DOI: 10.55643/fcaptp.1.60.2025.4606

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Received: 15/10/2024
Accepted: 29/01/2025
Published: 28/02/2025

ECOLOGICAL MODERNISATION OF PRODUCTION FOR INNOVATIVE DEVELOPMENT OF INDUSTRIAL ENTERPRISES

ABSTRACT

Rapid ecological modernisation of production and implementation of innovative environmental solutions are crucial conditions for ensuring the competitiveness of industrial enterprises in the context of the implementation of the decarbonisation policy, toughening environmental requirements for anthropogenic impact on the environment and high risks in the energy sector. It has been established that ecological modernisation helps to reduce anthropogenic impact on the environment, increase the efficiency of the use of raw materials, improve energy efficiency, and introduce the best available technologies and production methods.

Limited investment resources, short implementation time and high-security risks necessitate improving the efficiency of environmental management in terms of environmental investment. The purpose of the study is to develop proposals for improving the environmental management of industrial enterprises by developing an optimisation model for assessing the effectiveness of ecological modernisation and introducing innovative environmentally friendly technologies into production, which serves as an information base for making informed management decisions.

An optimisation modelling of investment in ecological modernisation is proposed, which will ensure the most efficient allocation of available resources. It is determined that the preparatory stage of investing in ecological modernisation includes an inventory of the quantitative and qualitative condition of production modules, an environmental audit of anthropogenic impact, an assessment of the potential for introducing the best technologies and management methods, and the development of alternative scenarios.

An integral indicator of the efficiency of ecological modernisation of production is proposed, which consists of two components: the index of return on investment and the index of environmental categories of impact. Optimisation modelling of efficiency of ecological modernisation allows identification and assessment of alternative scenarios of investing in ecological modernisation and selection of the best one. The practical use of optimisation modelling of ecological modernisation efficiency will help to improve the efficiency of environmental management and make informed decisions.

Keywords: enterprise, industry, environment, production, efficiency, technology, environmental modernisation, environmental management, environmental investment, innovative development

JEL Classification: D25, D24, M11, P28, Q01

INTRODUCTION

Ukraine's integration into the European economic area and the implementation of the concept of green post-war recovery of Ukraine are accompanied by new challenges and prospects for the operation and development of industrial enterprises. Decarbonisation of production and greening of technological processes remains an important global trend. Despite the military invasion, Ukraine is adhering to its approved strategic course of membership in the European Union and is actively harmonising its legislation with European norms and standards. Particular attention is paid to environmental regulations, the protection of which is recognised as a priority task of the European community.

The activities of industrial enterprises will be significantly affected by the implementation of Directive 2010/75/EU 'On Industrial Emissions (Integrated Pollution Prevention and Control)' [1]. The Directive provides for the introduction of an integrated permit for industrial enterprises for emissions and discharges of pollutants, waste generation, etc., as well as for the use of the best available technologies and management methods. These are the most effective technologies from the point of view of environmental protection, which are developed taking into account the specifics of industrial production and the economic feasibility of implementation. Thus, in the near future, safety and environmental efficiency will determine the competitiveness of industrial enterprises in the European and national markets [2].

In these circumstances, ecological modernisation of industrial processes and the introduction of innovative environmental solutions are of particular relevance. They should be aimed at reducing the anthropogenic impact of production, increasing the efficiency of the use of raw materials and supplies, and ensuring the energy independence of business entities.

LITERATURE REVIEW

The theoretical foundations of eco-innovative development of industrial enterprises were revealed by A. Omelchenko. He noted that eco-innovative growth will allow enterprises to ensure continuous economic development and be competitive in the market and will serve as the basis for the transition of the domestic economy to economic growth, ensuring the country's economic independence [3]. B. Kosovych substantiated the role of industrial greening in overcoming the risks of global ecosystem disruption and stabilising global climate threats [4]. The author revealed the key areas of greening entrepreneurship and outlined some tools for promoting the innovative development of green entrepreneurship in Ukraine.

