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Features of Providing Sustainable Regional Development in the Conditions of Globalization Challenges

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ABSTRACT

The article reveals the peculiarities of ensuring the sustainable development of regions in the face of globalization challenges. These challenges are manifested in the growth of the environmental crisis, the shortage of traditional resources for production, the strengthening of demographic imbalances, the growth of social inequality, the deformation of market structures, and the crisis of the efficiency of capital investments, among others. The timeliness of the research is determined by modern globalization challenges of social development, which have a paradigmatic direction toward the implementation of the sustainable development concept. The purpose of the study is to substantiate the areas of sustainable development of regions based on the identification of the most influential indicators on the comprehensive integrated index of sustainable development using the matrix game method. The methodological basis of the research is a systematic approach, which allows for the study of regions in the context of globalization challenges as part of the system and the application of mathematical tools such as correlation analysis, multiple regression, simulation modeling, and the matrix game method. The authors have improved the methodical approach to assessing the sustainable development of regions in the face of globalization challenges. This involves using the matrix game method to determine the most optimal strategy for the region's sustainable development by identifying the most influential indicators that ensure an increase in the integrated index of sustainable development in the future. The methodical approach was tested using examples from regions of Ukraine. The analysis results for two Ukrainian regions identified the most influential factor on the sustainable development of each region and enabled modeling of the integrated index of sustainable development considering this influence, which demonstrated positive dynamics in the growth of the integrated index of sustainable development for the regions.

1. INTRODUCTION

Globalization processes affect the trajectory of the development of national economies and their constituents, generating new problems and prospects for development. Modern globalization challenges that affect the development of economic systems, including at the regional level, include a growing environmental crisis, a shortage of traditional production resources, such as energy, increasing demographic imbalances, growing social inequality, deformation of market structures, and a crisis of capital investment efficiency, among others. Globalization challenges accompany the development of economic systems with new challenges, the paradigmatic direction of which is the generally accepted concept of sustainable development. The principles of sustainable development dictate the ideology of reasonable sufficiency, mutual assistance, and directing efforts toward the development of the social and ecological spheres of social production. At the same time, it is important to direct efforts to achieve the goals of sustainable development in the face of globalization challenges, which should be tailored to the unique, specific features of certain territories. It is the peculiarities of regional development that can yield the greatest effect in achieving the goals of sustainable development and ensuring the sustainable stability of economic systems at various levels. Such features can be determined using the matrix game method, which allows for the selection of the most optimal strategy through the linear approximation of regional development strategies.

The purpose of the article is to substantiate directions for ensuring the sustainable development of regions in the face of globalization challenges using the methodical approach of the matrix game. This approach enables the determination of the most influential indicators for the complex integrated index of sustainable development of the region.

2. LITERATURE REVIEW

Many publications by scientists from all over the world are devoted to ensuring the sustainable development of regions, as the modern challenges of globalization are of paradigmatic importance aimed at the implementation of the concept of sustainable development. Based on the results of the analysis of existing research on the mentioned issue, it is advisable to pay attention to the fact that the first articles appeared back in 1993. In the period from 1993 to 2023, 736 scientific works were published, which are indexed in the international scientometric database Scopus. Every year, the relevance of research on issues of sustainable development is increasing. According to the results of the analysis of publication activity in the period from 2018 to 2023, we note the following trend: 2018 - 49 articles, 2019 - 65 articles, 2020 - 68 articles, 2021 - 54 articles, 2022 - 73 articles, 2023 - 43 articles (Figure 1).

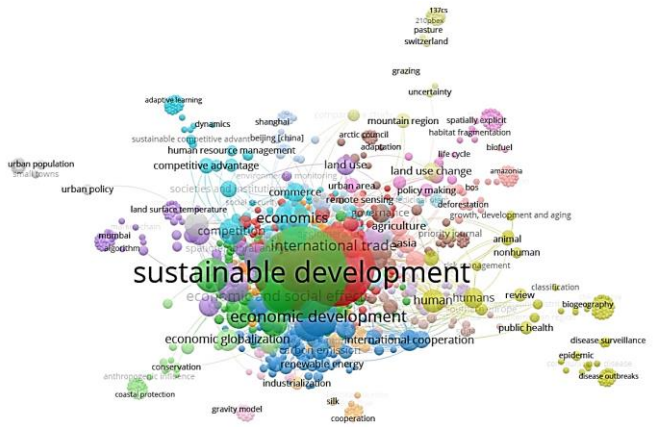

Figure 1. Map of the publication activity of scientists whose titles include "sustainable development", "region", "globalization" for the period 1993-2023
Source: Systematized by the authors using VOSviewer tools

If we consider the publication activity of scientists by field of knowledge, the following trend should be noted: social sciences (357 articles), environmental sciences (275 articles), business, management, and accounting (143 articles), engineering (122 articles), energy (115 articles), economics, econometrics, and finance (107 articles), etc. The leading countries in terms of publication activity on the issue of sustainable development are: China (112 articles), the United States (95 articles), the United Kingdom (46 articles), India (44 articles), Germany (34 articles), Australia (31 articles), Italy (27 articles), etc.

The authors of the article, Heydari et al. [1] systematized and outlined the main stages of the process of activation and intensification of the use of modern digital technologies for the development of the educational environment in the context of ensuring sustainable development of the region. During the study, the process of ensuring sustainable development of the region was investigated solely in the context of developing the educational environment and its digitalization and modernization. However, in our opinion, it should be taken into account that sustainable development is a complex concept that includes many elements.

The articles by Boiarynova et al. [2] and Popelo et al. [3] are of practical importance, within which the public management of innovative regional development is investigated in the context of sustainability and inclusiveness.

Within the scope of the article by Poveda [4], the main threats to the system of sustainable development and planning of the region from the perspective of ensuring the economic security of the state are identified and analyzed. The authors used a methodology that allows for establishing the dependence and connection between threats and determining the level of the measures' structure to counteract the negative impacts of these threats on a separate region. The scientists have formed a multi-level matrix of the hierarchy of the negative impact of threats on the system of sustainable development and planning of the region in the context of ensuring the economic security of the state.

The scientists Abisheva et al. [5] proposed scientific and methodological foundations for the sustainable development of the region's economy. It was established that the main directions for ensuring sustainable development and competitiveness of the region involve studying economic specializations, conducting a comprehensive study of the socio-economic situation, examining the operational conditions of strategic industrial structures, and identifying factors influencing the region's sustainable development.

The authors Pivnyak et al. [6] argue that the concept of sustainable development, which seeks a balance between technological advancements, economic growth, social equity, and ecological considerations, is becoming an increasingly relevant environmental issue owing to the depletion of natural resources and the escalation of environmental issues. They defined and substantiated strategic underpinnings for the development of engineering education focused on creating a unified international platform for the sustainable use of the world's natural resources.

