РОЗДІЛ 5. ЕКОНОМІКА ПРИРОДОКОРИСТУВАННЯ ТА ОХОРОНИ НАВКОЛИШНЬОГО СЕРЕДОВИЩА

ASSESSMENT OF THE OVERALL LEVEL OF ENVIRONMENTAL SAFETY OF THE ENTERPRISE: POSSIBILITIES OF APPLICATION OF MODERN ECONOMIC AND MATHEMATICAL METHODS

ОЦІНКА ЗАГАЛЬНОГО РІВНЯ ЕКОЛОГІЧНОЇ БЕЗПЕКИ ПІДПРИЄМСТВА: МОЖЛИВОСТІ ЗАСТОСУВАННЯ СУЧАСНИХ ЕКОНОМІКО-МАТЕМАТИЧНИХ МЕТОДІВ

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Effective encouragement of enterprises in the direction of environmental protection, reduction of the negative impact of production on the environment, increase of investment attractiveness and environmental image is possible provided that the methodology for assessing the overall level of environmental safety of the enterprise is developed and practically tested. In the article, the formula for calculating the integral indicator of the overall level of the enterprise's environmental safety is developed; it is based on three partial integral coefficients: an integral coefficient of environmental damage; an integral coefficient of the impact of economic factors; an integral coefficient of the impact of environmental and economic factors. The use of correlation and regression analysis has confirmed the validity of the developed economic and mathematical model, the existence of interconnections between its indicators.
Key words: *environmental safety, integral indicator, overall level of environmental safety, correlation and regression analysis.*

Эффективное стимулирование отечественных предприятий к охране окружающей среды, снижению негативного влияния производства на природу, повышению инновационно-инвестиционной привлекательности и экологического имиджа возможны при условии разработки и практической апробации методики оценки общего уровня экологической безопасности предприятия. В статье разработана формула расчета интегрального показателя общего уровня экологической безопасности предприятия, основанная на трех частных интегральных коэффициентах: интегральном коэффициенте экологического ущерба; интегральном коэффициенте влияния экономических факторов; интегральном коэффициенте влияния эколого-экономических факторов. С помощью корреляционно-регрессионного анализа обоснована достоверность разработанной экономико-математической модели, подтверждена реальность взаимосвязей и взаимозависимостей между ее показателями.
Ключевые слова: *экологическая безопасность, интегральный показатель, общий уровень экологической безопасности, корреляционно-регрессионный анализ.*

Ефективне стимулювання національних підприємств у напрямі охорони навколишнього природного середовища, зниження негативного впливу виробництва на довкілля, підвищення інноваційно-інвестиційної привабливості, екологічного іміджу та поліпшення екологічної ситуації в Україні можливі за умови розроблення та практичної апробації методики оцінки загального рівня екологічної безпеки підприємства. Актуальність вирішення даної наукової проблеми полягає у тому, що обчислення загального рівня екологічної безпеки підприємства важливо враховувати під час розрахунку екологічного податку та встановлення певної диференціації стосовно платників екологічного податку для оцінки їх екологічної та соціальної відповідальності перед державою і суспільством. Метою проведеного дослідження є розроблення інтегрального показника загального рівня екологічної безпеки підприємства та обґрунтування можливостей використання кореляційно-регресійного аналізу для підтвердження адекватності й взаємозв'язків між його складниками. Методологічною основою дослідження стали фундаментальні положення загальної економічної теорії, економіки природокористування та охорони навколишнього природного середовища, статистики та економетрії. У статті розроблено формулу розрахунку інтегрального показника загального рівня екологічної безпеки підприємства, який базується на трьох часткових інтегральних коефіцієнтах: інтегральному коефіцієнті екологічної шкоди; інтегральному коефіцієнті впливу економічних чинників; інтегральному коефіцієнті впливу еколого-економічних чинників. Обґрунтовано достовірність розробленої економіко-математичної моделі, підтверджено реальність взаємозв'язків і взаємозалежностей між її показниками за допомогою кореляційно-регресійного аналізу. Результати проведеного дослідження можуть бути корисними для оцінки загального рівня екологічної безпеки будь-якого підприємства незалежно від його форми власності, організаційно-правової форми, виду діяльності, галузевих особливостей та територіального розташування.
Ключові слова: *екологічна безпека, інтегральний показник, загальний рівень екологічної безпеки, кореляційно-регресійний аналіз.*

