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The Evaluation Methodology for the Ecological and Economic Potential of the Metallurgical Cluster

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***Abstract* – The article presents the author's methodology for the formation of a key indicator system for the evaluation of the ecological and economic potential of the metallurgical cluster. This being the case, special attention was paid to the development of an indicator system for evaluating the second-level potentials uniting the environmental and economic components of the integrated study subject. The study aims to develop a comprehensive methodology for evaluating the ecological and economic potential adapted to unique features of the metallurgical cluster of the Republic of Kazakhstan. In preparing the material, the authors used comparative analysis and integral economic and statistical indicator building methods. Individual assessments of the first and second tiers were integrated by calculating criterion integrated indicators. The study concluded that a balanced evaluation of the ecological and economic potential of the metallurgical cluster can be obtained by integrating estimates of second-tier potentials representing the joint influence of a group of enterprises in the metallurgical industrial cluster. The provisions and conclusions of the described paper can be applied by the management of iron and steel companies to justify corporate development programmes, as well as regional authorities to identify areas of investment attractiveness growth of the region. The empirical basis of the analysis was obtained from the results of studies carried out as part of the research work "Improvement of the state policy regulation for accelerated clustering of the industrial regions", executed under grant financing of the Ministry of Education and Science of the Republic of Kazakhstan.**

***Keywords* – Ecological and economic potential; industrial cluster; integrated potential evaluation; metallurgy; Republic of Kazakhstan; sustainable development.**

1. INTRODUCTION

Metallurgy plays a crucial role in the economy of the Republic of Kazakhstan. Currently, the mining and metals sector accounts for about 7.3 % of GDP, 24.7 % of industrial production, and 24 % of exports. The industry is represented by more than 800 companies, which employ about 160 000 people.

Kazakhstan is one of the top ten countries in terms of raw mineral potential and has historically been one of the key players in the global mining and metals industry. The country is ranked 1st in the world in terms of tungsten reserves, 2nd in uranium and chromium reserves, 4th and 5th in manganese, silver, zinc, lead and other minerals. It is one of the top 5 exporters of ferrous alloys, top 10 exporters of zinc, copper, lead, coal, and is ranked 1st in the world in uranium mining.

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In the regional context, Karaganda, Pavlodar and East Kazakhstan regions make the greatest contribution to the development of the processing industry (a total of about 41 %) due to the concentration of large steel mills, which account for 76.5 % of the industry's gross added value. In the commodity structure, for 2010–2018 the largest amounts of exports of the processing industry also account for the steel industry. Apart from that, it should be noted that there has been a significant shift in Kazakhstan steel industry: a transition from the production of base metals (copper, lead, zinc, etc.), intermediate products (slabs, blooms and other blanks) and semi-finished (rolled) products to the production of finished products (steel pipes, metal structures, rails, wires) that defined the largest investment in the steel industry – 34.6 % of the total investment of major processing industries for the entire period. At the same time, Kazakhstan steel industry demonstrates a significant negative environmental impact. Thus, both the Karaganda Metallurgical Plant and the chemical and metallurgical plant of TEMK are the main atmosphere polluters in Temirtau, and in the Karaganda region, ArcelorMittal Temirtau and Kazakhmys account for up to 70 % of total emissions. Every year, ArcelorMittal Temirtau's activities are recorded exceeding the emission limits, non-complying with environmental requirements for the discharge of domestic wastewater and waste management, as well as environmental conditions. According to the authors, it is the creation of cluster organisational systems that can reduce this negative impact. Given the above, the study aims to develop a methodology for a balanced evaluation of the ecological and economic potential of the industrial cluster adapted to the activities of the metallurgical cluster of the Republic of Kazakhstan.

To achieve this goal, the authors proposed the following tasks:

– suggest the author's wording of the term “metallurgical industrial cluster”;
– characterise the metallurgical industrial cluster of the Republic of Kazakhstan;
– develop a system of key indicators for evaluating the ecological and economic potential of the metallurgical industrial cluster;
– offer a criterion integrated indicator for evaluating the ecological and economic potential of the metallurgical industrial cluster.

