


# “Assessing regional innovative development: A methodological approach based on an integral index”


## AUTHORS

Svitlana Tulchynska 



Olha Popelo 



Artur Zhavoronok 



Marta Derhaliuk 



Anna Pohrebniak 



Olena Kostyunik 



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Artur Zhavoronok, Marta Derhaliuk,  
Anna Pohrebniak, Olena Kostiunik,  
2026

Svitlana Tulchynska, D.Sc. in  
Economics, Professor, Department  
of Economics and Entrepreneurship,  
National Technical University of  
Ukraine Igor Sikorsky Kyiv Polytechnic  
Institute, Ukraine.

Olha Popelo, D.Sc. in Economics,  
Professor, Department of Management  
and Administration, Chernihiv  
Polytechnic National University,  
Ukraine.

Artur Zhavoronok, Ph.D. in  
Economics, Associate Professor,  
Department of Finance and Credit,  
Yuriy Fedkovych Chernivtsi National  
University, Ukraine. (Corresponding  
author)

Marta Derhaliuk, D.Sc. in Economics,  
Professor, Department of Economics  
and Entrepreneurship, National  
Technical University of Ukraine Igor  
Sikorsky Kyiv Polytechnic Institute,  
Ukraine.

Anna Pohrebniak, Ph.D. in Economics,  
Associate Professor, Department of  
Economics and Entrepreneurship,  
National Technical University of  
Ukraine Igor Sikorsky Kyiv Polytechnic  
Institute, Ukraine.

Olena Kostiunik, Ph.D. in Economics,  
Associate Professor, Department of  
Economics and Entrepreneurship,  
National Technical University of  
Ukraine Igor Sikorsky Kyiv Polytechnic  
Institute, Ukraine.



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Svitlana Tulchynska (Ukraine), Olha Popelo (Ukraine), Artur Zhavoronok (Ukraine),  
Marta Derhaliuk (Ukraine), Anna Pohrebniak (Ukraine), Olena Kostiunik (Ukraine)

# ASSESSING REGIONAL INNOVATIVE DEVELOPMENT: A METHODOLOGICAL APPROACH BASED ON AN INTEGRAL INDEX

## Abstract

The innovative development of Ukraine's regions requires advanced assessment approaches that account for regional specificities and ensure the effective use of existing potential. This study aims to evaluate the level of innovative development of Ukrainian regions under current socio-economic and wartime challenges. Innovative development is conceptualized as a process of transforming regional economic systems through the generation and implementation of new knowledge, technologies, and managerial solutions, ensuring both qualitative and quantitative changes, sustainable development, post-war recovery, improved resource efficiency, and enhanced competitiveness. The methodological framework is based on a comprehensive multi-stage analytical model for determining an integral indicator. The approach involves a system of input indicators reflecting innovation activity in wartime conditions, followed by correlation analysis to detect multicollinearity among variables. To increase analytical accuracy, regions are clustered by their contribution to gross value added using the interval multiplicity method. The results showed that the Integral Innovation Index of Ukraine for 2018–2024 was characterized by unstable dynamics, a significant decrease in 2022 (0.608), and the absence of a trend. This indicates the sensitivity of innovative development to adverse transformational factors, particularly the challenges posed by war. However, despite the significant deterioration in the value of the Integral Innovation Index during the period of the beginning of large-scale war operations on the territory of Ukraine, the situation improved in the following period (2023 – 0.840, 2024 – 0.952).

## Keywords

potential, strategy, innovation activity, regional economic development, regional economy, sustainable development, integral index, cluster analysis

## JEL Classification

O31, O38, R11, C38

## INTRODUCTION

The modern progress of social development, globalization processes, rapid changes in market conditions, and the post-industrial vector of development are increasingly actualizing the issue of innovative development of the regions, which will contribute to ensuring economic growth on the principles of sustainable development, increasing their competitiveness on domestic and foreign markets. The innovative development of the regions of Ukraine is of particular relevance in the current conditions of military operations. Their innovative basis ensures the achievement of sustainable development goals, which aim not only at creating new opportunities for the production sector but also at increasing the effectiveness of actions aimed at restoring the economic capacities of those affected by military operations, solving social and environmental challenges, ensuring the competitiveness of the country's regions, and their sustainability.

