical study on the state and realities of innovation in Ukraine in general and in particular in the mining industry, identification of trends in world practice and the results of analysis of scientific works in this area were conducted using methods of content analysis, quantitative and qualitative comparison.

Methods of scientific abstraction and the use of a systems approach were used to develop strategies and the basic algorithm for project environmental and economic management in subsoil use.

Mathematical methods from different fields of mathematics were used to develop a mathematical model and coordinate it with the developed algorithm of project environmental and economic management for subsequent use in the system of perception and support of solutions for effective environmental and economic management.

Results. Ukraine's position on the level of innovation is quite significant.

Thus, according to the Global Competitiveness Index, Ukraine ranks *92nd* in 2020 and according to the Innovation Capacity Index takes *58th* place, and according to the ICT Implementation Index – *77th* place, *60th* place – according to the driver "Innovative opportunities" (The Global Competitiveness Report 2019. World Economic Forum).

According to the Global Innovation Index, which is 36.32 for Ukraine, Ukraine ranked *45th*, ahead of Romania (*46th*) and the Russian Federation (*47th*).

At the same time, the dynamics of change in the Global Innovation Index of Ukraine (Fig. 1) is disappointing, as the results of the analysis show – the last two years there has been a steady decline and the rate of decline is significant.

The Innovation Union Scoreboard in 2016 was 28.9 %, decreasing by more than 1 % annually. According to this trend of change Innovation Union Scoreboard Ukraine is classified as a group of "slow innovators". According to the driver "Technology and Innovation" which covers two groups of indicators – "Technological basis" and "Ability to innovate" – Ukraine ranks *75th* and *68th*, respectively (The Global Innovation Index, 2020).

The trend of change in positions on these indices, primarily the trend of the Global Innovation Index for 2018–2020 (Fig. 1) is confirmed by the dynamics of changes in related indices, in particular the Investment Index (Fig. 2) for 2017–2020. Data on the Investment Index for analytical research were used at the end of each first half of the year. The coincidence in the time of the beginning of the deterioration of the Global Innovation Index and the Investment Index is characteristic [16].

These trends are confirmed by the analysis of statistical data.

Thus, a comparative analysis of the cost of innovation of industrial enterprises in the areas of innovation (Fig. 3) indicated that, despite some hikes in the change in the indicator of "costs for the purchase of machinery, equipment and software" in 2017, there is, according to this indicator, a certain increase in the cost (unadjusted to current inflation) of innovation in other positions (State Statistics Service of Ukraine, 2020). But, as the results of the analysis show, the dynamics of spending on innovation, taking into account inflation under other items, namely, "internal GDR", "external GDR" is disappointing. According to the item "acquisition of other external knowledge" the situation is even worse – there is a long-term trend to reduce costs (Fig. 3) (State Statistics Service of Ukraine, 2020) [16].

The comparative analysis of the dynamics of implemented innovative and resource- and nature-conserving projects