Introduction. Environmental protection, rational use of natural resources, environmental safety of human life is a prerequisite for sustainable economic and social development of society. However, today in Ukraine there is a high level of environmental pollution caused by inappropriate nature management, imperfection of regulatory and legal adjustment in this area, the use of outdated and environmentally

hazardous fixed assets, decreased social responsibility of business with negative environmental and economic consequences both for the economy of the country, and for society as a whole.

Nowadays, the country intervenes in the ecological and economic state of Ukrainian enterprises by regulating the amount of pollutant emissions into the environment and the size of their environmental tax. During 2010-2015 there was an increase in the amount of environmental tax imposed on national enterprises, organizations and institutions for pollution of the environment, on average, by 20% annually. This tendency, in our opinion, in some way stimulates environmental activity of enterprises, and environmental tax becomes a kind of regulator of their environmental safety. Nevertheless, the mechanism of collection of environmental tax in its present form is imperfect as it does not effectively fulfill its environmental protection functions. This is due to the fact that its calculation does not take into account the overall level of environmental safety of the enterprise, and calculations are carried out separately, depending on the type of emissions of pollutants into the environment. So, the companies investing heavily in environmentalization of their own production and improvement of technologies to reduce the negative environmental impact on the environment pay the same amount of environmental tax as the companies earning money without any remorse. Therefore, it is now important to take into account the overall level of environmental safety of the enterprise when calculating environmental taxes and to establish a certain differentiation in relation to payers of environmental taxes.

Review of Literature. In view of this, fundamental scientific investigations in which environmental, economic and environmental issues become the object of special attention have been made by domestic and foreign scientists recently. In particular, the works of S. V. Goshovsky, B. M. Danilishin, A. B. Kaczynski, N. F. Reimers, K. F. Frolov, O.V. Kharlamova, V. M. Shmandy are devoted to the development of these issues. The issues of assessing the level of the enterprise's environmental safety and its impact on the ecosystem, strengthening of environmental protection activities and social responsibility in business have been investigated in the works by Ya. O. Adamenko, V. I. Bendyuh, B. N. Porfiryev, A. I. Potapov, T. A. Khorunzhy and others.

However, studies conducted by our predecessors have not had proper practical application and do not allow us to assess the overall level of environmental safety of the enterprise [1-5]. In addition, modern scientific literature and current normative documents contain a large number of individual criteria for assessing environmental safety or unsafety of the enterprise, but there are no methods for calculating its overall level. This determines the timeliness of the chosen research and confirms its extremely important sigificance.

The purpose of the article. The aim of the article is to develop an integral indicator of the overall level of environmental safety of the enterprise and to justify the possibility of using correlation and regression analysis to confirm interrelationship between its components.

Results. Nowadays in Ukraine, legislative regulation of environmental activities of economic entities is carried out by various regulatory and legal documents, which are often not consistent with each other and, unfortunately, do not contain a generic methodology for assessing the overall level of the enterprise's environmental safety. Moreover, there is no coherent approach to the system of indicators that can characterize the overall level of environmental safety of the enterprise in the scientific economic literature at present.

In this regard, the authors made an attempt to derive a formula for assessing the overall level of environmental safety of the enterprise as a relative integral indicator. It was developed on the basis of the scientific work by Mamchuk I. V. [1], which gives reasons for the necessity of using the so-called "level of environmentally oriented development of technopark design" for ecological and economic evaluation of the processes of restructuring chemical enterprises within the framework of technopark design.

We are convinced that taking into account the above-mentioned factors, the integral indicator of the overall level of the enterprise's environmental safety should be based on three partial integral indicators:

– an integral coefficient of environmental damage;

– an integral coefficient of the impact of economic factors;

– an integral coefficient of the impact of environmental and economic factors.