The article by Huan et al. [7] argues that the interplay between the Sustainable Development Goals (SDGs) is critical to prioritizing these goals and accelerating overall progress. The study focuses on Asia's Water Tower region, which poses significant challenges to progress towards the SDGs in Asia and globally. The researchers assessed the spatial and temporal variations in the interactions and priorities of sustainable development in the region based on correlation coefficients and network analysis.

The scientists Tulchynska et al. [8] and Kryvda et al. [9] presented a study on the harmony of ecological development in regions amidst the formation of a circular economy. According to the authors, this made it possible to identify a balance in the state of the environment that supports the advancement of the circular economy towards achieving sustainable development goals. The role of eco-industrial parks within the circular economy is also examined.

The study by Anusha et al. [10] conducted a land suitability analysis, assessing the impact of whether a specific parcel of land is appropriate for a given use. The scientists consider the study of land suitability for growing agricultural crops a crucial contemporary step in formulating strategies for sustainable land use to enhance land potential. As a result of the study, a conceptual approach to land suitability analysis is proposed, which contributes to increasing the green cover and addressing environmental issues in the pursuit of sustainable development.

In the study by Huan et al. [11], the authors identified five sustainable development goals related to livelihoods, energy, ecosystem, and water. These goals have been shown to be closely interconnected, with progress in these areas being a substantial stride towards the achievement of other SDGs. Upon compiling the results, the authors prioritized 24 goals to provide evidence-based support for identifying holistic and synergistic

actions at various scales. Notably, the following goals were identified as priorities: 2.3 - agricultural productivity, 7.1 - access to modern energy services, 7.2 - increased use of renewable energy sources, 15.2 - sustainable management of forests, 15.5 - conservation of mountain ecosystems, 15.6 - fair sharing of the benefits arising from the utilization of genetic resources, as well as the mobilization of resources.

The authors Aragonés-Beltrán et al. [12] highlight that when a regional government considers the possibility of investing in the sustainable development of its region, it must take into account the real needs of the population and the achievement of the Sustainable Development Goals. The scientists believe that identifying these needs should involve the support of local stakeholders from various social groups.

According to the results of the studies by Novomlynets et al. [13], Shaposhnykov et al. [14], and Dubyna et al. [15], the characteristics of enterprises' foreign economic activities under modern conditions and the incorporation of the sustainability concept are discussed. The authors present a vision for a VAT administration ecosystem tailored to e-commerce transactions that aligns with the sustainable development goals.

In the paper by Akomaning et al. [16], the authors analyze the contribution of non-wood forest products to the economic development of the Eastern region and the achievement of the SDGs in Ghana. The study concludes that non-timber forest products significantly contribute to the economic development of the Eastern region and the country through employment and direct taxes.

According to scientists Wang et al. [17], progress in global efforts to achieve the Sustainable Development Goals is increasingly hampered by the degradation of critical and fundamental resources such as water, food, energy, and ecosystem services. The study identifies 37 relationships and clarifies the nature of their interactions, 12 of which are significant and directly related to the sustainable development goals.

In the scientific papers by Tulchynska et al. [18], Popelo et al. [19], and Garafonova et al. [20], modeling the harmonious economic development of regions within the context of sustainable development was carried out. As a result, regions were grouped and ranked according to the specified indicator, and cartographic analysis was conducted. The authors researched the main principles, methods, tools, and stages of greening production. They proposed a methodological approach for evaluating greening production using standardization methods, complex indicators, and comparison. A list of recommended measures for enterprises to green their production in the context of implementing sustainable development goals has been created.

In the research conducted by Li et al. [21], the authors analyzed the importance of promoting sustainable development in resource-dependent regions, noting it as a significant challenge for policymakers. They suggest that investigating the impact of sustainable development strategies on income inequality is appropriate. The study reveals that reducing dependence on natural resources is a potential and vital mechanism, as shown by the mediation effect model.

Annamalaisamy and Vepur Jayaraman [22] studied the effects of global climate change, which has already caused noticeable negative impacts on the ecological system. They highlight the challenge for every country to achieve further economic growth without compromising environmental quality. The authors examined the single, combined, and interrelated effects of income growth, foreign direct investment inflows, renewable energy, and regulatory quality on climate change. They discuss climate change-related policy interventions by various economies in the Asia-Pacific region aimed at achieving the Sustainable Development Goals.

However, despite the existing scientific works, the study of the features of ensuring sustainable development of regions through the impact study of its main components in the context of globalization challenges is extremely relevant and timely.

3. METHODOLOGY

For the development of the regional economic systems in the conditions of globalization, an important factor in activating their development is the identification of specific economic indicators that are most influential in the development of a specific region. The most accurate method that makes it possible to do this is the matrix game method, which allows modeling the influence of indicators on the sustainable development value of the region, which is represented by a complex integral index.

The matrix game method refers to the theory of games, which is a mathematical modeling of a certain situation and the search for an optimal solution based on this, which is the most optimal development strategy. A certain situation is the result of each player's choice of strategy. The process of solving a matrix game is finding an equilibrium situation, while the solution takes into account both random events, which are a mechanism of random selection, and personal moves, which are deliberate actions of the player.

The matrix game method includes the fact that two systems, which are regions, are represented by matrices of evaluation indicators. The game method has been used in general for a long time, but the regions, which are complex interconnected systems, were not its objects.

Therefore, in order to assess sustainable development of regions in the face of global challenges and to identify strategic areas of efforts to ensure sustainable development, it is suggested to use the matrix game method, as well as to carry out calculations in the following sequence:

I. firstly, substantiation of the indicators of the regional sustainable development in the conditions of globalization challenges, which makes it possible to carry out calculations, analyze the dynamics and develop strategies for sustainable development of the regional economic systems in the future;
II. secondly, using the multiple regression method, calculate integral indices of the components of sustainable development and the complex integral index of the regional sustainable development under the conditions of globalization challenges;
III. thirdly, to single out, in accordance with the impact on the complex integral index, the most influential indicators and integral indices to ensure sustainable development of regions;
IV. fourthly, to model the influence of the most influential factors on the integrated index of sustainable development of regions to determine the sustainable development strategy of the region using the matrix game method.

Let's consider in more detail the proposed algorithm for conducting research on the justification of ensuring the sustainable development of the region, taking into account its features.