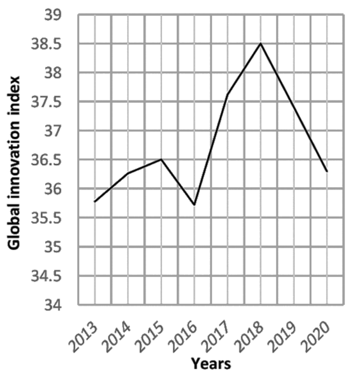

Fig. 1. Dynamics of change in the Global Innovation Index of Ukraine

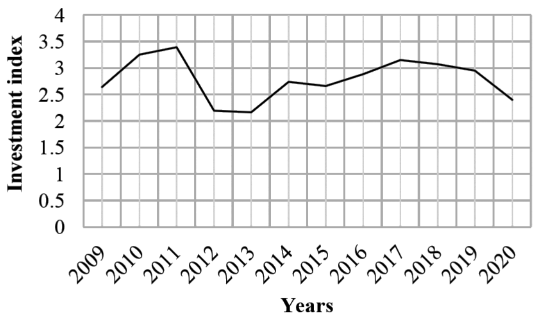

Fig. 2. Dynamics of change in the Investment Index

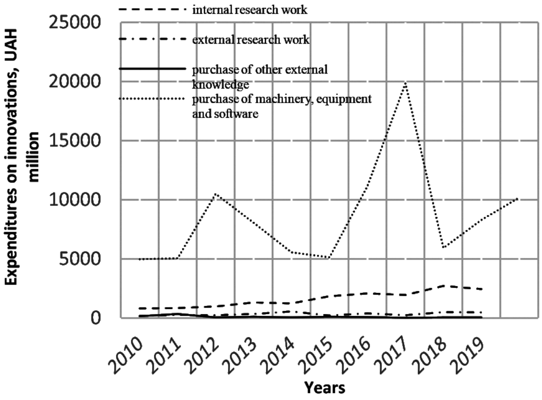

Fig. 3. Dynamics of costs for innovations of industrial enterprises in the areas of innovation

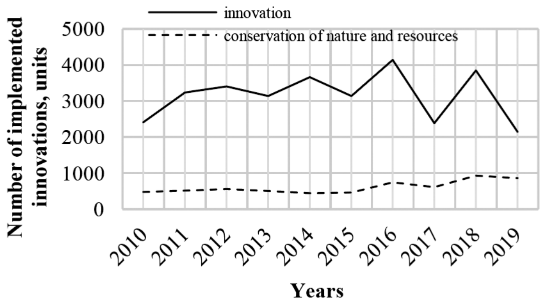

Fig. 4. Dynamics of implementation of innovative and resource- and nature-saving projects

(Fig. 4) in quantitative terms, indicates, on the one hand, a reduction in the number of innovative projects to the level of 2013, on the other hand, a certain increase in resource- and nature conservation projects, which is particularly evident in the dynamics of reducing the ratio of these projects to their numbers (State Statistics Service of Ukraine, 2020).

The tendency to reduce attention to research and R&D is also traced in the analysis of data (State Statistics Service of Ukraine, 2020), processed and presented in Fig. 5. This figure clearly shows the reduction in the share of expenditures on research and development in GDP over the past decade.

A comparative analysis of the intensity of R&D expenditures by areas of economic activity (Table 1) compiled according to the European Business Association on regular surveys of business representatives (European Business Association. Research and analytics, 2021) indicates that this indicator for foreign trade "Mining and quarrying" is relatively

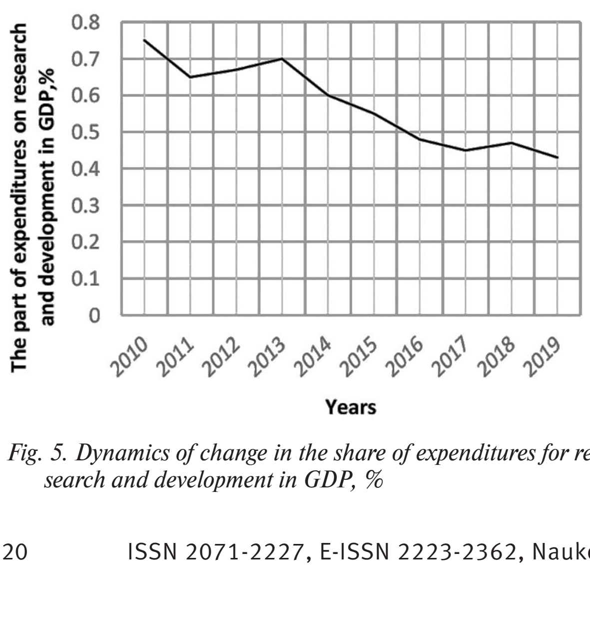

Fig. 5. Dynamics of change in the share of expenditures for research and development in GDP, %

Table 1

R&D expenditures by areas of economic activity

Classification of economic activities' (CEA) code	Name of economic activity	R&D costs (% of value added of economic activities)
05–09	Mining and quarrying	0.8
19	Manufacture of coke and refined petroleum products	1.17
20	Production of chemicals and chemical products	6.52
24	Metallurgical production	2.07
35–39	Electricity, gas, steam and conditioned air supply, water supply; sewerage, waste management	0.35
41–43	Construction of buildings, construction of structures, specialized construction work	0.21

comparable to relevant indicators, in some ways, similar in type of industry.