At present, there is quite a large amount of literature dedicated to the definition of the “cluster” concept. In their works, Ketels C. H. and Schmitz H. stressed the importance of considering the spatial patterns [1], [2] when defining the clusters. Tempman, Bergman and Hartmann, Voronov, and Sokolenko focused on food patterns when highlighting clusters [3]–[6]. Role patterns describing behavioural models of cluster participants [7]–[10] and macroeconomic patterns allowing to characterise the extent of the impact of macroeconomic processes on the development of clusters [11]–[13] clusters are also important in the analysis of clusters. However, as part of this study, the sector-wide characteristics of cluster-forming industries come to the fore. It is these patterns that define the nature of the anthropogenic impact of the cluster on the environment and determine the potential of such an impact. To ensure maximum consideration of the industry patterns, the authors proposed the definition of the term “metallurgical industrial cluster”. The formulation stages for the author's definition of the term "metallurgical industrial cluster" are shown in Fig. 1.

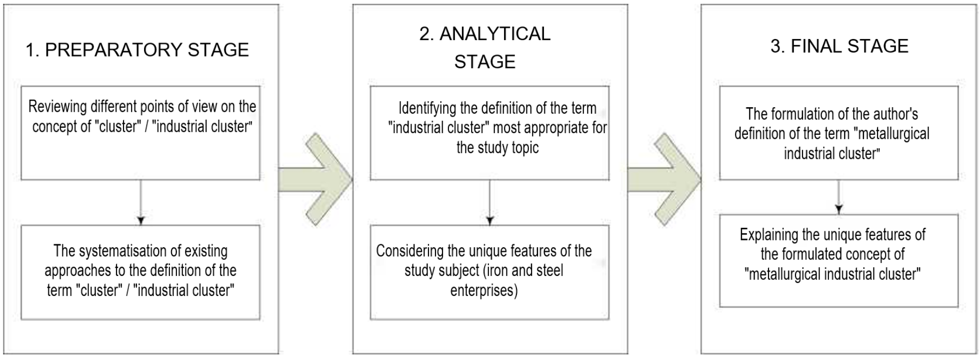

Fig. 1. The formulation stages for the author's definition of the term "metallurgical industrial cluster".

In formulating the definition, the authors relied on the requirements to industrial clusters, as set out in the regulatory documents of the Republic of Kazakhstan and the Russian Federation [14], [15]. Given the above, the following requirements were formulated defining the classification of body corporates to metallurgical industrial clusters:

a) The unification of organisations for the purpose of production support of industrial companies that were classified as part of the ferrous (non-ferrous) metal industry under the specifics of their activities and statutory documents, in which case enterprises interact on the organisational and production level due to geographical location and functional dependence;
b) Substantial (more than 20 % of the total production of steel processing) product integration, except for final metallurgical products;
c) The existence of production participants in the metallurgical industrial cluster; basic university; infrastructure support facilities;
d) The co-direction of the development of the metallurgical cluster and the provisions of the strategic documents for the production site locations;
e) Greater efficiency in the use of resources within a cluster structure as compared to industry averages.

The authors considered it necessary to include the following factors to the main organisational features of the metallurgical industrial cluster:

a) Cluster-integrated metallurgical enterprises form vertically-integrated holding structures [16];
b) Significant social and economic importance for the facility locations. In some cases, iron and steel enterprises are the basis for a single-industry entity;
c) The substantial value of the assets of enterprises in the metallurgical cluster;
d) The combined nature of the production activities of iron and steel enterprises involves a combination of steel and chemical production processes.

Given the complexity of the organisational and operational structure, the metallurgical industrial cluster can act as an independent subject of economic study. At the same time, the results obtained during the evaluation of this territorial body corporate can be extrapolated to the entire industry, considering the geographical features. Then the administration of this site, which is based on the principles of sustainable development, should be aimed not only at ensuring the economic development of the cluster, but also at minimising its negative environmental impact.

In modern literature, the consideration of the economic and environmental potential of clusters as independent categories prevails. For example, economic potential is usually reviewed considering existing requirements and constraints of the social and economic nature [17]–[19]. During its evaluation, accounting and analytical approaches prevail [24]–[27]. For the purposes of this study, the economic potential of the metallurgical industrial cluster will mean the sum of capabilities of the integrated economic entity to carry out production and related activities based on the synergistic unity of the cluster's enterprises and components of its potentials, which contribute to the achievement of strategic development goals and the growth of competitiveness among the cluster's enterprises.