Stepanenko A. and Omelchenko A. revealed the environmental imperatives of modernisation and the concept of harmonisation of economic growth and improvement of the quality of the environment and proposed a structure of forms of ecological modernisation [5]. Zaitseva L. argued the need for ecological modernisation through the targeted introduction of new social practices to reduce the negative impact of humanity on the environment through the 'green growth' of the economy [6].

Huber J. and Mol Arthur P.J. described the key role of ecological modernisation in bringing about sustainable development, industrial transformation and environmental reform [7, 8]. Martin Jänicke and Helge Jörgens substantiated the shortcomings of ecological modernisation. They have determined the structural stability of the economy, modernisation of infrastructure, rational land use, and consumer changes to stimulate ecological modernisation. To implement these tasks, the authors proposed the implementation of the strategy of ecological modernisation 2.0, which includes long-term investments in modernisation, cooperation, and financial compensation instruments. [9]. Rolf Lidskog Ingemar Elander analysed the ecological Modernization in Sweden [10].

Many scientists have devoted their research to studying the impact of environmental modernisation and the implementation of environmental innovations on the economic efficiency of businesses and the national economy as a whole. Bugden D. investigated the connection between technological innovations and their impact on the environment. He performed a panel regression analysis using data on environmental technologies in 35 countries from 1982 to 2016. The scientist established that the introduction of environmental technologies does not significantly mitigate the impact of economic activity on the country's ecological footprint. At the same time, the direct impact of patents is to increase, not decrease, a country's ecological footprint [11].

Kupalova H., Bukharina L., Goncharenko N., Demianenko K. unified methodology for assessing the competitiveness of business entities in the context of ecological management has not yet been developed. The article proposes to assess the competitiveness of confectionery enterprises on the basis of integral index problems [12].

Eva M. García-Granero, Laura Piedra-Muñoz, and Emilio Galdeano-Gómez proposed a multivariate measurement model for environmental innovation in the agriculture and food industry. The model makes it possible to assess the connection between the effectiveness of ecological innovations and ecological corporate culture, drivers of commercial orientation. The developed model was tested using the partial least squares method based on data collected from a sample of 93 companies located in southeastern Spain [13]. Duanyang Geng, Kee-hung Lai, and Qinghua Zhu investigated how the implementation of eco-innovations affects company performance and environmental management. The authors established that internal source reduction is helpful for technology and management innovation to deliver environmental performance [14].

Environmental modernisation of logistics has become an important area of research. Thus, N. Kalycheva studied the environmental component of the management of enterprises in the field of transport to ensure their sustainable development. The author acknowledged that the implementation of environmental modernisation of transport enterprises is currently

slow and is not always accompanied by the introduction of the latest technologies. This harms the economic activity of railway transport enterprises and does not benefit the environment [15]. G. Kupalova, N. Goncharenko, and J. Khrutba defined that for the purposes of optimising the commodity flows of the enterprises with reference to the economic and environmental factors, one should use the following models: gravity model, simulation modelling, and linear programming. Authors build a set of objective and relevant analytical data for the organisation of commodity flows; the recommendation is to use the method of linear programming while taking into account the ecological factors of both the manufacturer and the consumer [16].

Preeti Pal, P.R.C. Gopal, M. Ramkumar identified the transportation factors that affect climate change and the factors related to its preventive measures based on the 'environment', 'sociology' and 'modernity' elements of Ecological Modernization Theory [17].

It is advisable to single out scientists who have studied the peculiarities of environmental modernisation management. Thus, O. Shkarupa highlighted the theoretical foundations of ecological modernisation management of the socio-economic development of the region [18]. Gale R. proposed tracing costs and benefits according to this UNDSD methodology, which is considered a "reflexive" modernisation strategy in this article and sheds new light on cleaner production initiatives for corporate sustainability [19]. Akopov A.S., Beklaryan A.L., Saghatelyan A.K., and Sahakyan L.V. developed an information system for controlling the ecological modernisation of enterprises of the Republic of Armenia. The authors used the simulation modelling methods and implemented them using the example of industrial enterprises. The system has been developed for strategic decision-making directed at the modernisation of enterprises in Armenia. The system will be used for enterprises' ecological transformation and cleaner production [20]. Kachynska N., Prakhovnik N., Zemlyanska O., Ilchuk O., and Kovtun A. investigated environmental risk management in the context of the ecological modernisation of enterprises [21].