At the same time, innovation activity is one of the important factors of long-term economic growth and increased productivity of regional economies (World Bank, 2026). In addition, regions with higher levels of innovation activity demonstrate greater resilience to crises and rapid adaptation to changes in the external environment.

The innovative development of the regions of Ukraine is understood as the process of developing regional economic systems, based on the generation of new ideas, knowledge, technologies, and other results of innovative activity, and their implementation in the socio-production spheres of economic activity. These management decisions ensure qualitative and quantitative transformations of regional development processes and contribute to the sustainability, meeting growing demand, increasing the efficiency of resource use, and the competitiveness of regions.

This issue becomes particularly relevant in the context of martial law, which is confirmed by analytical assessments of international organizations, according to which the recovery of the Ukrainian economy largely depends on the use of innovation potential, digitalization, and modernization of production infrastructure (World Bank, 2026). At the same time, analytical reports indicate significant differentiation of the levels of innovation development of regions, which necessitates the use of integrated approaches to their assessment and comparison.

The above outlines the need for a comprehensive assessment of innovative development of Ukrainian regions under current socio-economic and wartime challenges.

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## 1. LITERATURE REVIEW

In the current conditions of economic transformation and increased global competition, innovative development is a key factor in ensuring economic growth, increasing the competitiveness of territories, and forming an effective model of regional development (Adamowicz, 2021; Popadynets et al., 2021; Andriushchenko et al., 2022; Hrubliak et al., 2025). At the same time, the analysis of scientific sources indicates the absence of a unified approach to interpreting the essence of the innovative development of regions, which necessitates the systematization of existing approaches.

A significant number of scientific works are devoted to the study of theoretical and practical aspects of innovative development of the economy and regions. Mushenyk (2021) examines the mechanisms of forming a regional innovation system and tools for stimulating investment activity in regions. Vo. Virchenko and Vi. Virchenko (2022) define the essence, types, features, and roles of innovative activity in the context of economic reindustrialization (Khodakivska et al., 2022; Krasnostanova et al., 2021; Vakhovych et al., 2021; Ključnikov et al., 2020).

According to Danylyshyn et al. (2021), Shkarlet et al. (2015), and Shmygol et al. (2021), the innovative development of the region is considered a systemic process based on the functioning of the regional innovation system, within which the interaction of subjects, institutions, and resources takes place in order to create and disseminate knowledge. In this context, innovative development is interpreted as the result of the effective organization of knowledge flows and institutional interaction.

Within the framework of current regional development theory, the innovative development of regions is most often considered through the concept of regional innovation systems (Lopez-Rubio et al., 2020; McCann & Ortega-Argiles, 2011; Uzlov & Li-chun, 2017). Thus, Doloreux and Parto (2005) noted that the innovative development of regions results from the functioning of a system that reflects how technological development occurs within a given territory through the interaction of subjects, institutions, and resources. Pino and Ortega (2018) interpret the innovative development of a region as a process based on the functioning of a regional innovation system that unites institutions, organizations, and mechanisms for the creation, dissemination, and use of knowledge. Samara et al. (2024) consider the inno-

vative development of a region as a dynamic process of creation, transfer, and commercialization of knowledge, which is implemented through the interaction of enterprises, universities, and state institutions.

Moreover, a significant number of studies focus on the process approach, which understands innovative development as a dynamic process of knowledge creation, transfer, and commercialization that drives structural changes in the region's economy.

The results of modern scientific research indicate that the essence of innovative development of regions is revealed through a combination of systemic, institutional, spatial, and evolutionary approaches that focus on the role of knowledge, the interaction of actors, and the territorial features of development. An important contribution to understanding the essence of innovative development of regions was made by Asheim et al. (2019), who prove that innovative development is a consequence of the formation of regional capacity to create and disseminate knowledge; that is, knowledge flows, regional specialization, and institutional support for innovative activity play a key role. Tkachuk et al. (2023) and Andrusiv et al. (2023) consider innovative development of the region through the prism of an innovative ecosystem, which includes development goals, subjects of innovative activity, the environment, and the system of relationships among them.