The main theoretical approaches to the definition of the concept of "environmental potential" were revealed by Borisova, Oleynik, and Pavlov [28]–[30]. Then, by systematising existing approaches and adapting them to the specifics of the study subject, the environmental potential of the metallurgical industrial cluster means a comprehensive evaluation of the environmental activities of the cluster's group of enterprises representing the possibility of preserving and maintaining the operation of natural systems and rational use of all components of the biosphere for the sustainable development of the territory.

Given the extent of the negative impact of the steel industry on the environment, the authors consider it appropriate to move from an independent assessment to an integrated evaluation of the environmental and economic potential of metallurgical clusters. To do this, the authors formulated the concept of "environmental and economic potential of the metallurgical industrial cluster" as a quantitative assessment of the cluster's ability to carry out the production in the context of the accompanying preservation and maintaining the operation of natural systems and the rational use of all components of the biosphere.

In developing a methodology for evaluating the environmental and economic potential of the metallurgical industrial cluster, the authors used the accumulated experience in the analysis of environmental and economic systems [31]–[34], as well as the experience in the economic evaluation of environmental aspects of production complexes' development. There are three key approaches to evaluating potentials of industrial clusters: a resource approach [39], [40], an indicative approach [41]–[45] and an approach based on the evaluation of the expected efficiency of potential utilisation [46]–[50]. The authors developed a technique that belongs to the indicative approach group. The possibility of a comprehensive evaluation of the environmental and economic potential is granted by the use of the system of indicators proposed by the authors.

As part of this study, the authors consider it essential to emphasize the need for a comprehensive evaluation of the ecological and economic potential of the metallurgical industrial cluster due to its high negative impact on the state of the environment and significant economic impact.

2. STUDY METHODOLOGY

The development of a methodology for evaluating the ecological and economic potential of the metallurgical industrial cluster included three stages. In the first stage, the factors that determine the ecological and economic potential were arranged. All the factors important for the study were gathered into two groups - economic factors and environmental factors. In turn, economic and environmental factors were divided into local and non-local. Local factors characterize the influence at the operational level, and non-local factors describe the impact of the unique operation features of the cluster's enterprises on the environment. The combination of factors, which joint influence determines the ecological and economic potential of the metallurgical cluster, is shown in Table 1.

TABLE 1. FACTORS THAT DETERMINE THE ECOLOGICAL AND ECONOMIC POTENTIAL OF THE METALLURGICAL CLUSTER

Pos. No.	Factor group name	Factor name
1. Economic factors		
1	Local economic factors	Financial potential
2		Infrastructure and production capacity
3		Labour potential
4		Innovation and technology potential
5		Management potential
1	Non-local economic factors	Company development potential
2		Sustainability level of development potential
2. Environmental factors		
1	Local environmental factors	Pollutant emission and discharge reduction potential
2		Production waste application expansion potential
3		Production waste utilisation capacity expansion potential
4		Environmentally-friendly technology introduction potential
5		Production resource intensity reduction potential
6		Biodiversity conservation potential in the surrounding territories
7		Operation planning potential, considering the need to comply with the established regulations of negative impact on the environment.
1	Non-local environmental factors	Company's development potential within the environmental management system
2		Sustainability level of development potential within the environmental management system
3		The company's development potential, considering the social and cultural interests of the population living within the area of business
4		The sustainability level of the development potential, considering the social and cultural interests of the population living within the area of business

In the second stage, parameters for the evaluation of environmental and economic potential were formulated. The overall level of the ecological and economic potential of the metallurgical industrial cluster in the author's model is described by a criterion parameter (P_{cr}). The impact of economic and environmental factors is described by integral indicators (P_i). In turn, the values of integral parameters are determined by individual indicators, generalizing the impact of local and non-local factors (P_{ij}). Finally, individual capacity indicators are based on the aggregation of statistics parameters forming second-tier potentials (P_{ijz}). The parameter calculation sequence and their components are shown in Table 2.