Despite the research that has been conducted and the important scientific results, current challenges require deepening scientific research on environmental modernisation as a factor in the innovative development of Ukrainian industrial enterprises. It took EU countries almost 30 years to reduce their emissions of pollutants and greenhouse gases significantly and reach the current level. Environmental projects implemented in all sectors of the economy were largely financed by state aid and European investment [22]. Given the limited investment resources, unpredictable security conditions, and a potentially short period of implementation of the directives, the urgent need of the hour is to develop innovative tools and solutions for the environmental modernisation of industrial enterprises in Ukraine, in particular in the environmental management system.

AIMS AND OBJECTIVES

In view of the above, the purpose of the article is to develop proposals for improving the ecological management of industrial enterprises by developing an optimisation model for assessing the efficiency of modernisation, introduction of innovative environmentally friendly technologies into production, which will facilitate making informed management decisions.

METHODS

Traditional and specific economic, mathematical and economic-logical scientific methods were used to reach the above purpose. In analysing the dynamics of air pollutant emissions by country and industry, traditional methods of economic analysis were used – comparison, time series, averages.

In order to improve the level of the ecological management of industrial enterprises, the article substantiates expediency of application of economic and mathematical modelling and uses the method of linear programming in building an optimisation model.

The index method is used to assess the effectiveness of ecological modernisation of industrial enterprises.

RESULTS

Currently, more than 50 per cent of the world's carbon dioxide emissions are produced by the economic systems of the world's largest countries – China (26.0 per cent), the United States (11.6 per cent) and India (14.3 per cent) (Table 1).

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Table 1. Dynamics of the volume and share of CO_2 in total emissions by country, 2022-2023. Note: * Compiled based on materials from Carbon Monitor. *(Source: [23])*

Country	CO_2 emissions, Mt			Share, %		
	2022	2023	increase, +/-	2022	2023	increase, +/- p.p.
China	8226.4	8503.2	276.8	20.47	31.47	11.00
USA	3702.3	3798.9	96.6	9.21	14.06	4.85
27 EU countries and the UK	2388.5	2253.4	-135.1	5.94	8.34	2.40
India	1998.5	2167.5	169.0	4.97	8.02	3.05
Germany	492.6	454.5	-38.1	1.23	1.68	0.45
Other countries	23388.8	9839.5	-13549.3	58.18	36.43	-21.75
Total	40197.1	27017.0	-13180.1	100.00	100.00	-

The relatively low level of the European Union's carbon footprint is illustrative. They were among the first to implement the strategy set out in the Kyoto Protocol and achieved a significant reduction in greenhouse gas emissions.

The industry and energy sectors are the world's 'leaders' in terms of CO_2 emissions. According to the international agency Carbon Monitor, in 2022-2023, the share of industry in total greenhouse gas emissions was 30.75%, and the share of the energy sector was 39.53% (Table 2).

Table 2. Dynamics of the volume and share of CO_2 in total emissions by sectors of the global economy in 2022-2023. Note: * Compiled based on materials from Carbon Monitor. *(Source: [23])*

Sector of economy	CO_2 emissions, Mt			Share, %		
	2022	2023	increase, +/-	2022	2023	increase, +/- p.p.
Domestic aviation	237.5	266.8	29.3	0.59	0.99	0.40
Transport	9765.3	4970.1	-4795.2	24.29	18.40	-5.89
Industry	16646.5	8308.1	-8338.4	41.41	30.75	-10.66
International aviation	348.6	427.7	79.1	0.87	1.58	0.71
Energy sector	10688.7	10679.3	-9.4	26.59	39.53	12.94
Residential sector	2510.5	2365.0	-145.5	6.25	8.75	2.50
Total	40197.1	27017.0	-13180.1	100.00	100.00	0.00

In 2020, the following industries had the largest negative impact on the air in Ukraine: metallurgical production – 0.729 Mt of pollutants, coke and petroleum products production – 0.0299 Mt, and mining – 0.366 Mt. The energy industry caused the release of approximately 0.849 Mt of pollutants [24].