A separate group comprises studies that consider innovative development through the ecosystem approach, where the key lies in the relationships among the state, business, scientific institutions, and innovation infrastructure. This approach allows us to take into account the complexity and multi-level nature of innovation processes in the regional dimension.

Significant attention is also focused on identifying specific factors of regional development. For example, innovation can be a key factor of economic growth and competitiveness of the state (Stepanenko et al., 2025). The relationships between innovative development, economic growth, and environmental sustainability are interesting to research (Serohina et al., 2023). The impact of

spatial knowledge spillovers on the innovative development of regions and economic growth (Qiu et al., 2018) and the impact of research and development (R&D) spending and highly skilled labor on the innovative activity of regions (Kanellopoulos, 2026; Sokira et al., 2021; Doschanov et al., 2023; Štefenberga et al., 2023) are also relevant. Ponsiglione et al. (2018) argue that innovative development is the result of the dynamic interaction of resources, competencies, and self-organization mechanisms of the regional economy.

Buiak et al. (2023), Horoshkova et al. (2020), and Zhytar et al. (2022) paid considerable attention to building models of regional innovative development that allow the identification of key factors of innovative activity, the relationships between participants in the innovation system, and the forecasting of prospects for regional economic growth. Melnykova (2017), Chorny et al. (2025), and Gumenna and Korotka (2012) study key factors and prerequisites for the formation of an innovation model and regional economic development strategies. Pidorycheva et al. (2020) developed a conceptual model of a regional innovation ecosystem based on the interaction of the main actors of the innovation process – the state, business, scientific institutions, and innovation infrastructure. The model takes into account the institutional environment, the system of connections among participants, and the goals of innovation ecosystem development. The results showed that innovation activity in EU regions is concentrated in knowledge-intensive macroclusters. To increase regional innovativeness, it is advisable to establish regional innovation councils and coordination centers for innovation support (Kharazishvili et al., 2023).

Huang (2022) proposed a model for assessing the innovative capacity of a regional innovation system based on the SRE-framework (subject–resource–environment). The model analyzes the interaction of three key components: participants in innovation activity, resource provision, and the external institutional environment (Kurmanov et al., 2023; Kurmanov et al., 2022; Bischof & Hartl, 2023).

Furthermore, the innovative development of regions is a multidimensional phenomenon that combines systemic, process, and institutional

characteristics and is manifested in the region's ability to generate, disseminate, and effectively use knowledge to ensure economic growth and increase competitiveness.

The next important area of research is the assessment of the innovative development of regions. A number of methodological approaches have been developed in the scientific literature that differ in the set of indicators, data aggregation methods, and analytical tools. Some researchers propose assessing innovative development using technological indicators, such as patent activity and the intensity of innovation processes. Other approaches are based on the use of integral indices that combine quantitative and qualitative indicators of the development of innovation infrastructure, human capital, and the institutional environment.

Qiu et al. (2018) developed a spatial econometric model of regional innovation development that accounts for spatial knowledge spillovers. The model shows that the spread of knowledge between regions is an important factor in innovative growth. Empirical analysis of panel data from regions has shown that external knowledge effects contribute to the acceleration of innovative development of less developed territories and reduce regional disparities (Matricano, 2022; Tsonkov & Zlatev, 2025; Ardila & Valencia, 2021).

Considerable attention is also paid to the sectoral aspects of innovative development of regions. Trusova et al. (2020) investigate the impact of innovations on increasing the competitiveness of the agricultural sector and ensuring the economic security of regions (Baidybekova et al., 2025; S. Semenov & N. Semenov, 2024). At the same time, innovative development of regions is also associated with the modernization of transport and logistics infrastructure (Mordovtsev et al., 2025) and the integration of production and logistics systems (Liu et al., 2024; Shan et al., 2025).