TABLE 2. PARAMETERS FOR EVALUATING THE ECOLOGICAL AND ECONOMIC POTENTIAL OF THE METALLURGICAL INDUSTRIAL CLUSTER

Criterion parameter (P_{cr})	
Integral parameters (P_i)	
Economic factors (П1)	Environmental factors (П2)
Individual indicators (P_{ij})	
Local economic factors (П1.1) Non-local economic factors (П1.2)	Local environmental factors (П2.1) Non-local environmental factors (П2.2)
Second-tier potentials (P_{ijz})	
Financial potential (П1.1.1) Infrastructure and production potential (П1.1.2) Labour potential (П1.1.3) Innovation and technology potential (П1.1.4) Management potential (П1.1.5) Company development potential (П1.2.1) Sustainability level of development potential (П1.2.2)	Pollutant emission and discharge reduction potential (П2.1.1) Production waste application expansion potential (П2.1.2) Production waste utilisation capacity expansion potential (П2.1.3) Environmentally-friendly technology introduction potential (П2.1.4) Production resource intensity reduction potential (П2.1.5) Biodiversity conservation potential in the surrounding territories (П2.1.6) Operation planning potential, considering the need to comply with the established regulations of negative impact on the environment (П2.1.7) Company's development potential within the environmental management system (П2.2.1) Sustainability level of development potential within the environmental management system (П2.2.2) The company's development potential, considering the social and cultural interests of the indigenous people living within the area of business (П2.2.3) The sustainability level of the development potential, considering the social and cultural interests of the indigenous people living within the area of business (П2.2.4)

In the third stage, an approach was proposed to evaluate the second-tier potentials. The following requirements were made to the second-tier potential evaluation parameters:

1. Only relative parameters are used.
2. Minimum number of parameters with maximum semantic load;
3. Parameters should not duplicate each other.
4. Parameters should fully describe all the presented second-tier potentials;
5. Parameters are calculated based on the consolidated reporting indicators for the metallurgical industrial cluster.

To assess the second-tier potentials, the authors propose a set of absolute and relative parameters. The second-tier potential evaluation parameters are shown in Table 3.

TABLE 3. SECOND-TIER ECONOMIC POTENTIAL EVALUATION PARAMETERS

The unit of all indicators is a decimal fraction / coefficient

Pos. No.	**Second-tier potential name**	**Parameter name**
Economic factors		
1	Financial potential (П1.1.1)	Financial status evaluation parameters: 1. Financial solvency evaluation parameters: equity to total assets ratio, the proportion of long-term liabilities in debt capital 2. Liquidity evaluation parameters: absolute, current and total liquidity ratios 3. Business performance evaluation parameters: return on assets, return on equity, equity turnover
2	Infrastructure and production potential (П1.1.2)	Property status evaluation parameters: 1. Tangible asset ratio in the property 2. The proportion of fixed assets
3	Labour potential (П1.1.3)	1. Staff turnover rate 2. Job security ratio 3. The proportion of workers who have completed professional development in the current year 4. The proportion of workers with higher education corresponding to the staffing position
4	Innovation and technology potential (П1.1.4)	1. The proportion of intangible assets in the property 2. Parent update rate
5	Management potential (П1.1.5)	1. Management decision rate 2. The proportion of the company's revenue generated through the "project-based approach"
6	Company development potential (П1.2.1)	1. Share of reinvested profits 2. The investment-to-return ratio in the reviewed period
7	Sustainability level of development potential (П1.2.2)	1. The increase in investment costs in the reporting year compared to last year. 2. Equity investment ratio

The second-tier environmental potential evaluation parameters are shown in Table 4.

TABLE 4. SECOND-TIER ENVIRONMENTAL POTENTIAL EVALUATION PARAMETERS

The unit of all indicators is a decimal fraction / coefficient

Pos. No.	**Second-tier potential name**	**Factor Name**
Environmental factors		
1	Pollutant emission and discharge reduction potential (П2.1.1)	1. Growth rate (positive or negative) of pollutant emissions 2. Emission concentration rate
2	Production waste application expansion potential (П2.1.2)	1. The proportion of the patents of invention for production waste processing in the total number of patents of the subject 2. The proportion of the investment budget aimed at expanding the application of production waste in the overall investment budget