A more detailed analysis of the dynamics of capital investment in tangible assets in different areas of activity on foreign trade "Mining and quarrying" (Fig. 6) indicates not only a significant gap in volume between them, but in opposite trends. Thus, with a rapid increase in investment in iron ore mining, a moderate but steady increase in investment in coal mining, there is a tendency to reduce investment in stone, sand and clay (NACE Code 08.1) (State Statistics Service of Ukraine, 2020).

At the same time, a comparison of trends in capital investment in tangible assets (Fig. 6) and intangible assets (Fig. 7) in

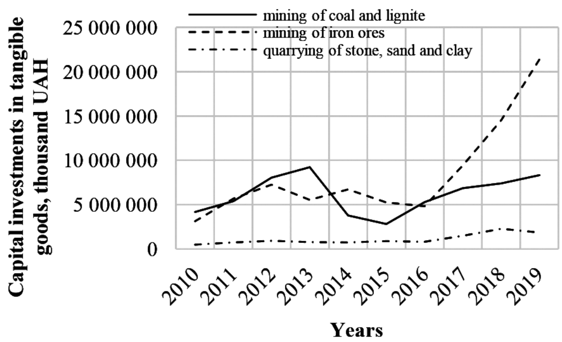

Fig. 6. Dynamics of investments in tangible assets, thousand UAH

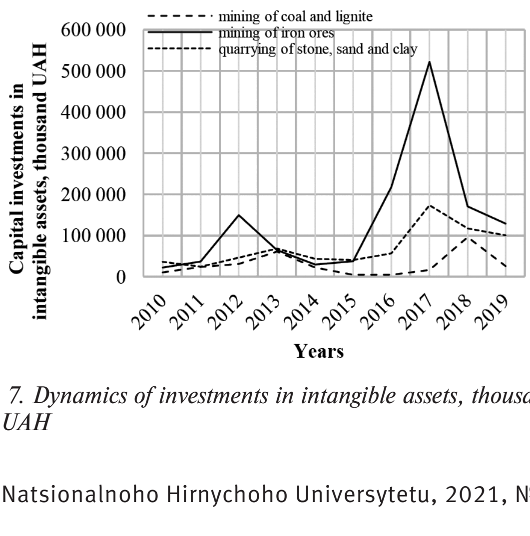

Fig. 7. Dynamics of investments in intangible assets, thousand UAH

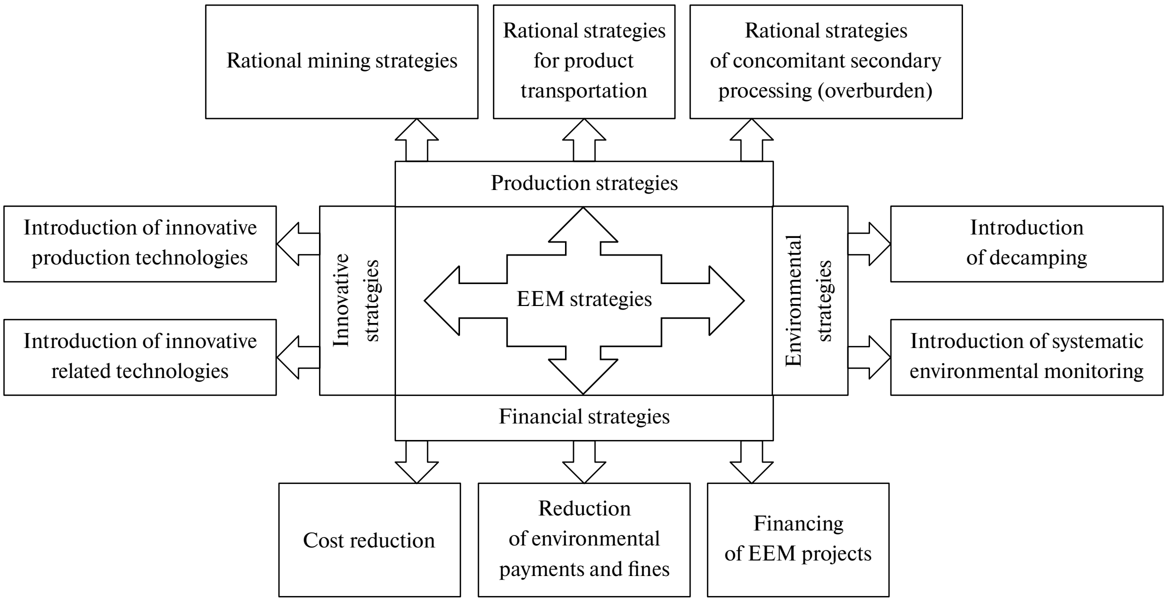

Fig. 8. Strategies of ecological and economic management in the mining industry of Ukraine

the same areas of activity on foreign trade "Mining and quarrying" indicates opposite trends in their changes in years. Moreover, these trends coincide, with a certain lag in time, with the trends of change in the Global Innovation Index of Ukraine (Fig. 1) and the Investment Index (Fig. 2).