These indicators are interrelated and interdependent. They enable assessing the impact of environmental, economic as well as environmental and economic factors on the level of environmental safety of the enterprise as a whole.

The integral coefficient of environmental damage is a generalized indicator reflecting a relative average environmental damage to the environment caused by economic activity of the enterprise. It is calculated by the formula (1):

$$K_{ed} = \sqrt[n]{\frac{\frac{E_{i1}}{MPC_1} * E_{i2}}{MPC_2} * \ldots * E_{in}}{MPC_n}, \qquad (1)$$

where, – K_{ed} is an integral coefficient of environmental damage,

$E_{i1}, E_{i2}, \ldots, E_{in}$ - is actual volumes of emissions of i-th pollutant into the air, and / or into waters, and / or waste placement, and / or generation of radioactive wastes;

$MPC_1, MPC_2, \ldots, MPC_n$ – is value of the maximum permissible concentration of a pollutant.

This coefficient reflects the proportion of actual emissions in maximum permissible concentrations of harmful substances in the environment under normal conditions of use, that is, the level of compliance with environmental standards. Ideally, the values of actual emissions should correspond to the normative values of the maximum permissible concentrations of pollutants specified in the Tax Code of Ukraine [6]. Thus, the lower the value of this indicator is, the higher the level of environmental safety of the enterprise is. And since the integral coefficient of environmental damage is a destimulating indicator, then it should be included in the formula for assessing the overall level of environmental safety of the enterprise with the reverse value as 1- K_{ed} .

Primary data for calculating an integral coefficient of environmental damage were obtained from the official publications of the State Statistics Service of Ukraine for the period from 2011 to 2015 (Table 1).

Adding the integral coefficient of the impact of economic factors to the general formula is connected with the need to assess the condition of fixed assets and the level of capital investment in objects for environmental use. After all, they greatly affect the level of environmental safety of the enterprise. At the same time, the higher the values of this indicator are, the higher the overall level of environmental safety of the enterprise is.

The integral coefficient of the impact of economic factors is calculated by determining the cubic root of the product of the coefficient of suitability of fixed assets, the coefficient of renewal of fixed assets and the share of capital investment in fixed assets of environmental protection:

$$K_{econ} = \sqrt[3]{K_s * K_{rn} * d_{ci}}, \quad (2)$$

where K_{econ} – is an integral coefficient of the impact of economic factors;

K_s $K_{зн}$ – is a coefficient of suitability of fixed assets;

K_{rn} – is a coefficient of renewal of fixed assets;

d_{ci} – is the share of capital investment in fixed assets of environmental protection.

The components of the integral coefficient of the impact of economic factors for production enterprises of Ukraine for the period from 2011 to 2015 are given in Table 2.

Determination of the integral coefficient of the impact of environmental and economic factors is conditioned by the need to assess the impact of environmental loss, eco-capacity, the proportion of environmental expenditures in product cost and the share of recycled wastes in the total volume of their generation on the level of environmental safety of the enterprise. Its value, ideally, should exceed 1, because the higher the value of this indicator is, the higher the level of environmental safety of the enterprise is. The integral coefficient of the impact of environmental and economic factors is proposed to be calculated according to the formula:

$$K_{ecol-econ} = \sqrt[4]{L_{ecollos} * EC * d_{ecoexp} * d_w}, \quad (3)$$

where $K_{ecol-econ}$ – is an integral coefficient of the impact of environmental and economic factors;

$L_{ecollos}$ – is environmental loss of production;

EC – is eco-capacity of production;

d_{ecoexp} – is proportion of environmental expenses in production cost;

Table 1

The ratio of actual volumes of pollutant emissions to the MPC for production enterprises of Ukraine from 2011 to 2015 [7]