Pos. No.	Second-tier potential name	Factor Name
3	Production waste utilisation capacity expansion potential (П2.1.3)	1. The growth rate of sludge waste recycling 2. The growth rate of dump waste recycling 3. Waste recycling ratio 4. Resource utilisation rate obtained after processing
4	Environmentally-friendly technology introduction potential (П2.1.4)	1. Cost increase rate regarding the introduction of environmentally-friendly technologies 2. The proportion of the patents of invention for the ways of ecologically friendly technologies implementation in the total number of patents of the subject 3. The proportion of the investment budget aimed at expanding introducing environmentally-friendly technologies in the overall investment budget
5	Production resource intensity reduction potential (П2.1.5)	1. Growth rate (positive or negative) of production resource intensity 2. Share of introducing production facilities aimed at reducing resource intensity of the production 3. The proportion of the patents of invention for the ways of reducing production resource capacity in the total number of patents of the subject 4. The proportion of the investment budget aimed at introducing technologies providing resource intensity reduction in the overall investment budget
6	Biodiversity conservation potential in the surrounding territories (П2.1.6)	1. Growth rate (positive or negative) of biodiversity in the surrounding territories 2. Share of introducing production facilities, which involve the preservation of biodiversity in the surrounding territories 3. The proportion of patents for the invention of methods for the conservation of biological diversity in the territories of presence in the total number of patents of the subject 4. The proportion of the investment budget aimed at introducing technologies providing the preservation of biodiversity in the surrounding territories
7	Operation planning potential, considering the need to comply with the established regulations of negative impact on the environment (П2.1.7)	1. The proportion of production processes included in the value creation card (of each product range) that takes into account compliance with current environmental impact standards in the total number of production processes 2. The proportion of production processes for which environmental impact standards are met in the total number of production processes
8	Company's development potential within the environmental management system (П2.2.1)	1. The proportion of production processes regulated by internal standards of the environmental management system in the total number of production processes
9	Sustainability level of development potential within the environmental management system (П2.2.2)	1. The growth rate of processes regulated by internal standards of the environmental management system 2. The growth rate of workers who know the company's mission and strategy in the field of ecology
10	The company's development potential, considering the social and cultural interests of the population living within the area of business (П2.2.3)	1. The growth rate of investments in the development of social and cultural sites in the area of business

Pos. No.	Second-tier potential name	Factor Name
11	The sustainability level of the development potential, considering the social and cultural interests of the population living within the area of business (П2.2.4)	1. The growth rate of strategic (and current) programmes and activities aimed at preserving and developing social and cultural sites in the area of business

The final criterion parameter is calculated according to the formula of a simple geometric average. Given the equal importance of environmental and economic components for the purpose of calculating the ecological and economic potential of the metallurgical industrial cluster, the formula will look like this:

$$P_{\mathrm{cr}} = \sqrt[2]{P_1 \cdot P_2}$$

Integral and individual indicators are calculated in the same way. Thus, moving from individual indicators to integral aggregates estimates, the methodology allows us to evaluate the ecological and economic potential of the entire cluster.

Then, the change in values in dynamics of each of the indicators presented in Table 3 and Table 4 will provide a similar direction of change in the final value of P_{cr}. At the same time, an increase in all, without exception, indicators for assessing the potential of the second level can be regarded as a positive phenomenon, since, as a result, it ensures the growth of the entire economic and environmental potential of the economic entity under consideration.

3. The Background of the Metallurgical Cluster of the Republic of Kazakhstan

The largest cluster-forming steel industry enterprise in the Republic of Kazakhstan is the Karaganda Metallurgical Plant in Temirtau. It incorporates two full-cycle plants that use iron-ore concentrates imported from the Kostanay region and a semi-integrated steel plant that uses scrap metal. The plant produces cast iron, steel, thin sheet rolling, etc. An important branch of Kazakhstan's iron and steel industry is the extraction and concentration of iron ore at the Sokolovsky-Sarbay Mining and Refining Production Association (Rudny) and Orken LLC (Lisakovsk) in the Kostanay region.

Karaganda Metallurgical Plant is a part of ArcelorMittal Temirtau JSC, which includes a coke and by-product process facility, agglomerate production, blast shop, steel-smelting facility, envelope shop, rolling facility, CHP plant, coal department and other facilities [51].

ArcelorMittal Temirtau is a member of ArcelorMittal Group and is the largest company in the mining and metallurgical sector of the Republic of Kazakhstan. The company is an integrated mining and metallurgical facility with own coal, iron ore and energy base.

ArcelorMittal Temirtau includes:

- steel department;
- coal department;
- iron ore department.

The geographical localisation of the departments of ArcelorMittal Temirtau JSC, which form a metallurgical industrial cluster in the Karaganda region, is represented in Fig. 2.