Comparative analysis of the dynamics of investment in intangible assets by type of activity in the "Mining and quarrying" points to the rapid decline in investment in iron ore mining, a moderate decrease in investment in coal mining and a sharp decline in investment in mining and sand, stone and clays (CEA 08.1) (State Statistics Service of Ukraine, 2020).

This leads to the need to streamline the strategies of environmental and economic management (EEM) of mining and processing enterprises of Ukraine (Fig. 8) and to develop an EEM algorithm (Fig. 9).

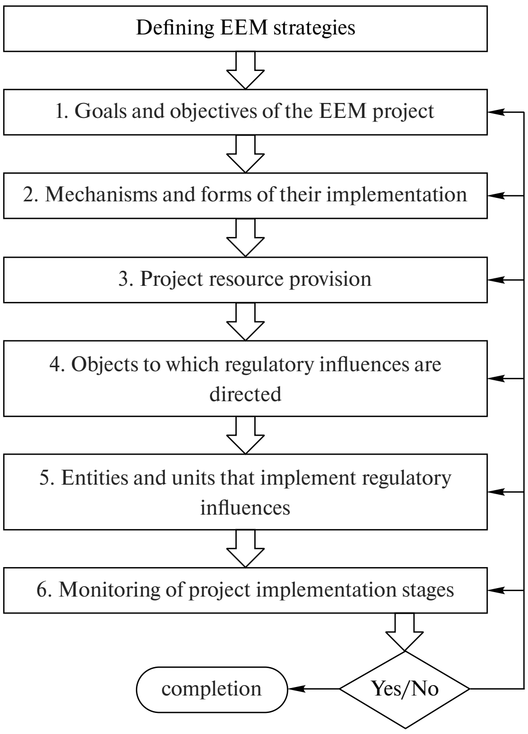

Fig. 9. Algorithm of project economic and ecological management

The management of enterprises should, in accordance with the areas of activity – environmental, innovative, financial, production, allocate a range of tasks for the use of project management tools, determine the goals and objectives of each project, mechanisms and forms of implementation of these goals, resource provision of each project by its stages, projects and units that implement regulatory influences and ensure reliable monitoring (Fig. 9).