At the first stage, there is a selection and substantiation of the evaluation indicators of sustainable developmentof regions in the conditions of globalization challenges, as well as its standardization. The procedure of normalization of indicators brings them to a comparable measurement, which is very important when determining the most influential indicators on the resulting characteristic. Rationing is carried out using the formula:

$$x_{ij}^{t} = \frac{X_{i_{jt}}}{X_{i_{cpjt}}} \quad (1)$$

$$X_{ij}^{t} = \left(x_{1it}, x_{2it} \ldots x_{jit} \right) \quad (2)$$

where, x_{ij}^{k} – normalized value of the jth partial indicator of sustainable development of the regional economic system, which characterizes the ith region; $x_{i\,jt}$ – natural value of the jth partial indicator selected from statistical data; x_{icpjt} – assessment of the mathematical expectation of the jth taken for standardization of the sustainable development indicator of the ith region for the period of this study; t – research period, years (in our case, the period is 2013-2021) (t=1, …, 9).

According to the second stage, the calculation of integral indexes of the regional sustainable development in the conditions of globalization challenges is carried out. Social, economic and ecological components of sustainable development are usually used for calculations, according to which integral indices are determined. In our opinion, without denying the correctness of such a distribution, we will add to them the production component, innovative-entrepreneurial and scientific component. The selected components relate to sustainable development, as scientific developments provide an opportunity to intensify the innovative and entrepreneurial activity, which in turn has a positive effect on the production component. Expanding the assessment of the components of sustainable development provides more opportunities for developing regional strategies for directing resources in a specific direction, which can give the greatest effect for ensuring sustainable development of regions in the face of globalization challenges.

Thus, the complex integral index of sustainable development will be determined based on six integral indices that are its components, namely:

- integral index of economic development (I_1);
- integral index of production development (I_2);
- integral index of innovative and entrepreneurial development (I_3);
- integral index of scientific development (I_4);
- integral index of human development (I_5);
- integral index of ecological development (I_6).

The list of evaluation indicators, which are divided into six components of sustainable development of regions in the face of globalization challenges, is presented in Table 1.

Thus, for the calculation of the complex integral index of sustainable development, which consists of six components, 25 evaluation indicators were selected, on the basis of which the calculations were made.

The selection of indicators for the calculation of integral indexes of the components of sustainable development and their normalization makes it possible to carry out further calculations using the correlation analysis method.

Table 1. A list of partial indicators for assessing sustainable development of regions in the face of globalization challenges

No.	Indexes
	Estimated indicators of the economic component of sustainable development
x_1	GRP per capita, USD
x_2	Capital investments, per capita, USD
x_3	Direct investments (equity capital) per capita by the region of Ukraine, USD
x_4	Commissioning of housing for 1,000 people, m² of total area
x_5	Own revenues of local budgets without transfers per capita, USD
	Estimated indicators of the production component of sustainable development
x_6	Volume of sold industrial products (goods, services) per capita of the population, USD
x_7	Profitability of operating activities of enterprises, %
x_8	Total volumes of export of goods, million USD
x_9	Total volumes of export of services, million USD
x_{10}	Livestock production (at constant 2010 prices), million USD
x_{11}	Crop production (at constant 2010 prices), million USD
	Evaluation indicators of the innovative and entrepreneurial component of sustainable development
x_{12}	Number of innovatively active enterprises in industry, units
x_{13}	Volume of implemented innovative products that are new to the market, thousand USD
x_{14}	Introduction of innovative types of products in industry, names
x_{15}	Implementation of innovative technological processes in industry, processes
	Estimated indicators of the scientific component of sustainable development
x_{16}	Total volume of innovation costs, thousand USD
x_{17}	Internal current costs for carrying out scientific research and development, in actual prices; thousand USD
x_{18}	Number of employees involved in scientific research and development, persons
	Estimated indicators of the social component of sustainable development
x_{19}	Number of people engaged in economic activity, thousands
x_{20}	Natural increase (reduction) of the population, persons
x_{21}	Migration growth (decrease) of the population, thousands
x_{22}	Disposable income of the population per capita, USD.
	Estimated indicators of the ecological component of sustainable development
x_{23}	Capital investments for environmental protection, in actual prices; million USD
x_{24}	Current costs for environmental protection, in actual prices; million USD
x_{25}	Capacity of treatment facilities, million m³

The correlation analysis method assumes that the standardized evaluation indicators of sustainable development are elements of a correlation matrix, which has the form:

$$k_{xa,xb} = \frac{cov(x_a, x_b)}{D[x_a^2] \cdot D[x_b^2]} \quad (3)$$

where, $k_{xa,xb}$ – correlation of estimated indicators of sustainable development; $cov\ (x_a,x_b)$ – covariance between standardized evaluation indicators of the components of sustainable development x_a, x_b; $D[x_a^2]$, $D[x_b^2]$ – variances of normalized evaluation indicators that are not equal to zero.

The use of correlation analysis for evaluation indicators, as well as for integral indices of the components of sustainable development, makes it possible to determine the weight of the influence of the evaluation indicator on the integral index, as well as the weight of the influence of the integral indices of the components of sustainable development on the complex integral index. The weighting coefficients are a regression function.

The use of correlation analysis becomes the basis for calculating integral indices of the components of sustainable development, and the complex integral index using the multiple regression method using the following formula:

$$I_k = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{19} \\ x_{21} & x_{22} & \dots & x_{29} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nt} \end{bmatrix} \quad (4)$$

where, I_k – k-th integral index of the sustainable development component (in this case, they were justified by k=6); x_{n1}-x_{nt} – normalized evaluation indicators of the components of sustainable development, which are taken for a certain period of the study (in our case, for 9 years t=9).

The following multiple regression formula is used to calculate the complex integral index of sustainable development of regions:

$$I_{cp} = \begin{bmatrix} I_{11} & I_{12} & \dots & I_{19} \\ I_{21} & I_{22} & \dots & I_{29} \\ \dots & \dots & \dots & \dots \\ I_{k1} & I_{k2} & \dots & I_{kt} \end{bmatrix} \quad (5)$$

where, I_{cp} – complex integral index of sustainable development of the region; I_{k1}–I_{kt} – integral indexes of the components of sustainable development (k=6 for 9 years t=9).