In Ukraine, despite the gradual tightening of state environmental regulation since 2000, the level of capital investment in the environmental modernisation of industrial enterprises is insignificant. For example, according to an audit by the State Energy Supervision Inspectorate of Ukraine, over the past 10 years, only a third of coke and sinter production facilities have undergone the necessary ecological modernisation. In 2021, 68 out of 75, or 90.7%, of thermal power plants' units were operating beyond their design life. At the same time, the degree of depreciation of industrial facilities was 70% [24].

When justifying the areas and objects of green investment, the management of industrial enterprises faces the problem of choosing the best solution from a number of alternative options for environmental modernisation. With limited funding, it is important to maximise future benefits and the integrated environmental and economic impact of all potential modernisation scenarios. Economic and mathematical modelling methods are best suited for this purpose, particularly in building an optimisation model.

Formulation of the optimisation problem

Let's assume that an entity plans to carry out an ecological modernisation of production, which will include technological changes and upgrading of the company's equipment. The investment budget constraints do not allow for a complete

modernisation of all production processes at once, so it is necessary to determine how to allocate investment resources to achieve maximum production efficiency. The optimisation should take into account that the production process is multi-stage, there are several potential upgrade sites, and there are certain benefits and disadvantages to be gained from each investment scenario.

Preparation for building an optimisation model for investing in the ecological modernisation of industrial enterprises involves the following steps:

1. Conducting an inventory of all production modules (number, nomenclature, technological performance, level of physical and moral wear and tear, frequency of accidents that resulted in excessive emissions/discharges, etc.).
2. Conducting an ecological audit in terms of the intensity of anthropogenic impact of production modules (types of anthropogenic impact on the environment, compliance with emission and discharge limits, waste generation, etc.).
3. Assessing the potential for using the best available technologies and management methods.
4. Development of alternative scenarios for the ecological modernisation of production modules that have a significant anthropogenic impact are obsolete, etc.
5. Preparation of investment estimates.
6. Assessment of each scenario with regard to economic and environmental indicators and financial support.
7. Calculation of net cash flow based on the production plan.

According to the results of our research, the basic limitations of the ecological modernisation of industrial production within the optimisation model are as follows:

- a limited and defined amount of investment funds;
- the technological process allows for a fragmented modernisation, upgrading individual industrial modules (e.g., filtration equipment, kilns, mills, transport conveyors, etc., can be replaced separately at a cement plant);
- the number of industrial modules that can be modernised is determined;
- the modernisation is carried out by introducing new, more modern equipment within the existing technology or with its complete replacement;
- an industrial module can be replaced or eliminated, which will also affect the final environmental balance;
- plans for modernisation scenarios are available for each of the industrial modules.

The objective of the optimisation problem is to maximise the total environmental and economic efficiency with a limited budget for investment projects, taking into account economic and environmental efficiency for each of the modernisation scenarios.

The optimisation model is based on the efficiency of ecological modernisation of production.

$$\mathrm{E}_{EMP} = \mathrm{E}_{ecol.} * \mathrm{E}_{econom.} \quad (1)$$

The effectiveness of ecological modernisation for the *i-th* scenario consists of two components: the return-on-investment index and the overall impact index by category.

The effectiveness of ecological modernisation of production in the optimisation model is the coefficient of the independent variable and is calculated as follows

$$c_i = \mathrm{E}_{\mathrm{EMB}_i} = \frac{\mathrm{PI}}{I_{\mathrm{KB_i}}} = \frac{\frac{\sum_{t=1}^{n} \frac{CF}{(1+r_i)^t}}{\sum_{t=1}^{n} \frac{KI}{(1+r_i)^t}} * 1}{\mathrm{I}_{\mathrm{KB_i}}}, \quad (2)$$

where: $\mathrm{E}_{EMP_i}\mathrm{E}_{\mathrm{EMB}_i}$ *is the efficiency of ecological modernisation of production under the i-th scenario,* CF *- is the net cash flow of the i-th scenario in the period t,* KI *– are the capital investments of the i-th scenario in the period t,* t *is the serial number of the period,* m *is the total number of periods, i is the serial number of the scenario; n is the total number of modernisation scenarios.* $\mathrm{I}_{\mathrm{KB_i}}$ *is the overall ecosystem impact index by category for the i-th scenario.*