Fig. 8 presents a scheme for the formation of strategies for economic and environmental management of mining and processing enterprises in certain areas of activity, which is formed using a systematic approach.

In this case, the use of a system approach means the need to have all the properties of the system in a comprehensive approach to the formation of computer strategies of mining enterprises: emergence, inertia, integrity, and so on. That is, it is impossible to single out only production strategies or environmental ones. All these strategies affect each other and, whether they form a synergistic effect of strengthening the implementation of innovations or, in the case of isolating individual strategies and not coordinating them, weakening the position of the enterprise.

The urgency of forming EEM strategies of mining and processing enterprises in certain areas of other approaches to innovation management is due, in particular, that the analysis of the level of funding for innovation processes in industry, in particular in the mining industry, indicates the impossibility of expanded production and technological restructuring subsoil use using only the existing research potential of the industry. The decisive factor in this is the limited own financial resources of enterprises and the lack of opportunities for external borrowing for environmentally friendly innovative projects. With expensive credit resources, low-cost projects are out of time.

That is, the existing objective reasons for the difficulty of innovation processes in the mining industry are due, in particular, to the lack of investment financial resources and excessive macroeconomic risks for investors.

The main dichotomy in the formation of EEM problems is the presence of a certain gap in social priorities for environmental protection and economic feasibility of innovative processes of enterprises.

This dichotomy is exacerbated by the lack of transparency of innovation programs and virtually no access to them by both outside experts and NGOs.

The lack of developed regulatory and legal mechanisms of environmental and economic management in subsoil use and inconsistency of regulations in this area often disorient management in forming an innovative concept of the enterprise.

In addition, the effectiveness of the formation of the innovative concept of enterprises is exposed to the disproportion of the levels of research potential and the real economic condition of the mining industry.

These factors necessitate the detailing of strategic approaches to environmental and economic management of mining and processing enterprises and the formation of project computer algorithms.

Management of enterprise innovation, in particular, in the environmental field should be based on the following basic principles:

- ensuring the economic growth of the extractive industry with the effective implementation of environmental innovations;
- implementation of innovative projects is not an end in itself, but a response to existing challenges;
- innovative projects are a tool for solving problems posed by EMM;
- implementation of innovative projects should be accompanied by a reduction in production costs;
- implementation of innovative projects should be adjusted with marketing activities and work organization;
- EEM should constantly monitor and evaluate both the impact of production processes on the environment and activities in this area of national and foreign competitors, using their experience in this area.

Implementation of the algorithm for the effective operation of the support and decision-making system of EMM requires the formation of a mathematical model.

Mathematical modeling of EEM is complicated not only by the many criteria nature of the EEM problems of the mining industry, but also by the multiplicative nature of the local objective functions of individual subtasks. These local objective functions form a multi-component integrated target function for innovative projects.

Regarding terminology. The local objective function in this case is a function that forms the purpose of the local task in solving the general problem described by the integral objective function of the EEM. Thus, the economic components (financial, budgeting, marketing, investment, and others) are local tasks, as well as the achievement of certain environmental goals – by environment (air, surface water), by area of damage, by age and occupational risk groups, and so on.

Mathematical modeling of such local objective functions is different in factors: quantitative and qualitative, rational numbers and fuzzy quantities, stochastic and deterministic, which are not only measured in different systems of units but also described by different sections of mathematics. That is, formally, they are not subject to joint mathematical processing, even simple arithmetic operations (addition, subtraction, etc.). Therefore, we used and modified the approaches recommended in Latysheva [17], Salas-Molina [18], Kotenko [19], Nitsenko [20].

The first step, in accordance with the algorithm (Fig. 9), is to determine the purpose of the EEM. This purpose must unambiguously define the integral objective function (φ).

The second step in the problem by the method of decomposition highlights the subtasks of the EEM.

These subtasks are defined by certain sets of impact parameters, which are sorted by the degree of impact of factor analysis.