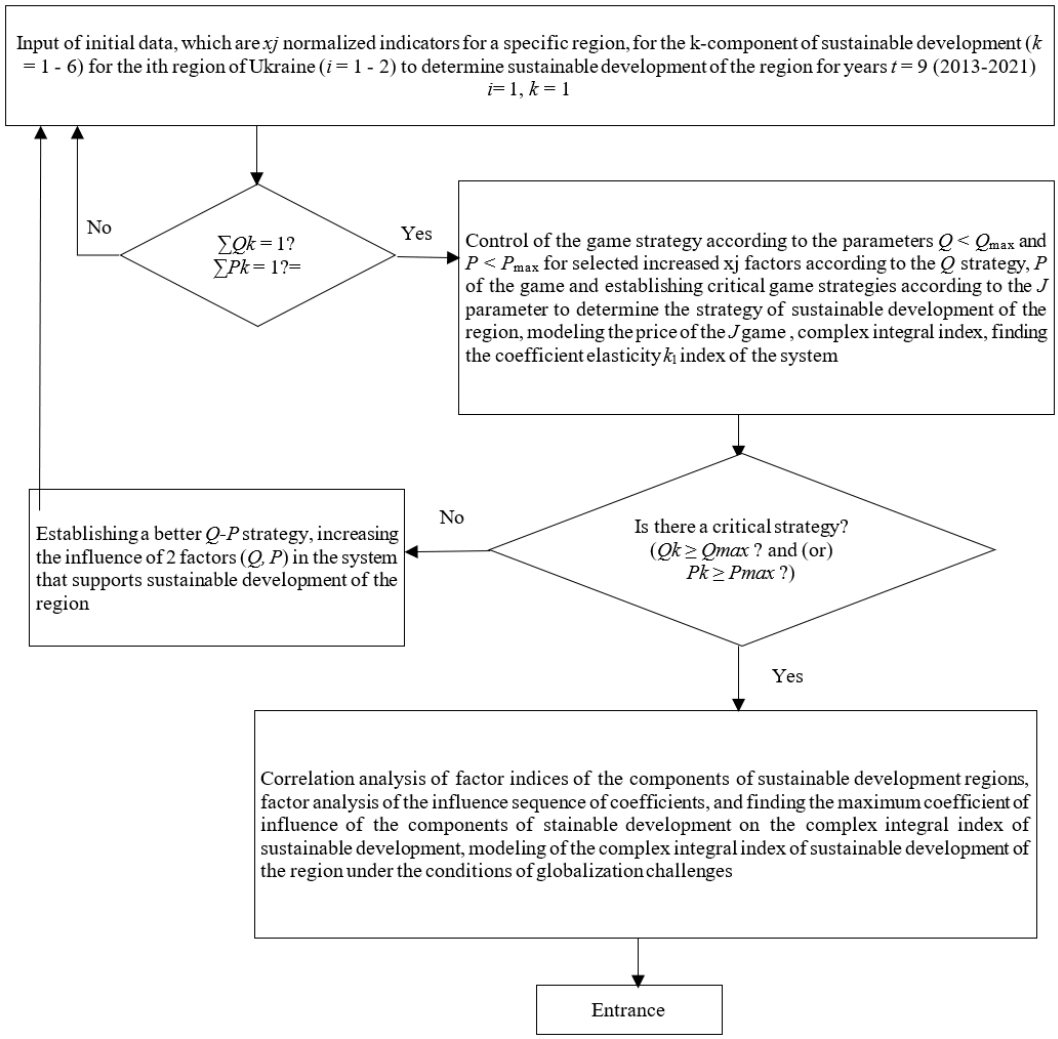

Figure 2. Algorithm for calculating the complex integral index of the i-th sustainable development of the region based on modeling the impact of evaluation indicators on the values of the complex integral indices of sustainable development of regions using the matrix game method

Source: Suggested by the authors

The final stage of the methodological approach proposed by the authors consists in modeling the impact of evaluation indicators on the integral indices of the components of sustainable development, and the complex integral index of sustainable development of the region using the matrix game method.

The algorithm for applying the matrix mountain method to substantiate the most effective strategy for sustainable development of the region in the face of globalization challenges is presented in Figure 2.

When using this method, it is assumed that a certain strategy is conventionally chosen in which one participant (region) wins, and the other loses, or vice versa. And in this way, all possible variants of the strategies for sustainable development of the regions are sorted out. Strategies of the regions selected for analysis are presented as follows:

$$\sum Qk=1; \sum Pk \quad (6)$$

where, *Q, P* – strategies of the respective region; *k* – number of components, which in our case are integral indices.

The use of the matrix game method makes it possible to single out exactly that evaluation indicator and integral index, the change of which will give the most positive result for sustainable development of the region under the conditions of globalization challenges, that is, the most optimal strategy for the development of the region is determined, which is determined by the complex integral index of sustainable development of the region under the conditions of globalization challenges. The obtained regional development strategies are optimal because they are determined by critical values of the coefficients. This approach of the matrix game ensures the accuracy of proving statistical methods of solving the set problems due to the linear approximation of the optimal strategies for the development of the region. This approach of the matrix game ensures the accuracy of proving the statistical methods of solving the set problems due to the linear approximation of the optimal strategies for the development of the region. The region, which is expressed through integral components, is a complex, dynamic, self-regulating system characterized by heterogeneous cause-and-effect relationships. All this makes it possible to take into account the use of the matrix game method.

4. RESULTS

In accordance with the proposed stages, we are testing the proposed approach. The Kiev region and the city of Kyiv were chosen for the calculations. Statistical data were taken from the State Statistical Service of Ukraine for 2013-2021, for 2022 statistical data in connection with the state of war in Ukraine as a result of military operations on the territory of the state have not been made public. All calculations were made using the Madhcad software.

The Kiev region and the city of Kyiv were chosen to test the approach of using the matrix game because they have approximately similar indicators of sustainable development. Sustainable development of each region is characterized by six components, which are taken as a basis for identifying the most influential factor of sustainable development of the region with a constant comparison of integral indicators using the matrix game method.

The authors of the study suggest using integral indices as input data when using the matrix game method to determine the strategies of sustainable development. Integral indices are determined using the multiple regression method. Multiple regression makes it possible to substantiate the correctness of the selected evaluation criteria of the regional development, the level the influence of the dimensionality of the evaluation indicators, as well as to identify the influence coefficients when calculating integral indices.

Calculations of the integral indices of the components of sustainable development and the complex integral index are presented in the Table 2.

Table 2. The value of the integral indices of the components of sustainable development and the complex integral index of sustainable development of the regions selected for approval for 2013-2021

Region	*I*									I_{avg}
	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average for 2013-2021
Integral index of economic development (I_1)										
Kiev region	0.084	0.085	0.096	0.105	0.113	0.125	0.139	0.128	0.144	0.113
Kyiv	0.084	0.095	0.103	0.106	0.107	0.110	0.123	0.133	0.141	0.111
Integral index of industrial development (I_2)										
Kiev region	0.145	0.181	0.196	0.178	0.122	0.132	0.181	0.195	0.209	0.171
Kyiv	0.132	0.180	0.193	0.180	0.130	0.107	0.195	0.249	0.251	0.180
Integral index of innovative and entrepreneurial development (I_3)										
Kiev region	0.036	0.040	0.039	0.048	0.053	0.038	0.046	0.036	0.089	0.047
Kyiv	0.061	0.070	0.065	0.080	0.072	0.054	0.066	0.042	0.060	0.063
Integral index of scientific development (I_4)										
Kiev region	0.047	0.044	0.047	0.036	0.036	0.036	0.048	0.051	0.069	0.046
Kyiv	0.065	0.061	0.067	0.076	0.070	0.084	0.087	0.090	0.098	0.078
Integral index of human development (I_5)										
Kiev region	0.057	0.056	0.057	0.058	0.059	0.061	0.065	0.079	0.088	0.064
Kyiv	0.084	0.111	0.149	0.120	0.110	0.116	0.131	0.107	0.076	0.111
Integral index of ecological development (I_6)										
Kiev region	0.122	0.134	0.135	0.138	0.144	0.150	0.164	0.167	0.146	0.145
Kyiv	0.123	0.129	0.134	0.138	0.139	0.141	0.153	0.156	0.174	0.143
Comprehensive integrated index of sustainable development (Iavg)										
Kiev region	0.573	0.622	0.655	0.641	0.596	0.612	0.724	0.752	0.909	0.676
Kyiv	0.541	0.649	0.759	0.708	0.588	0.646	0.764	0.728	0.693	0.675