Indicators	Years				
	2011	2012	2013	2014	2015
iron and its compounds	0,00695	0,00708	0,00680	0,00623	0,00268
lead and its compounds	0,00667	0,00333	0,00333	0,00333	0,00333
chromium and its compounds	0,00067	0,00067	0,00067	0,00067	0,00067
aluminum oxide	0,00140	0,00110	0,00110	0,00100	0,00080
nitrogen oxide	0,00362	0,00208	0,00223	0,00178	0,00145
nitrogen dioxide	0,08325	0,08313	0,08333	0,07203	0,05845
ammonia	0,00648	0,00600	0,00565	0,00533	0,00470
sulfur dioxide	13,33100	13,99200	13,81800	11,33300	8,30300
carbon monoxide	0,00355	0,00335	0,00336	0,00276	0,00255
organic amines	0,00067	0,00100	0,00133	0,00133	0,00133
methane	0,21955	0,22173	0,23023	0,14505	0,12853
chlorine and its compounds	0,00001	0,00001	0,00001	0,00001	0,00001
fluorine and its compounds	0,00020	0,00010	0,00010	0,00010	0,00010
cyanides	0,00008	0,00005	0,00005	0,00003	0,00003
in addition, carbon dioxide	0,67407	0,66058	0,65873	0,55642	0,46311
Integral coefficient of environmental damage	0,07261	0,06734	0,06733	0,06146	0,05769

Table 2

Components of the integral coefficient of the impact of economic factors for production enterprises of Ukraine from 2011 to 2015

Indicators	Years				
	2011	2012	2013	2014	2015
Coefficient of suitability of fixed assets	0,325	0,262	0,557	0,397	0,231
Coefficient of renewal of fixed assets	0,005	0,009	0,038	0,027	0,015
Share of capital investment in the fixed assets of environmental protection	0,025	0,023	0,025	0,036	0,028
Integral coefficient of the impact of economic factors	**0,186**	**0,195**	**0,284**	**0,270**	**0,213**

Table 3

Calculation of the integral coefficient of the impact of environmental and economic factors for production enterprises of Ukraine from 2011 to 2015

Indicators	Years				
	2011	2012	2013	2014	2015
Proportion of recycled waste in its total amount	0,328	0,301	0,307	0,287	0,276
Environmental loss of production	0,015	0,001	0,002	0,002	0,001
Eco-capacity of production	0,101	0,010	0,011	0,010	0,009
Proportion of environmental expenditures in cost of sales	0,009	0,010	0,011	0,010	0,010
Integral coefficient of the impact of environmental and economic factors	**0,216**	**0,121**	**0,131**	**0,124**	**0,115**

d_w – is proportion of recycled wastes in the total amount of their generation.

In turn, the indicator of environmental loss of production shows the amount of environmental tax, which amounts to 1 UAH of manufactured products. This indicator is destimulating, since its increase will result in decrease of the integral coefficient of the impact of environmental and economic factors. Therefore, it is necessary to calculate environmental loss of production by comparing it with the reference value by the formula (4):

$$L_{ecollos} = 1 - \frac{ET}{Q}, \quad (4)$$

where ET – is the amount of environmental tax;

Q – is volume of manufactured products (goods, works, services).

Eco-capacity of production is determined by the ratio of the amount of environmental expenses to the cost of manufactured products and reflects the level of environmental expenses per hryvnia of manufactured products:

$$ET = \frac{E_{colexp}}{Q}, \quad (5)$$

where E_{colexp} – is the amount of environmental expenses;

Q – is volume of manufactured products (goods, works, services).

The proportion of environmental expenses in production costs is calculated by the formula:

$$d_{ecoexp} = \frac{E_{colexp}}{PC}, \quad (6)$$

where E_{colexp} – is the amount of environmental expenses;

PC – is production cost.

The proportion of recycled waste in the total amount of its generation is determined by the ratio of the amount of recycled waste to the total amount of x generation:

$$d_w = \frac{W_r}{W_g}; \quad (7)$$

where W_r – is the amount of recycled waste;

W_g – is the amount of generated waste.

In this case, the components of the integral coefficient of the impact of environmental and economic factors for production enterprises of Ukraine from 2011 to 2015 are given in Table 3.