The objective function can be detailed as follows:

DOI: 10.55643/fcaptp.1.60.2025.4606

$$F = \sum_{i=1}^{n} \quad (3)$$

Based on the detailed objective function, we obtain the following constraints:

$$x_1 * \sum_{t=1}^{m} \frac{\mathrm{KI}_{1t}}{(1+r_1)^t} + x_2 * \sum_{t=1}^{m} \frac{\mathrm{KI}_{2t}}{(1+r_2)^t} + \ldots x_n * \sum_{t=1}^{m} \frac{\mathrm{KI}_{nm}}{(1+r_n)^m} \leq K_{total}, \quad (4)$$

$$NPV_i = \sum_{t=1}^{m} \frac{CF}{(1+r_i)^t} \geq 0, \quad (5)$$

$$I_{\mathrm{KB}_t} > 0, \quad (6)$$

$$x_1, x_2, \ldots x_n \in [0:1], \quad (7)$$

The first constraint of the model is that the amount of capital investments under each of the alternative scenarios should not exceed the total investment budget. The second constraint imposes requirements for the amount of net present value in the *i*-th scenario, a requirement that follows the logic of project analysis. It considers investment projects with a negative value of this indicator to be unprofitable. The third restriction concerns the impact index by category, which can only take positive values. The fourth constraint allows the coefficient x_i to be assigned only binary values for acceptance or rejection of the project, taking into account ecological and economic efficiency and budget constraints.

The effectiveness of ecological modernisation can be calculated for each individual industrial module's modernisation scenario, i.e., unit efficiency will be determined. If the management of the enterprise succeeds in maximising the aggregate balance of unit efficiencies under the existing constraints, it can be argued that the achieved level of overall efficiency of ecological modernisation of production under the given conditions will be optimal. Accordingly, the objective function of the problem is as follows:

$$F = c_1 x_1 + c_2 x_2 + \ldots + c_n x_n \rightarrow \max, \quad (8)$$

where F is the aggregate ecological and economic efficiency under the selected modernisation scenarios; x_i - is the scenario approval ratio ($x_i = 1 \rightarrow$ the scenario is recommended for approval, $x_i = 0 \rightarrow$ the scenario should be rejected); c_i - is the efficiency of ecological modernisation for the i-th scenario, i.e., E_{EMP_i}; i - is the serial number of the scenario; n - is the total number of modernisation scenarios.

As an example of the application of the proposed optimisation model, let us consider the situation of finding the best investment solution for a notional enterprise in the cement industry. In Ukraine, only 2 cement enterprises with a full production cycle (or a quarter of them) have switched to a modern, environmentally friendly dry cement production technology. Therefore, the development of an effective approach to selecting the best alternative for modernising production is relevant to the needs of the industry.

The model of ecological modernisation of production developed by us was tested on the basis of a notional clinker production enterprise (the main raw material for cement production) with a full technological cycle, which reflects the average performance of enterprises in the cement industry of Ukraine. Clinker production is known to have the greatest negative impact on the environment. For this reason, the management is faced with the task of choosing one production scenario from a number of alternative options for the environmental transformation of production.

Let's assume that an enterprise has the opportunity to raise a certain amount of funds that is close to the cost of a complete replacement of production technology. At the same time, there are other alternatives for investing funds and obtaining economic and environmental benefits. The optimisation model will help the company's management make an informed decision that takes into account a large number of parameters for each modernisation option.

The cement company has the following set of alternatives for the ecological modernisation of production:

- x_1- replacement of three wet-type furnaces with one dry-type furnace;
- x_2- replacement of the raw material mill with a new one with lower energy consumption;
- x_3- replacement of the old generator with high fuel consumption, which is used for drying coal, with an energy-efficient one (Table 3).