In the third step of the mathematical model implementation, the influencing factors are divided into groups: quantitative, qualitative, rational numbers, fuzzy quantities, stochastic, deterministic, etc.

Influencing factors ϑ, divided into groups ($i \in 1, 2, 3, ..., n$) in accordance with the local objective functions to solve each of the individual local problems may, in the general case, intersect

$$\vartheta \supset \vartheta_1, \vartheta_2, \vartheta_3, ..., \vartheta_n, \quad (1)$$

where $\vartheta_1, \vartheta_2, \vartheta_3, ..., \vartheta_n$ are groups of factors influencing local objective functions that can be interpreted as vectors in the parameter space [19].

Obviously, neither the set ϑ, which, in the terminology of this branch of mathematics, is a superset, nor, respectively, the subsets $\vartheta_1, \vartheta_2, \vartheta_3, ..., \vartheta_n$, cannot have empty component sets. Then

$$\vartheta_1, \vartheta_2, \vartheta_3, \dots, \vartheta_n \to \begin{cases} \in \vartheta \\ \neq \varnothing. \\ \cup \vartheta \end{cases} \quad (2)$$

All subsets $\vartheta_1, \vartheta_2, \vartheta_3, ..., \vartheta_n$, have the property of nontriviality. Then the following condition will be fulfilled

$$\vartheta - \sum_{1}^{n} \vartheta_i = \varnothing. \quad (3)$$

By the steepest ascent method we find the optimal values of local objective functions as corresponding vectors in the parameter spaces $\vartheta_1, \vartheta_2, \vartheta_3, ..., \vartheta_n$

$$\varphi_i \to \textit{extr}. \quad (4)$$

The next step is to determine the value of the integral objective function φ, which can be interpreted as a tensor [19], [20], according to the formed set of the best values of φ_i To do this game theory can be used, in particular, games with a nonzero sum (Nash method) in the case of a limited number of groups of parameters, or, for large amounts of data, methods of tensor analysis [19].

Further, to compare the achieved result with the public interest, in order to minimize the technogenic impact on the environment, it is possible to compare a step-by-step approximation to the best value of the objective function with Harrington's desirability function.

Harrington's desirability function is a generally accepted and well-known generalized criterion for assessing the environmental impact of industrial, in particular mining, enterprises. But, in this case, the main attention should be focused not on the specific meaning of Harrington's function, but on the tendency of its change with step-by-step changes of the integral objective function.

Harrington's function is defined as follows

$$d = \exp(-e^{-\omega}), \quad (5)$$

where d is the value of the desirability of the level of man-made impact on the environment ($d \in (0, 1)$); ω is a response function that is variable depending on the circumstances of man-made impact and is usually recorded on a certain conditional scale.

For the expert, the dynamics of changes in Harrington's function will characterize environment changes in man-made environmental impact in the implementation of EEM without detailing the policy of enterprises and the whole set of environmental and economic information.

The developed mathematical model allows finding the best value of the integral objective function not only to fix the optimal values of local objective functions, but also to determine the mechanisms of implementation of local problems, because it is now possible to form strategies for the best management of group factors ($i \in 1, 2, 3, ..., n$).

That is, with a formal approach, to proceed to the implementation of paragraph 2 of the algorithm of project economic and environmental management (Fig. 9).

The next step in the implementation of the proposed algorithm is to determine the necessary and sufficient resources of the project (paragraph 3 of the algorithm presented in Fig. 9), determine the regulatory impacts on project objects (paragraph 4 of the algorithm presented in Fig. 9), set tasks for units (paragraph 5 of the algorithm presented in Fig. 9).

Thus, the EEM management can implement optimal innovation strategies in the best way.

The proposed system approaches, project management algorithms and the mathematical apparatus of optimal management for EEM decision support systems will increase the efficiency of environmental and economic management of the implementation of innovative response of mining companies to challenges.