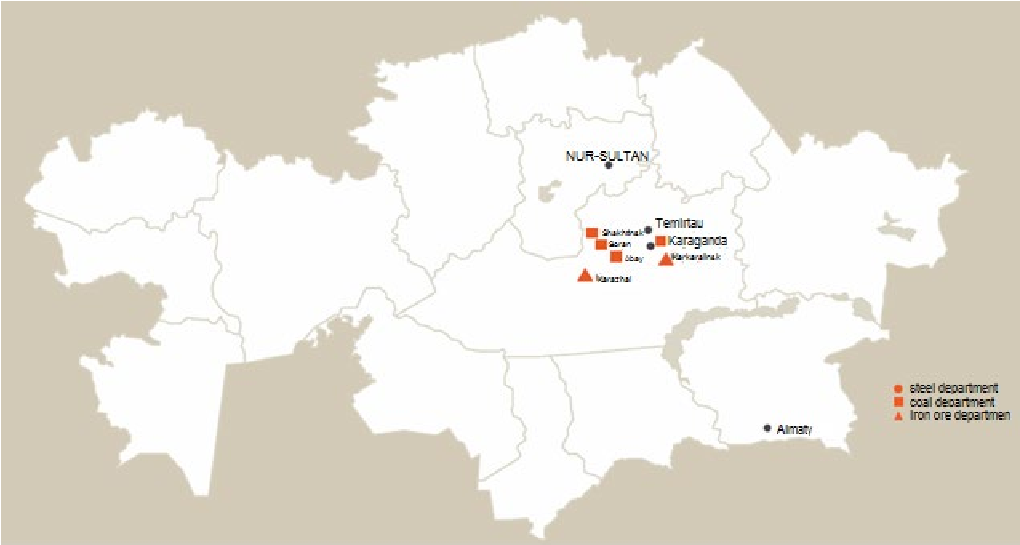

Fig. 2. Geographical representation of the metallurgical industrial cluster of the Republic of Kazakhstan (Karaganda region).

At the same time, considering the scale of ArcelorMittal Temirtau LLC's activities and the specifics of the steel industry, the company's industrial facilities have a negative environmental impact on the plant's territory. However, the company's stated principles of sustainable development are designed to partially offset the negative anthropogenic impact.

4. Approbation of the Methodology Development for Evaluating the Ecological and Economic Potential of the Metallurgical Industrial Cluster

Testing of the presented methodology was carried out at one of the metallurgical plants of Karaganda region of the Republic of Kazakhstan, while localization of production conversions within the plant's territory suggests its similarity with the structure of the cluster as a whole.

During the study, at the initial stage, value of the criterion indicator for assessing the economic and environmental potential for the standard period was calculated and depicted in (Fig. 3):

- Private indicators as:
  - Potential power of local economic factors – 0.36
  - Potential power of nonlocal economic factors – 0.91
  - Potential power of local ecological factors – 0.47
  - Potential power of nonlocal ecological factors – 1.01
- Integrated indices as:
  - Potential power of local economic factors – 0.57
  - Potential power of local ecological factors – 0.68
  - *Criteria indicator of economic and ecological estimation – 0.62*

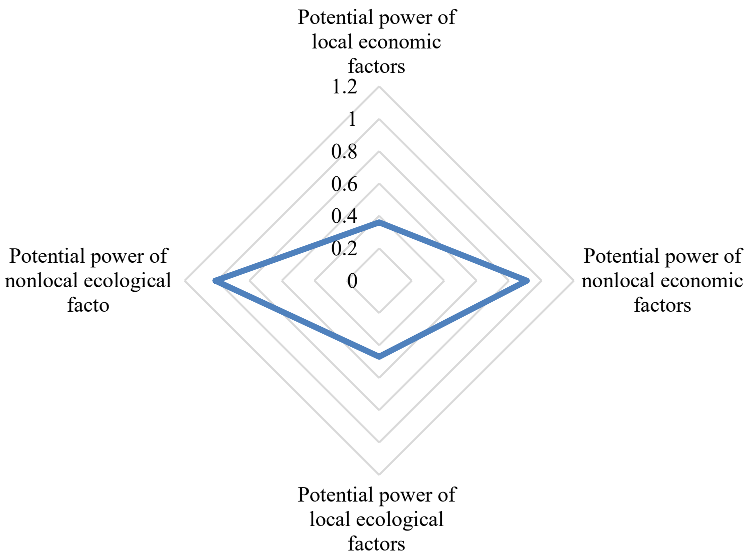

Fig. 3. Diagram of private potentials' indicators influence for the standard period.