Source: Calculated by the authors according to the proposed methodical approach

According to integral indices of economic and ecological development, the Kiev region has greater values than the city of Kyiv. The comprehensive integral index of sustainable development of the city of Kyiv and the Kiev region is presented in Figure 3.

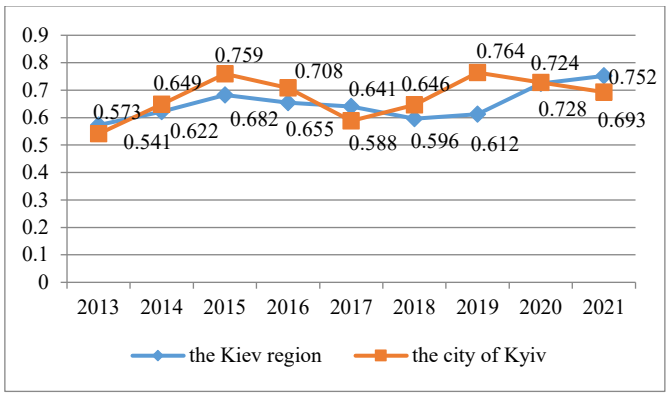

Figure 3. Comprehensive integral index of sustainable development of the Kiev region and the city of Kyiv for 2013-2021
Source: Calculated by the authors

The presented visualization of the integrated index of sustainable development of the city of Kyiv and the Kiev region demonstrates that in 2013, 2017 and 2020-2021 the values of the integrated index of sustainable development in the Kiev region were greater than the values of the integrated index of the city of Kyiv. The average arithmetic value of the complex integral index of sustainable development of the Kiev region is slightly higher than the complex integral index of the city of Kyiv.

The performed calculations provide an opportunity to carry out further calculations. For this, we single out the most influential evaluation indicators found in the integral indexes of the components of sustainable development, which were calculated as weighting factors using the correlation analysis. The most influential evaluation indicators for the selected regions for approval are presented in the Table 3.

From the data presented in Table 3, it can be noted that the most influential factors in four components of sustainable development are the same in the Kiev region and the city of Kyiv, and in two they are different. In further modeling using the matrix game to determine the most optimal strategy for sustainable development of the regions in the face of globalization challenges, these indicators, which are the most influential according to the results of the correlation analysis, take part. Further matrices for the matrix game are compiled on the basis of the singled out most influential indicators. In general, the matrix should have the following form:

$$r = \begin{bmatrix} 0 & \frac{x_3}{x_{11}} & \frac{x_{19}}{x_{11}} & \frac{x_{18}}{x_{11}} & \frac{x_{25}}{x_{11}} & \frac{x_{12}}{x_{11}} \\ \frac{x_{11}}{x_3} & 0 & \frac{x_{19}}{x_3} & \frac{x_{18}}{x_3} & \frac{x_{25}}{x_3} & \frac{x_{12}}{x_{11}} \\ \frac{x_{11}}{x_{19}} & \frac{x_3}{x_{19}} & 0 & \frac{x_{18}}{x_{19}} & \frac{x_{25}}{x_{19}} & \frac{x_{12}}{x_{19}} \\ \frac{x_{11}}{x_{18}} & \frac{x_3}{x_{18}} & \frac{x_{19}}{x_{18}} & 0 & \frac{x_{25}}{x_{18}} & \frac{x_{12}}{x_{18}} \\ \frac{x_{11}}{x_{25}} & \frac{x_3}{x_{25}} & \frac{x_{19}}{x_{25}} & \frac{x_{18}}{x_{25}} & 0 & \frac{x_{12}}{x_{25}} \\ \frac{x_{11}}{x_{12}} & \frac{x_3}{x_{12}} & \frac{x_{19}}{x_{12}} & \frac{x_{18}}{x_{12}} & \frac{x_{25}}{x_{12}} & 0 \end{bmatrix} \quad (7)$$

The matrix is built on the basis of taking into account the order of influence of the evaluation indicators on the integral index from the most influential to the least influential indicators of the components of sustainable development. The upper triangular values in the matrix (see formula 7) are mirrored in the lower triangular part of the matrix. Each element of the matrix represents the ratio of the average values of the most influential evaluation indicators to decrease their influence.

Table 3. The most influential evaluation indicators in the integrated indices of the subsystems of sustainable development and the most influential components of sustainable development in relation to the complex integral index

The Most Influential Evaluation Indicator in the Component of Sustainable Development						**The Most Influential Component of Sustainable Development**
I*1 *avg.	***I*2 *avg.***	***I*3 *avg.***	***I*4 *avg.***	***I*5 *avg.***	***I*6 *avg.***	***Iavg.***
			Kiev region			
direct investments (equity capital) per capita by region of Ukraine, USD *(x3)*	crop production (at constant 2010 prices), million USD *(x11)*	number of innovatively active enterprises in industry, units *(x12)*	number of employees involved in scientific research and development, persons *(x18)*	number of people engaged in the economic activity, thousands *(x19)*	capacity of treatment facilities, million m³ *(x25)*	*Component of production development (I2)*
			city of Kyiv			
direct investments (equity capital) per capita by region of Ukraine, USD *(x3)*	crop production (at constant 2010 prices), million USD *(x11)*	number of innovatively active enterprises in industry, units *(x12)*	number of employees involved in scientific research and development, persons *(x18)*	number of people engaged in the economic activity, thousands *(x19)*	capacity of treatment facilities, million m³ *(x25)*	*Component of production development (I2)*

Source: Calculated by the authors

As a result of substituting the values of the most influential evaluation indicators, we obtain a matrix of the following type:

$$r = \begin{bmatrix} 0 & 1.161 & 1.110 & 0.747 & 0.883 & 0.699 \\ 0.862 & 0 & 0.957 & 0.643 & 0.761 & 0.603 \\ 0.901 & 1.045 & 0 & 0.673 & 0.796 & 0.630 \\ 1.339 & 1.554 & 1.487 & 0 & 1.183 & 0.937 \\ 1.132 & 1.314 & 1.257 & 0.845 & 0 & 0.792 \\ 1.430 & 1.659 & 1.587 & 1.068 & 1.263 & 0 \end{bmatrix} \quad (8)$$

Using the principle of the matrix game method in which two regions participate makes it possible to determine the best strategy for each participant of the game. In this case, the player "*A*" is the Kiev region, and the player "*B*" is the city of Kyiv. According to the matrix (see Eq. (8)) given above, we get matrices for the Kiev region and the city of Kyiv.