Conclusions. The analysis revealed the comparison of many sets of statistics, in particular, on indicators of competitiveness and indices of international organizations, investment, investment costs of industrial enterprises in the areas of innovation, etc., the formation of recent trends to reduce innovation and investment activity.

At the same time, the share of resource- and nature-conservation projects in the total number of innovations in recent years has been increasing, as indicated by the dynamics of the ratio of these projects in their numbers.

As a result of the study, it was found that there is an increase in investment in tangible assets in certain areas of extractive industries. At the same time, there is a significant reduction in investment in intangible assets in the same areas of activity, which emphasizes the negative trends in the innovative development of the industry, which have been formed in recent years.

The determining imperative factor, as established by the study, is the constant tendency to reduce the share of spending on research and development in GDP.

In addition to macroeconomic factors, there are certain systemic reasons for the formation of trends to reduce innovation processes, in particular:

1. There is a gap in social priorities and the focus of innovation processes of mining enterprises.

2. Insufficient level of transparency of innovation programs and virtually no access to them by outside experts and NGOs.

3. There is an inconsistency of the regulatory framework of the EEM in subsoil use and the areas of practical activity of enterprises.

4. There is a significant disproportion between the levels of research potential and the real economic condition of mining enterprises.

To implement an effective EEM, a systematic approach to the formation of EEM strategies has been proposed, the algorithm of the design EEM and a mathematical model for the EEM decision support system have been developed.

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Еколого-економічне управління інноваційною діяльністю підприємств

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Мета. Провести аналіз поточного стану впровадження інновацій і природозахисних проектів, розробити стратегії менеджменту та алгоритм проектного еколого-економічного управління в надрокористуванні, запропонувати математичну модель системи сприйняття й супроводження рішень для ефективного еколого-економічного менеджменту.

Методика. Для проведення наукового дослідження були використані різні методи пізнання – і загальні, і спеціальні. Аналітичне дослідження стану й реалій упровадження інновацій в Україні в цілому і, зокрема, у добувній промисловості, виявлення тенденцій у світовій практиці проведено за використання методів контент-аналізу, кількісного та якісного порівняння. Методи наукового абстрагування й використання системного підходу застосовано для того, щоб розробити стратегії та базовий алгоритм проектного еколого-економічного менеджменту в надрокористуванні. Математичні методи застосовані для розробки математичної моделі та узгодження її з розробленим алгоритмом проектного еколого-економічного менеджменту для наступного використання в системі сприйняття й супроводження рішень.

Результати. Запропоновано системний підхід до визначення стратегій менеджменту та алгоритм проектного еколого-економічного менеджменту для реалізації ефективного економіко-екологічного управління підприємствами гірничої галузі. Розроблена математична модель, призначена для використання в системі сприйняття й супроводження рішень задля ефективного еколого-економічного управління. Проведене аналітичне дослідження стану впровадження інновацій в Україні в цілому і, зокрема, у добувній промисловості. Це надало можливість визначити тенденції в динаміці змін щодо впровадження інновацій і виявити причини наявних трендів.

Наукова новизна. У ході дослідження виявлені загрозливі тенденції щодо практики впровадження інновацій. Для вирішення виробничих і наукових задач за наявності значних викликів запропоновані нові інструменти пошуку оптимальних рішень в еколого-економічному менеджменті надрокористування. За використання системного підходу запропоновані механізм вибору стратегій, алгоритм проектного еколого-економічного менеджменту та оригінальна математична модель.

Практична значимість. Результати дослідження можуть бути використані як для створення нових засобів інформаційного супроводження еколого-економічного менеджменту, так і науковцями та практиками для вироблення ефективних рішень при управлінні та впровадженні інноваційних проектів у надрокористуванні.

Ключові слова: *інновації, економічна ефективність, еколого-економічний менеджмент, підприємства гірничої галузі*

Recommended for publication by O. Halytskyi, Doctor of Economic Sciences. The manuscript was submitted 07.03.21.