Table 3. Input data for determining a set of alternatives for the ecological modernisation of cement production.

Indicator	Unit of measurement	Value for the i-th module			Restrictions
		x_1	x_2	x_3	
$\sum_{t=1}^{m} \frac{CF_{it}}{(1+r_i)^t}$	USD million	183	49	37	-
$\sum_{t=1}^{m} \frac{KI}{(1+r_i)^t}$	USD million	150	40	31	<150
NPV_i	USD million	33	9	6	≥0
I_{KB_i}	c.u.	0.33	0.78	0.83	>0
E_{EMB_i}	c.u.	3.70	1.57	1.44	-

According to the input data, the objective function has the following form:

$$F = 3{,}7x_1 + 1{,}57x_2 + 1{,}44x_3 \rightarrow max.$$

System of restrictions:

$$\begin{cases} 150 * x_1 + 40 * x_2 + 31 * x_3 \leq 150, \\ 33 \geq 0, \\ 9 \geq 0, \\ 6 \geq 0, \\ 0.33 > 0, \\ 0.78 > 0 \end{cases}$$

As a result of solving the optimisation problem, the coefficients x_i and objective function were obtained: x_1 = 1; x_2 = 0; x_3 = 0; F = 3,69.

Thus, taking into account budgetary constraints and various economic and environmental effects of project implementation, it is advisable to replace three wet-type furnaces with one dry-type furnace. With this upgrade, the variable x_1 has acquired the value 1, whereas x_2 has had zero values. Therefore, the replacement of the raw mill with a new one with lower energy consumption and the replacement of the old generator with high fuel consumption, which is used for drying coal, with a more energy efficient one, should be rejected. With this solution to the management problem, the objective function expressed in terms of the total environmental and economic efficiency will be maximised, and its value will be 3.69 conventional units.

Thus, it is more profitable for a cement company to invest in a comprehensive modernisation of production than in a partial upgrade of production facilities. The environmental impact of switching to dry production technology will be much greater.

DISCUSSION

The necessity and goals of ecological modernisation and the provision of capital investments to reduce anthropogenic impact remain the subject of discussions among scientists. Andersen M.S. and Massa I. summarised the conceptual approaches of the theoretical justification of ecological modernisation. The authors concluded that economists consider environmental modernisation from the point of view of conventional efficiency measures [25]. In contrast to the above, scientists believe that ecological modernisation should provide radical structural changes that contribute to consistent ecological transformation. In general, we agree with the authors' statement that ecological modernisation can cover both individual industries (metallurgy, mining industry, energy, etc.) and enterprises directly. The result of environmental modernisation at the enterprise is an increase in environmental efficiency, which is reflected in the real economic dimension – a reduction in costs, resource consumption, and the formation of additional income. The cumulative ecological and economic effect of the industry enterprises forms a synergistic effect in the long term – the transformation of production, logistics, and other processes that have a minimal anthropogenic impact.

Langhelle O. justified why ecological modernisation and sustainable development cannot be equated. The author noted that ecological modernisation should be considered as a necessary but insufficient condition for sustainable development [26]. Kovalenko A.O. summarised the theoretical aspects of ecological modernisation and its role in Ukraine's transition to sustainable development. The scientist came to the conclusion that ecological modernisation is of decisive importance for the green transformation of Ukraine's economy [27]. At the same time, the author emphasised that the development of

DOI: 10.55643/fcaptp.1.60.2025.4606

specific strategic and planning tools and procedures for the implementation of ecological modernisation at different levels - national, regional and sectoral - is particularly relevant.

An optimisation model for assessing the efficiency of modernisation and the introduction of innovative environmentally friendly technologies into production, as proposed in the article, will contribute to the implementation of a sustainable environmental policy at industrial enterprises. Implementation of environmental policy in the long term will allow for the radically transformation of production, minimising the anthropogenic impact on the environment and achieving the goal of national environmental policy. Improvement of methodological tools of environmental management is important for increasing the efficiency of environmental management in Ukraine.