The assessment of the innovative development of regions is carried out using various methodological approaches, which differ in the set of indicators, data aggregation methods, and analysis tools. Alfeo et al. (2019) propose to assess regional innovative development based on the analysis of the dynamics of technological indicators, particularly

patent activity and technological trends across regions. Azimov (2025) suggests an integrated approach that combines quantitative and qualitative indicators (Ključnikov et al., 2020; Vakhovych et al., 2021).

In general, current research also accounts for spatial effects, particularly the spread of knowledge between regions (knowledge spillovers), enabling a more comprehensive assessment of innovation processes in the context of interregional interaction.

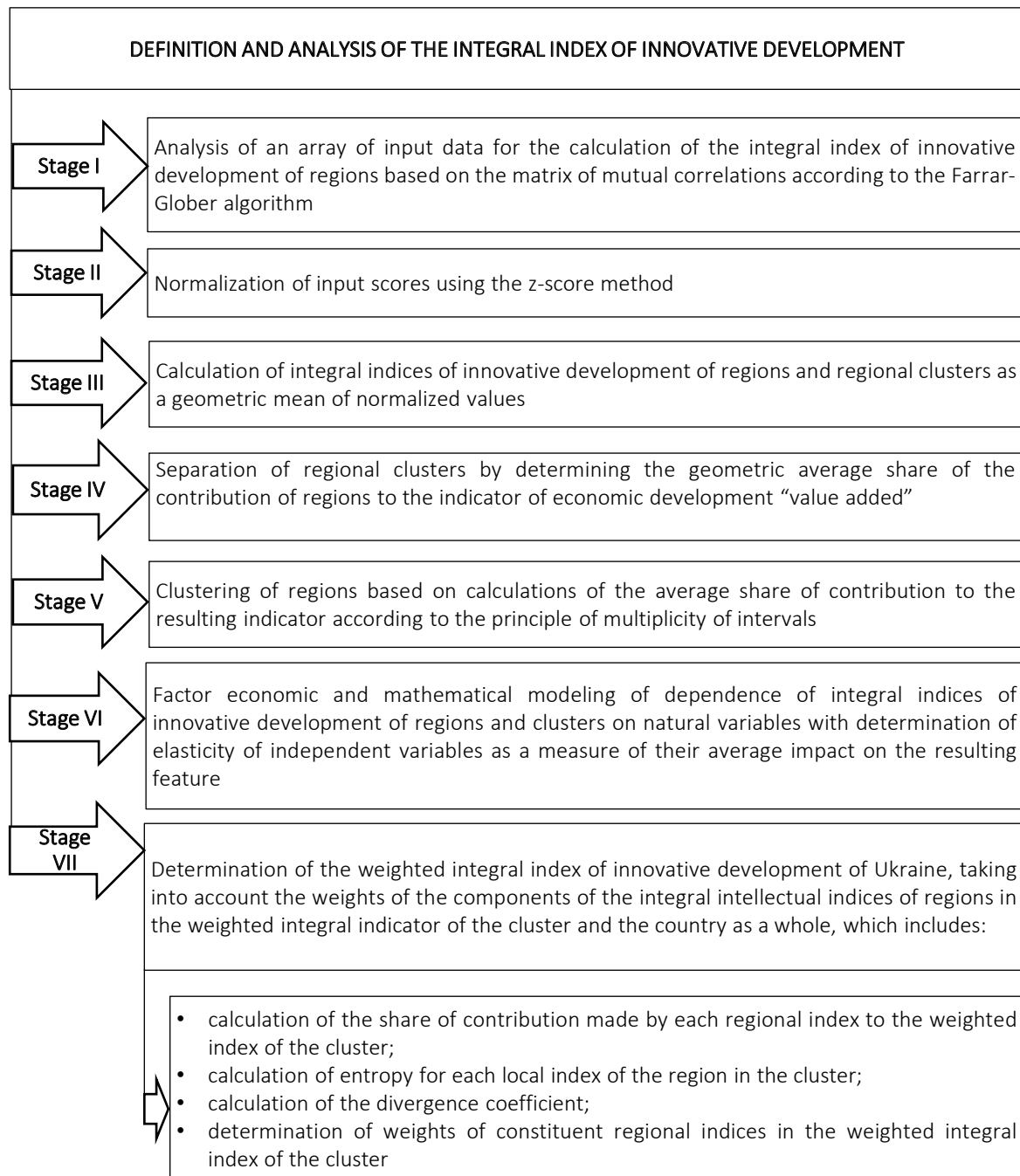
The analysis shows that existing methodological approaches to assessing the innovative development of regions do not fully account for the specifics of economic functioning under military challenges, particularly the impact of security risks, infrastructure destruction, migration, and economic structural transformation.