At the same time, matrix A is an inverse matrix:

$$A=r^{-1} \quad (9)$$

Matrix B is the inverse transposed matrix:

$$A=(r^{T})^{-1} \quad (10)$$

Eqs. (11)-(12) give calculations of the matrices:

$$A = \begin{bmatrix} -0.8 & 0.232 & 0.222 & 0.149 & 0.177 & 0.140 \\ 0.172 & -0.8 & 0.191 & 0.129 & 0.152 & 0.121 \\ 0.180 & 0.209 & -0.8 & 0.135 & 0.159 & 0.126 \\ 0.268 & 0.311 & 0.297 & -0.8 & 0.237 & 0.187 \\ 0.226 & 0.263 & 0.251 & 0.169 & -0.8 & 0.158 \\ 0.286 & 0.332 & 0.317 & 0.214 & 0.253 & -0.8 \end{bmatrix} \quad (11)$$

$$B = \begin{bmatrix} -0.8 & 0.172 & 0.180 & 0.268 & 0.226 & 0.286 \\ 0.232 & -0.8 & 0.209 & 0.311 & 0.263 & 0.332 \\ 0.222 & 0.191 & -0.8 & 0.297 & 0.251 & 0.317 \\ 0.149 & 0.129 & 0.135 & -0.8 & 0.169 & 0.214 \\ 0.177 & 0.152 & 0.159 & 0.237 & -0.8 & 0.253 \\ 0.140 & 0.121 & 0.126 & 0.187 & 0.158 & -0.8 \end{bmatrix} \quad (12)$$

As a result of the calculations of the matrices given in Eqs. (12)-(13) for the values of the Kiev region and the city of Kyiv, we obtain the following results: $|A|$=-0.2; $|B|$=-0.2.

This makes it possible to determine the strategies of sustainable development for regions in the face of globalization challenges, namely the strategies: *Q* strategy - for region "*A*" and *P* strategy - for region "*B*":

$$Q=A\cdot J;\ P=B\cdot J \quad (13)$$

where, *Q, P* – according to the strategy of sustainable development for selected regions; *A, B* – respectively, the Kiev region and the city of Kyiv; *J* – the price of the game modeled in the matrix game is a certain conditional indicator that reinforces the chosen strategy for the region. The cost of the game (*J*) is modeled before the emergence of aggregate unit strategies, since otherwise the condition would not hold: $\sum Q_i=1;\ \sum P_i=1$.

Modeling the *J* sequence makes it possible to determine the optimal sustainable development strategy for a specific region. That is, to find exactly that evaluation indicator that makes it possible to improve sustainable development, which is presented in the form of a complex integral index of sustainable development of the region under the conditions of globalization challenges.

Calculations carried out by the authors using the *Madhcad* software made it possible to determine *J* and calculate *Q, P* - sustainable development strategies for the Kiev region and the city of Kyiv based on the results of simulation, namely:

$$Q = \begin{pmatrix} 0.082 \\ -0.024 \\ 0.006 \\ 0.342 \\ 0.183 \\ 0.411 \end{pmatrix};\ P = \begin{pmatrix} 0.227 \\ 0.374 \\ 0.328 \\ -0.003 \\ 0.121 \\ -0.046 \end{pmatrix};\ J = 0.684$$

Therefore, the use of the matrix game made it possible to obtain certain strategies according to which the region can obtain the most positive results in sustainable development, which makes it possible to illustrate this through the value of the complex integral index of sustainable development of the region in the context of globalization challenges.

As a result of the calculations, the most attractive strategy for the Kiev region, which acted as player "A" in the matrix game, is to increase the number of innovatively active enterprises in industry (in the calculations, this was an indicator of x_{12}). The indicator of innovative and active enterprises belongs to the index component of the innovative and entrepreneurial development (I_3).

For the city of Kyiv, which acted as a "B" player, the most important indicator for ensuring the growth of the comprehensive integrated index of sustainable development was the indicator of direct investments per capita (estimate indicator x_3). The indicator of direct investment per capita refers to the component of economic development (I_1).

If the Kiev region directs efforts to increase the number of innovative and active enterprises, and the city of Kyiv to increase direct investments, then this will lead to the greatest positive effect in terms of sustainable development, namely, it will contribute to the increase of the complex integral index of sustainable development of these regions in the face of globalization challenges.

In Table 4, the values of integral indices and the complex integral index of sustainable development in the context of globalization challenges according to calculations and modeling carried out using the matrix game method are presented.

For the Kiev region, according to the results of the matrix game, the most influential indicator of sustainable development in the conditions of globalization is the evaluation indicator of the number of innovatively active enterprises, which belongs to the third component of sustainable development and is determined by the integral index of innovative and entrepreneurial development (I_3). Isolation of the most influential indicator made it possible to simulate possible changes in sustainable development of the region with the help of the *Madhcad* software, provided the number of innovative and active enterprises increases. These changes are reflected in the simulated values of the integral index of innovative and entrepreneurial development of the Kiev region and the complex index of sustainable development.

Table 4. Value of integral indicators of the components of sustainable development and the complex integral index of sustainable development for 2013-2021

Name of the Integral Index	Year								
	2013	2014	2015	2016	2017	2018	2019	2020	2021
Kiev region									
Integral index of innovative and entrepreneurial development (I_3)	0.036	0.040	0.039	0.048	0.053	0.038	0.046	0.036	0.089
Modeled integral index of innovative and entrepreneurial development ($I_{3\ integral}$)	0.060	0.067	0.066	0.086	0.090	0.064	0.073	0.058	0.130
Comprehensive integrated index of sustainable development (I_{avg})	0.573	0.622	0.655	0.641	0.596	0.612	0.724	0.752	0.909
Modeled complex integral index of sustainable development ($I_{avg\ integral}$)	0.631	0.664	0.708	0.730	0.723	0.690	0.746	0.732	0.852
city of Kyiv									
Integral index of innovative and entrepreneurial development (I_3)	0.084	0.095	0.103	0.106	0.107	0.110	0.123	0.133	0.141
Modeled integral index of innovative and entrepreneurial development ($I_{3\ integral}$)	0.142	0.140	0.154	0.162	0.176	0.167	0.162	0.153	0.163
Comprehensive integrated index of sustainable development (I_{avg})	0.541	0.649	0.759	0.708	0.588	0.646	0.764	0.728	0.693
Modeled complex integral index of sustainable development ($I_{avg\ integral}$)	0.588	0.705	0.834	0.758	0.737	0.696	0.824	0.780	0.724

Source: Calculated by the authors according to the proposed methodical approach

Simulation modeling was also carried out for the city of Kyiv, but in relation to the economic development index, since the most influential indicator according to the results of the matrix game turned out to be the volume of direct investments.