The integral indicator of the overall level of environmental safety of the enterprise is calculated on the basis of the above-mentioned partial integral indicators according to the formula (8):

$$LES = \sqrt[3]{(1 - K_{ed}) * K_{econ} * K_{ecol-econ}}, \quad (8)$$

where LES – is the integral indicator of the overall level of environmental safety of the enterprise;

K_{ed} – is an integral coefficient of environmental damage;

K_{econ} – is an integral coefficient of the impact of economic factors;

$K_{ecol-econ}$ $K_{ecol-econ}$ – the integral coefficient of the impact of environmental and economic factors.

The generalized indicators of the overall level of environmental safety of Ukrainian production enterprises are given in Table 4.

Statistical relationships of the dependence and influence of calculated partial integral coefficients (X) on the integral indicator of the overall level of envi-

Table 4

The overall level of environmental safety of Ukrainian production enterprises from 2011 to 2015

Years	The overall level of environmental safety (У)	Integral coefficient of environmental damage (X1)	Integral coefficient of the impact of economic factors (X2)	Integral coefficient of the impact of environmental and economic factors (X3)
2011	0,5778	0,0726	0,1855	0,2162
2012	0,5291	0,0673	0,1952	0,1206
2013	0,5713	0,0673	0,2844	0,1311
2014	0,5616	0,0615	0,2696	0,1240
2015	0,5339	0,0577	0,2135	0,1151

Table 5

Regression statistics

Multiplier R	**0,999999504**
R-square	0,999999008
Normalized R-square	0,999996031
Standard error	0,000044
Observation	5

Table 6

Dispersion analysis

Indicators	df	SumSquare (SS)	MeanSquare (MS)	F- criterion	Significance of F-criterion
Regression	3	0,00194	0,00065	335897,524	0,00127
Residual	1	0,00000	0,00000		
Total	4	0,00194			

Table 7

Analysis of coefficients

Indicators	Coefficients	Standard error	t-statistics	P-value
Y- point of intersection	0,3852	0,0003	1140,9722	0,0006
X1	-0,0326	0,0059	-5,5083	0,1143
X2	0,4079	0,0006	738,3250	0,0009
X3	0,5517	0,0009	634,6953	0,0010

ronmental safety of the enterprise (Y) were defined in order to substantiate the operations aimed at reducing the value of the integral indicator of the overall level of environmental safety of the enterprise. As a result, the regression equation (9) was obtained in Table 5-7:

$$Y = 0,3851 - 0,0326X1 + 0,4079X2 + 0,5517X3 \text{ , (9)}$$

The results of the analysis show that Fisher's criterion significantly exceeds the table value, that is, the obtained model is valid with a probability of 99.9%. The relative error of the model is 0.1%. Testing by Student's criterion made it possible to confirm the validity of all three coefficients.

At the same time, each factor has the further influence:

– reduction of an integral coefficient of environmental damage by 1 monetary unit will result in increase of the integral indicator of the overall level of environmental safety of production enterprises by 0,0326 p.;

– increase in an integral coefficient of the impact of economic factors by 1 monetary unit will lead to increase of the integral indicator of the overall level of environmental safety of production enterprises by 0.4079 p.;

– growth of an integral coefficient of the impact of ecological and economic factors by 1 monetary unit will cause increase of the integral indicator of the overall level of environmental safety of production enterprises by 0.5517 p.

Conclusion. Nowadays, there are different approaches to assessing the level of environmental safety of the enterprise, but none of the normative document contains a single methodology for its definition. In addition, in the scientific economic literature, scientists have no coherent approach to the system of indicators that can characterize the overall level of environmental safety of the enterprise.

According to the authors, the overall level of environmental safety of the enterprise should be determined taking into account the impact of various economic, environmental and organizational factors through the integral indicator of the overall level of the enterprise's economic security, which is based on three partial integral coefficients, namely: an integral coefficient of

environmental damage; an integral coefficient of the impact of economic factors; an integral coefficient of the impact of environmental and economic factors.

The use of correlation and regression analysis made it possible to confirm the adequacy of the developed economic and mathematical model and economic validity of interconnections and interdependencies between its indicators. The proposed methodology will allow us to accurately assess the overall level of environmental safety of the enterprise regardless of the type of its activities, organizational and technological features, and territorial location.

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