In this regard, there is an objective need to develop an improved integrated index of innovative development of regions, which would take into account not only traditional indicators of innovative activity, but also factors of military influence. Therefore, the aim of the study is to evaluate the level of innovative development of Ukrainian regions under current socio-economic and wartime challenges.

## 2. METHODOLOGY

To assess innovative development (ID), we use a systematic approach, which makes it possible to study complex phenomena in the interaction of system components in accordance with the principles of systematization and to identify the influence of different factors, including military actions, on the resulting feature of innovative development of the regional and national economic system.

We apply a set of quantitative methods to ensure a comprehensive assessment of innovative development. In particular, correlation analysis is used to formalize the input data, identify relationships between variables, and eliminate multicollinearity. Factor analysis determines the underlying structure of the data, reduces dimensionality, and identifies the most significant factors influencing innovative development.



**Figure 1.** Model of complex analysis of the IIRD as a step-by-step system process

Index analysis normalizes the selected indicators and constructs an integral index that reflects the overall level of innovative development of regions. At the same time, entropy-based methods are used to determine weight coefficients of the indicators, taking into account their variability and informational significance. In addition, clustering methods assess regional disparities, group regions by level of innovative development, and identify patterns of spatial differentiation.

The model of complex analysis of ID and calculation of the integral index of innovative development of regions (IIRD) as a step-by-step system process is presented in Figure 1.

The initial stage of determining the integral index of innovative development of regions (IIRD) is the substantiation of the initial assessment indicators. Thus, we, based on the analysis of existing methodological approaches to assessing the inno-

vative development of regions, determined the following estimated input indicators for 2018–2024:

- R&D expenditures, UAH million ( $X_{1(i,t)}^{idr}$ );
- number of innovatively active industrial enterprises, units ( $X_{2(i,t)}^{idr}$ );
- volume of innovative industrial products (goods, services) sold by enterprises, UAH million ( $X_{3(i,t)}^{idr}$ );
- capital investments in industrial economic activities, % ( $X_{4(i,t)}^{idr}$ );
- capital investments in scientific activities, % ( $X_{5(i,t)}^{idr}$ );
- number of industrial enterprises that introduced innovations, units ( $X_{6(i,t)}^{idr}$ );
- total expenditures of enterprises on innovations, UAH million ( $X_{7(i,t)}^{idr}$ );

In the presented input evaluation indicators  $X_{1(i,t)}^{idr} - X_{5(i,t)}^{inn}$ ,  $i$  - a number of the region,  $t$  - the observation period.

All of the above indicators, which are used for further calculations, were influenced by war actions, which is subsequently reflected in the results of the calculations.

To justify the choice of indicators and the separation of collinear factors from the array of initial input data, we carry out an initial analysis of the

input indicators based on the matrix of mutual correlations (equation 1) according to the Farrar-Glober algorithm.

Analysis of the input evaluation data determined the presence of multicollinearity according to the F-test of the input indicators  $X_{2(i,t)}^{idr}$ ,  $X_{6(i,t)}^{idr}$  та  $X_{7(i,t)}^{idr}$ , and with all other input indicators, as well as the collinearity according to the t-test of each pair of the specified input indicators. In further calculations of the IIIRP, it is advisable to reasonably remove the input indicators  $X_{2(i,t)}^{idr}$ ,  $X_{6(i,t)}^{idr}$  та  $X_{7(i,t)}^{idr}$  and from the array of estimated indicators.