In Figures 4-5, the dynamics of the complex integral index for the Kiev region and the city of Kyiv are presented.

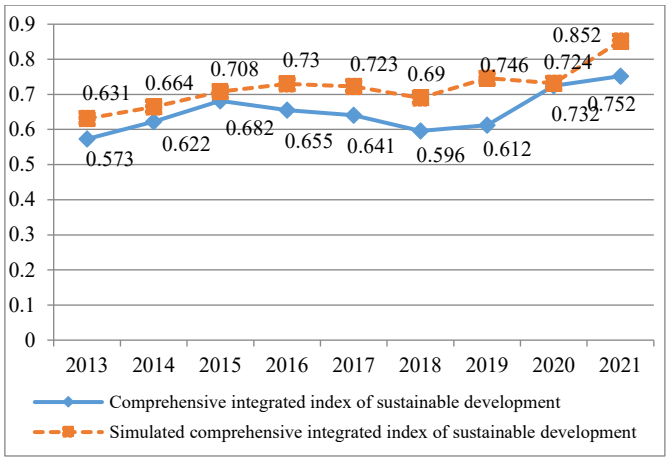

Figure 4. Calculated and modeled complex integral index of sustainable development of the Kiev region for 2013-2021

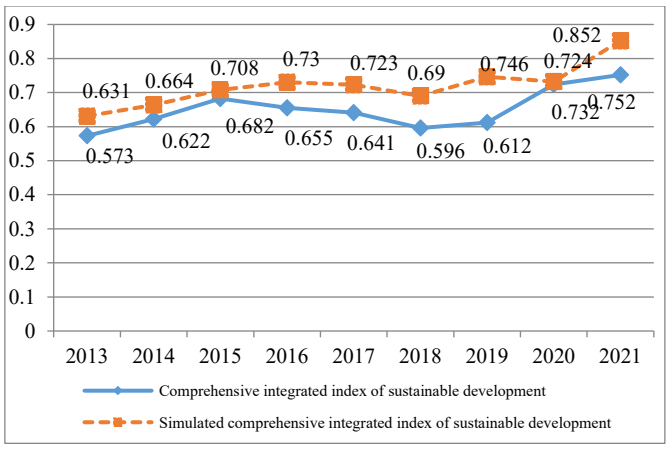

Figure 5. Calculated and modeled complex integral index of sustainable development of the city of Kyiv for 2013-2021

The presented results of the calculated and modeled complex integral indices of sustainable development for the Kiev region and the city of Kyiv (see Figures 4-5) clearly demonstrate positive dynamics of the modeled complex integral indices and their positive deviation from the calculated complex integral indices of sustainable development of these regions.

It should be noted that the simulated complex integral index for the Kiev region shows a smaller positive increase in relation to the increase of the simulated complex index of the city of Kyiv. This can be explained by the fact that the Kiev region is the leader and takes the first place in the rating of the comprehensive integrated index of sustainable development in Ukraine, which was calculated by the authors according to this methodological approach. Under such conditions, for greater growth, it is necessary to use a greater amount of resources and make greater efforts to obtain an increase in the comprehensive index of sustainable development.

Thus, the approbation of the methodical approach proposed by the authors to ensure sustainable development of regions in the conditions of globalization makes it possible to assess the state of sustainable development, as well as the influence of the most influential factors on changes in the complex integrated index of sustainable development of the region in the process of solving strategy matrices using the matrix game approach.

5. CONCLUSIONS

Thus, various methods and approaches were used in this study to substantiate the most influential indicators on sustainable development of the regions using the matrix game method, including: normalization – bringing all indicators of the assessment of sustainable development to a single standardized measurement; grouping - separation of the subsystems of sustainable development; graphic – illustrating the obtained calculation results. Also, a wide range of mathematical methods was used, including: correlation analysis, for calculations of integral indices of the components of sustainable development and complex index of sustainable development; multiple regression, to determine the influence coefficients when calculating integral indices; simulation modeling for modeling the principles of sustainable development on the example of specific regions; matrix game method for choosing the most optimal strategy for sustainable development of the regions in the future, taking into account the influence of integral indices and evaluation indicators on sustainable development of regions.

The scientific novelty of this study is the improvement of the methodical approach to assessing sustainable development of the regions in the context of globalization challenges,

which, unlike the existing ones, involves the use of the matrix game method, which makes it possible to determine the most optimal strategy for sustainable development of the region based on the determination of the most influential indicators that provide in the future, the increase of the complex integral index of sustainable development of the region.

In the proposed approach of determining the strategy of sustainable development of regions using the matrix game method, the object of this approach is to determine the most influential factors on sustainable development of regions, the subject of which is directly sustainable development. In order to achieve the most optimal results, it is proposed to determine the most influential indicators and integral indices that in the future contribute to the growth of the complex integral index of sustainable development of regions.

It should be noted that this method was not applied to regions, two regions of Ukraine were chosen as an example, but this method is also suitable for determining sustainable development strategies in the face of globalization challenges and for other regional economic systems of any level.

The use of the matrix game model for two players, which, in our case, the regions of Ukraine acted as, ensures the practical accuracy of proving the statistical methods of the solution thanks to the linear approximation of the strategies by optimizing the choice of the game strategy according to the coefficients of the influence of endogenous factors on the integral index for the two regions.

The matrix game method has certain drawbacks, like any other mathematical approach. In this case, the disadvantage is the fact that when many regions participate in the simulation, it makes it difficult to determine the optimal strategy for their development, because in this case certain coalitions of regions and transitions of regions from one coalition to another may arise. Therefore, to simplify the calculations, the authors suggest using the matrix game method only in relation to two regions.

The issue of developing the strategies for sustainable development of the regions, taking into account the singled out most influential indicators, requires further research, which in practice will make it possible to increase the effectiveness of the regional strategies for sustainable development.