CONCLUSIONS

The needs of the post-war economy, new economic, technological, safety and environmental challenges, and market prospects for European integration are shaping fundamentally new conditions for the functioning and development of industrial enterprises. To ensure the sustainable economic development of industrial enterprises, one of the priority tasks of strategic management is to intensify ecological modernisation aimed at reducing anthropogenic impact, improving energy efficiency, and implementing recycling technologies.

Industrial enterprises are among the main polluters of the environment. In Ukraine, metallurgical production, coke and petroleum products, mining, and energy sectors have the greatest negative impact on the air. At the same time, the level of capital investment in the ecological modernisation of industrial enterprises is insignificant.

When substantiating the directions and objects of green investment in the environmental management system of industrial enterprises, there is a need to choose the best solution from a number of alternative modernisation options, taking into account specific features and constraints. To solve this problem, it is advisable to use optimisation modelling. The task of the optimisation problem is to maximise the level of environmental and economic efficiency for each of the modernisation scenarios under a limited budget. Therefore, the basis of the optimisation model for investing in ecological modernisation is the indicator of production modernisation efficiency, which consists of two components: the return-on-investment index and the overall impact index by category. The use of this indicator will improve the information support of environmental management and make informed investment decisions for the rational use of limited financial and other resources.

ADDITIONAL INFORMATION

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FUNDING

The Authors received no funding for this research.

CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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ЕКОЛОГІЧНА МОДЕРНІЗАЦІЯ ВИРОБНИЦТВА В ЗАБЕЗПЕЧЕННІ ІННОВАЦІЙНОГО РОЗВИТКУ ПРОМИСЛОВИХ ПІДПРИЄМСТВ

В умовах реалізації політики декарбонізації виробництва, посилення екологічних вимог щодо антропогенного впливу на довкілля й високих ризиків в енергетичному секторі визначальною умовою забезпечення конкурентоспроможності промислових підприємств є швидка екологічна модернізація виробництва та впровадження інноваційних екологічних рішень. Установлено, що екологічна модернізація сприяє зниженню антропогенного впливу на довкілля, підвищенню ефективності використання сировини й матеріалів, підвищенню енергоефективності, впровадженню найкращих доступних технологій і методів виробництва.

Обмеження інвестиційних ресурсів, короткий термін імплементації та високі безпекові ризики обумовлюють необхідність підвищення ефективності екологічного менеджменту в частині екологічного інвестування. Метою дослідження є розробка пропозицій щодо вдосконалення екологічного менеджменту промислових підприємств шляхом розробки оптимізаційної моделі оцінювання ефективності екологічної модернізації, впровадження у виробництво інноваційних екологічно безпечних технологій, яка виступає інформаційною базою для ухвалення відповідних зважених управлінських рішень.

Запропоновано оптимізаційне моделювання інвестування в екологічну модернізацію, що забезпечить найефективніший розподіл наявних ресурсів. Визначено, що підготовчий етап інвестування в екологічну модернізацію включає: інвентаризацію кількісного та якісного стану виробничих модулів, екологічний аудит антропогенного впливу, оцінювання потенціалу впровадження найкращих технологій і методів управління, розробку альтернативних сценаріїв.

Запропоновано інтегральний показник ефективності екологічної модернізації виробництва, який містить дві складові: індекс рентабельності інвестицій та індекс екологічних категорій впливу. Оптимізаційне моделювання ефективності екологічної модернізації дозволяє визначити й оцінити альтернативні сценарії інвестування в екологічну модернізацію та обрати найкращу з них. Прикладне використання оптимізаційного моделювання ефективності екологічної модернізації сприятиме підвищенню ефективності екологічного менеджменту й ухваленню зважених управлінських рішень.

Ключові слова: підприємство, промисловість, навколишнє середовище, виробництво, ефективність, технологія, екологічна модернізація, екологічний менеджмент, екологічні інвестиції, інноваційний розвиток

JEL Класифікація: D25, D24, M11, P28, Q01