Assessment of innovative development of regions and the country as a whole involves taking into account heterogeneous indicators, both quantitative (measured in monetary units, numbers, persons, etc.) and qualitative (relative values, structural indicators, percentages, etc.). Also, when a variety of estimated indicators are used for a long period of time, there is a significant heterogeneity in the ratio of the maximum and minimum values of indicators and results. This requires the application of normalization of estimated indicators for the determination of dynamic changes and comparison of integral indicators.

At the second stage of determining IIIRD, it is proposed to normalize the input data to reduce them to relative values for further analysis and calculation of integral indicators. To normalize the input data, we use the Z-score method, since this method results in the normalized values of the input values being significantly less sensitive to anomalous values in the array, and the results obtained are easily interpreted.

$$\begin{pmatrix}
 & X_{1(i,t)}^{idr} & X_{2(i,t)}^{idr} & X_{3(i,t)}^{idr} & X_{4(i,t)}^{idr} & X_{5(i,t)}^{idr} & X_{6(i,t)}^{idr} & X_{7(i,t)}^{idr} \\
 X_{1(i,t)}^{idr} & 1 & 0.917 & 0.857 & 0.0495 & 0.419 & 0.92 & 0.938 \\
 X_{2(i,t)}^{idr} & & 1 & 0.935 & 0.0634 & 0.24 & 0.989 & 0.946 \\
 X_{3(i,t)}^{idr} & & & 0.99 & 0.204 & 0.305 & 0.932 & 0.905 \\
 X_{4(i,t)}^{idr} & & & & 0.99 & 0.08 & 0.053 & 0.158 \\
 X_{5(i,t)}^{idr} & & & & & 0.99 & 0.184 & 0.297 \\
 X_{6(i,t)}^{idr} & & & & & & 0.99 & 0.944 \\
 X_{7(i,t)}^{idr} & & & & & & & 0.99
 \end{pmatrix} \quad (1)$$

$$I_{X_{i,t}}^{idr} = \sqrt[4]{\left[ normX_{1(i,t)}^{idr} \right] \cdot \left[ normX_{3(i,t)}^{idr} \right] \cdot \left[ normX_{4(i,t)}^{idr} \right] \cdot \left[ normX_{5(i,t)}^{idr} \right]} \quad (2)$$

Next, integral indices of innovative development of regions are defined as the geometric mean of the normalized values of the input indicators included in the analysis, after checking the presence of multicollinearity according to the Farrar-Glober algorithm.

In the fourth stage, we divide the regions into certain clusters depending on their contribution to such a resultant general macroeconomic indicator of economic development as value added by determining the share of contribution to this indicator of all regions:

$$d_{Reg,i}^t = \frac{Y_{Reg,i}^t}{Y_{Ukr}^t}, \quad (3)$$

where  $Y_{Ukr}^t$  and  $Y_{Reg,i}^t$  – the value added by production costs of business entities for Ukraine of the  $i$ -th region for year  $t$ , respectively;  $t = 2018 - 2024$ ,  $i = 1 \div 25$  – region number.

The fifth stage uses the interval multiplicity method to group regions into clusters. This allows minimizing statistical errors associated with the high heterogeneity of the dataset and ensures more accurate formation of regional groups.

The sixth stage conducts a factor economic and mathematical modeling of the dependence of the IIIRD on the natural variables of indicators of innovative development of regions. The purpose is to establish estimates of the parameters of relationships ( $bi=\{b_0 - b5\}$ ) and basic statistics by building an economic and mathematical model of the following form:

$$\overline{I_{X_{i,t}}^{idr}} = F\left(X_{(i,t)\Sigma}^{idr(j=\overline{1,4})}\right), \quad (4)$$

where  $\overline{I_{X_{i,t}}^{idr}}$  – the average value of the IIIRD;  $t = 2018-2024$  – research period;  $j = \overline{1,4}$  – number of the cluster of regions;  $X_{(i,t)\Sigma}^{idr(j=\overline{1,4})}$  – natural variables, which are predetermined total natural indicators of innovative development of regions.