REFERENCES

[1] Heydari, Esmat, Solhi, M., Janani, L., Farzadkia, M. (2021). Determinants of sustainability in recycling of municipal solid waste: Application of community-based social marketing (CBSM). Challenges in Sustainability, 9(1): 16-27. https://doi.org/10.12924/cis2021.09010016

[2] Boiarynova, K., Popelo, O., Tulchynska, S., Gritsenko, S., Prikhno. I. (2022). Conceptual foundations of evaluation and forecasting of innovative development of regions. Periodica Polytechnica Social and Management Sciences, 30(2): 167-174. https://doi.org/10.3311/PPso.18530

[3] Popelo, O., Tulchynska, S., Marhasova, V., Garafonova, O., Kharchenko, Y. (2021). Public management of regional development in the conditions of the inclusive economy formation. Journal of Management Information and Decision Sciences, 24(S2): 1-8.

[4] Poveda, C.A. (2023). The criticality of using frameworks designed by consensus (FDC) to identify and select criteria and indicators to assess sustainability performance of cities and communities. Challenges in Sustainability, 11(1): 19-33. https://doi.org/10.12924/cis2023.11010019

[5] Abisheva, G.O., Mukhamadeyeva, R.M., Akokhova, N.V., Mukhamadeyeva, I.A., Mukhamadeyev, T.M. (2018). The integrated system of ensuring sustainable development of the region. In Proceedings of the 32nd International Business Information Management Association Conference, IBIMA 2018-Vision 2020: Sustainable Economic Development and Application of Innovation Management from Regional expansion to Global Growth, pp. 3708-3714.

[6] Pivnyak, G.G., Kovrov, O.S., Cherep, A.Y. (2013). Modern role of resource universities for ensuring sustainable environmental development of the mining regions. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 1: 77-83.

[7] Huan, Y., Zhang, T., Zhou, G., Zhang, L., Wang, L., Wang, S., Feng, Z., Liang, T. (2023). Untangling interactions and prioritizations among Sustainable Development Goals in the Asian Water Tower region. Science of The Total Environment, 874: 162409. https://doi.org/10.1016/j.scitotenv.2023.162409

[8] Dubyna, M., Popelo, O., Zhavoronok, A., Lopashchuk, I., Fedyshyn, M. (2023). Development of the credit market of Ukraine under macroeconomic instability. Public and Municipal Finance, 12(1): 33-47. http://doi.org/10.21511/pmf.12(1).2023.04

[9] Kryvda, O., Tulchynska, S., Smerichevskyi, S., Lagodiienko, N., Marych, M., Naghiyeva, A. (2022). Harmony of ecological development in the conditions of the circular economy formation. Environment and Ecology Research, 10(1): 11-20. https://doi.org/10.13189/eer.2022.1001

[10] Anusha, B.N., Babu, K.R., Kumar, B.P., Sree, P.P., Veeraswamy, G., Swarnapriya, C., Rajasekhar, M. (2023). Integrated studies for land suitability analysis towards sustainable agricultural development in semi-arid regions of AP, India. Geosystems and Geoenvironment, 2(2): 100131. https://doi.org/10.1016/j.geogeo.2022.100131

[11] Huan, Y., Zhu, X., Liang, T., Zhou, G., Wang, L., Zhang, L., Feng, Z. (2023). Identifying holistic actions for implementing the sustainable development goals related to livelihood–energy–ecosystem–water nexus in the Asian water tower region. Resources, Conservation and Recycling, 191: 106905. https://doi.org/10.1016/j.resconrec.2023.106905

[12] Aragonés-Beltrán, P., González-Cruz, M.C., León-Camargo, A., Viñoles-Cebolla, R. (2023). Assessment of the needs for the regional development according to criteria based on the sustainable development goals in the Meta region (Colombia). Sustainable Development, 31(2): 1101-1121. https://doi.org/10.1002/sd.2443

[13] Novomlynets, O., Marhasova, V., Tkalenko, N., Kholiavko, N., Popelo, O. (2023). Northern outpost: Chernihiv polytechnic national university in the conditions of the Russia-Ukrainian war. Problems and Perspectives in Management, 21(2): 1-9. http://doi.org/10.21511/ppm.21(2-si).2023.05

[14] Shaposhnykov, K., Abramova, A., Zhavoronok, A., Liutikov, P., Skvirskyi, I., Lukashev, O. (2021). Ecosystem of VAT administration in E-Commerce: Case of the eastern Europe countries. Estudios de Economía

Aplicada, 39(5): 4909. https://doi.org/10.25115/eea.v39i5.4909
[15] Dubyna, M., Popelo, O., Kholiavko, N., Zhavoronok, A., Fedyshyn, M., Yakushko, I. (2022). Mapping the literature on financial behavior: A bibliometric analysis using the VOSviewer program. WSEAS Transactions on Business and Economics, 19: 231-246.
[16] Akomaning, Y.O., Darkwah, S.A., Živělová, I., Hlaváčková, P. (2023). Achieving sustainable development goals in Ghana: The contribution of non-timber forest products towards economic development in the Eastern Region. Land, 12(3): 635. https://doi.org/10.3390/land12030635
[17] Wang, S.W., Kim, W., Song, C., Park, E., Jo, H., Kim, J., Lee, W. (2023). Relationships among water, food, energy, and ecosystems in the mid-latitude region in the context of the sustainable development goals. Environmental Reviews, 31(1): 111-121. https://doi.org/10.1139/er-2022-0041
[18] Tulchynska, S., Popelo, O., Marhasova, V., Nusinova, O., Zhygalkevych, Z. (2021). Monitoring of the ecological condition of regional economic systems in the context of sustainable development. Journal of Environmental Management & Tourism, 12(5): 1220-1228. https://doi.org/10.14505//jemt.v12.5(53).06
[19] Popelo, O., Shaposhnykov, K., Popelo, O., Hrubliak, O., Malysh, V., Lysenko, Z. (2023). The influence of digitalization on the innovative strategy of the industrial enterprises development in the context of ensuring economic security. International Journal of Safety and Security Engineering, 13(1): 39-49. https://doi.org/10.18280/ijsse.130105
[20] Garafonova, O., Marhasova, V., Popelo, O., Tulchynska, S., Pohrebniak, A., Tkachenko, T. (2022). Environmentalization of Production as a direction of ensuring sustainability of production activities of enterprises and increasing their economic security. International Journal of Safety and Security Engineering, 12(2): 159-166. https://doi.org/10.18280/ijsse.120203
[21] Li, M., Liu, J., Chen, Y., Yang, Z. (2023). Can a sustainable development strategy reduce income inequality in resource-based regions? A natural resource dependence perspective. Resources Policy, 81: 103330. https://doi.org/10.1016/j.resourpol.2023.103330
[22] Annamalaisamy, B., Vepur Jayaraman, S. (2023). Renewable energy for sustainable development in Asia-Pacific region: Do foreign direct investment and regulatory quality matter? Sustainable Development, 31(1): 108-124. https://doi.org/10.1002/sd.2377