Next, we calculated the effect of investment project's implementation on construction of a new sulfuric acid production line with increased capacity of one and a half times more for processing sulfur dioxide and replacing electrostatic precipitators for gas treatment of fluidized bed furnaces with four-pole electrostatic precipitators with a higher degree of purification of sulfur-containing gases from impurities (Fig. 4). At the same time, implementation period of the investment project presented above and the base period were not crisis for the global and territorial economies, and were also characterized by relatively stable prices for non-ferrous metals on the London Commodity and Raw Materials Exchange:

- Private indicators:
  - Potential power of local economic factors – 0.30
  - Potential power of nonlocal economic factors – 0.94
  - Potential power of local ecological factors – 0.51
  - Potential power of nonlocal ecological factors – 1.08
- Integrated indices:
  - Potential power of economic factors – 0.53
  - Potential power of ecological factors – 0.74
  - *Criteria indicator of economic and ecological estimation – 0.63*

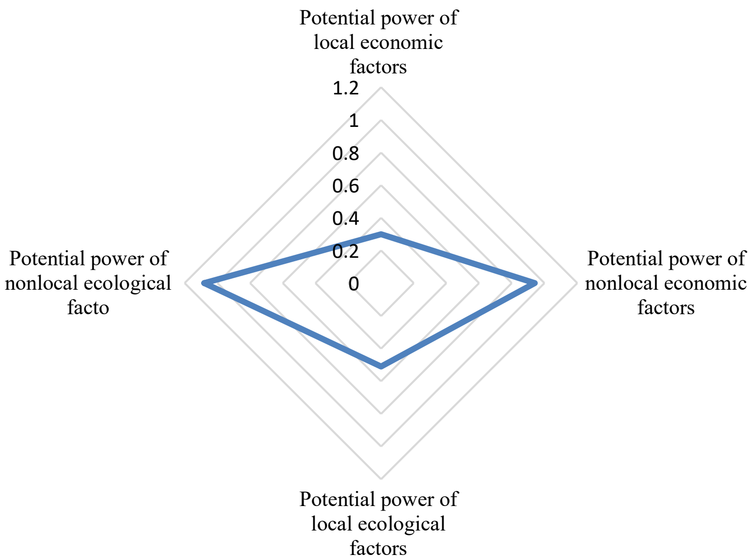

Fig. 4. Diagram of private potentials' indicators influence for the analysed period.

Thus, even despite the deterioration of the integral indicator of the potential influence of economic factors caused by deterioration in financial condition of the analysed enterprise due to implementation of capital-intensive investment projects, as a result, we observe positive dynamics of the criterion indicator, proving an increase in environmental and economic potential.

5. Conclusion

The study produced the following results:

- requirements are formulated regarding the classification of corporate associations as metallurgical industrial clusters, including the territorial principle for the placement of production and related enterprises of the cluster, the requirement for substantial food integration, the existence of a basic educational institution and related infrastructure facilities, the holding organisational and management structure, etc.;
- the metallurgical industrial cluster of the Republic of Kazakhstan is identified and described; It was found out that it includes the coke and by-product process facility, agglomerate production, blast shop, steel-smelting facility – envelope shop, rolling facility, CHP plant, coal department and other facilities, as well as illustrated geographical localisation of the departments of ArcelorMittal Temirtau JSC;
- a system of key indicators is developed for assessing the ecological and economic potential of the metallurgical industrial cluster, including the criterion parameter, integral indicators of economic and environmental factors, individual local and non-local economic and environmental factors, as well as the second-tier economic and ecological potentials. At the same time, in order to assess the potentials of the second tier, the authors compiled a set of parameters that meet the following requirements:

only relative parameters are used, the minimum number of parameters with maximum semantic load, parameters should not duplicate each other, parameters should fully describe all the presented second-tier potentials, parameters are calculated based on the consolidated reporting indicators for the metallurgical industrial cluster

– a methodical approach to evaluating the ecological and economic potential of the metallurgical industrial cluster is offered based on a rating assessment of the second-tier potentials and the calculation of the criterion integrated indicator.

The study concluded that a balanced evaluation of the ecological and economic potential of the metallurgical cluster can be obtained by integrating estimates of second-tier potentials representing the joint influence of a group of enterprises in the metallurgical industrial cluster.

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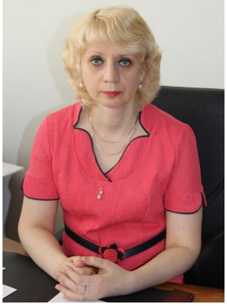

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