The resulting feature is the average value of the IIIRD of the corresponding cluster of regions  $\left(I_{X_{i,t}}^{idr(1)}\right)$ .

Elasticity of the independent variables  $\left(E_{X_i}\right)$  as a measure of their average impact on the resulting trait – IIIRD in the regional cluster was calculated according to the formula:

$$E_{X_i} = b_i \frac{\overline{X_{n(i,t)}^{idr}}}{I_{X_{i,t}}^{idr}}. \quad (5)$$

The elasticities of the independent variables can be used by the governing bodies that make decisions to increase the intellectual potential of the region. Comparing the elasticities for the corresponding variables in the model for different clusters makes it possible to determine their efficiency and sensitivity to development.

Estimates of the relationship parameters  $bi=\{b_0 - b5\}$  are determined using the function “LINEST (known\_values\_Y; known\_values\_X; const; statistics)” in MS Excel.

The reliability of the approximation of statistical data by the model for the IIIRD is  $R^2=0.903$ , confirming the validity of economic modeling. Verification of the significance of the estimation of the parameters of the bi relationships of regression multivariate models and determination of the acceptability/inadmissibility of the hypothesis H:1 (TRUE/FALSE) on the significance/insignificance of the estimates was carried out using the logical function “IF(logical\_expression; Meaning\_if\_true; Value\_if\_false)” in the acceptability/unacceptability value of hypothesis H:1 (TRUE/FALSE) in MS Excel.

The final stage is determining the weighted integral index of innovative development of Ukraine taking into account the contributions of clusters to the overall innovative development of the country, calculated using equation (6)  $I_t^{Ukr}$ :

$$I_t^{Ukr} = \sqrt[m]{\prod_{j=1}^m \left(\overline{I_{X_{i,t}}^{idr}}\right)^{w_j}}, \quad (6)$$

where  $t$  – the interval of the study;  $j = \overline{1,m}$  – the number of components of the integral indices of

regions in the cluster;  $w_j$  – the relative value of the  $j$ -th regional index in the structure of the weighted integral index  $I_t^{Ukr}$ .

Determination of the weights of innovative components ( $w_{j(idr)}$ ) in the assessment of weighted IIIRD is carried out according to the following calculations:

$$\left\{ \begin{array}{l} P_{j(inn)} = \frac{\overline{I_{X_{i,j}}^{idr}}}{\sum I_{X_{i,j}}^{idr}} \\ E_{j(idr)} = -\frac{1}{\ln(m)} \sum_{j=1}^m P_{ij} \ln(P_{ij}), \\ D_{j(idr)} = 1 - E_j \\ w_{j(idr)} = \frac{D_j}{\sum_{j=1}^m D_j} \end{array} \right. \quad (7)$$

where  $P_{j(idr)}$  – the share of the contribution made by each regional III;  $E_{j(idr)}$  – entropy of each regional IIIRD;  $D_{j(idr)}$  – the coefficient of divergence and weight of IIIRD;  $w_j$  – the relative value of the  $j$ -th regional index in the structure of the weighted integral index of innovative development of Ukraine,  $I_t^{Ukr}$ .

A set of estimated indicators is the basis for building economic and mathematical factor models and determining integral indices. The assessment of the dynamics of integral indices is carried out by determining their general trend and establishing the reasons for such dynamics by analyzing their information content and entropy capacity. Thus, a set of approaches forms an idea of the state, causes, dynamics, and structure of the IIIRD and determines the directions for managerial decisions on innovative development.

The selected indicators reflect both the resource provision of innovative activity and the results of its implementation, which allows for a comprehensive assessment of the innovative development of regions. At this stage, a coordinated array of input indicators is formed, suitable for further modeling. Using clustering, it is possible to increase the accuracy of further analysis and take into account the spatial heterogeneity of development, which allows identifying the most influential factors of

innovative development and justifying management decisions.

The proposed approach provides a comprehensive analysis of their state, dynamics, and structural features and creates an analytical basis for making effective management decisions in the face of modern challenges.

### 3. RESULTS

The full-scale Russian invasion significantly affects the economic development of Ukraine and has an asymmetric regional nature. Thus, in 2022, a sharp deterioration in the values of most indicators was observed in the regions that were directly affected by the hostilities (Donetsk, Luhansk, Kharkiv, Kherson, and Zaporizhzhia regions) due to the destruction of production infrastructure, a reduction in the innovative activity of enterprises, and a decrease in the volume of sales of innovative products. At the same time, relatively stable or even improved indicators in the western regions (Lviv, Zakarpattia, and Ivano-Frankivsk regions) are explained by the relocation of business, the concentration of investments, and the intensification of innovative activity in the conditions of the redistribution of economic activity. In 2023–2024, a gradual recovery of indicators is observed; however, their dynamics remain uneven, which confirms the significant impact of the war on the innovative development of the regions of Ukraine.

Normalization of selected input indicators for calculating the integral index of innovative development of regions allows us to bring the indicators to comparable relative values, which is necessary due to the significant heterogeneity of the output data in both parametric and non-parametric characteristics. The results of normalization of input indicators using the Z-score method are given in Table 1.

The normalized input data allows us to proceed to the next third stage of calculations, where the normalized values of indicators,  $n = 1, 3, 4, 5$ , are the basis for calculating the IIIRD for 2018–2024 (equation 2). Table 2 shows the calculations of the IIIRD.

**Table 1.** Z-score normalization of data for the analysis of an intelligent indicator

Region	R&D costs $normX_{1(i,t)}^{idr}$							Volume of innovative industrial products (goods, services) sold by enterprises $normX_{3(i,t)}^{idr}$						
	2018	2019	2020	2021	2022	2023	2024	2018	2019	2020	2021	2022	2023	2024
Vinnitsia	-1.22	-1.07	-0.56	0.38	0.50	0.45	1.53	-0.57	-0.82	-1.07	-0.41	0.23	1.69	0.70
Volyn	-1.47	-0.48	-0.05	0.29	-0.47	0.42	1.74	-1.40	-0.67	0.04	0.36	0.70	1.22	-0.70
Dnipropetrovsk	0.05	-0.01	1.31	1.32	-1.01	-1.00	-0.64	0.44	-0.56	-1.56	0.10	-0.44	0.86	1.35
Donetsk	-1.50	-0.20	0.94	0.31	1.07	-1.11	0.48	-0.48	-0.58	-0.68	-0.49	-0.47	0.79	1.93
Zhytomyr	2.22	-0.46	-0.55	-0.50	-0.21	-0.39	-0.11	-0.58	-0.66	-0.75	-1.03	0.58	0.80	1.52
Zakarpattia	-1.84	-0.76	0.61	1.14	0.27	0.20	0.38	1.58	0.46	-0.66	-0.38	0.53	-1.50	-0.07
Zaporizhzhia	-1.18	-0.90	-0.57	0.16	0.25	0.51	1.73	1.07	0.59	0.12	1.18	-4.34	-1.02	-1.14
Ivano-Frankivsk	-1.30	-0.95	-0.61	0.17	0.42	0.91	1.37	0.11	0.55	1.00	1.13	-0.22	-1.09	-1.43
Kyiv	-1.29	-1.07	-0.59	0.61	0.27	0.80	1.27	0.05	-0.40	-0.83	2.13	-1.04	0.03	-0.39
Kirovohrad	-1.65	-0.64	-0.34	1.07	1.16	0.38	0.03	-0.97	-0.79	-0.62	1.64	-0.08	1.07	-0.22
Luhansk	0.13	0.65	0.68	1.45	-0.85	-0.97	-1.09	-1.04	-0.98	-0.93	1.08	0.24	1.28	0.27
Lviv	-0.16	-0.59	0.07	0.94	1.22	0.27	-1.74	-0.07	-0.57	-1.08	-0.98	0.16	0.95	1.57
Mykolaiv	-1.07	-1.12	-0.40	0.04	0.32	0.52	1.71	0.16	-0.52	-1.21	0.32	-0.38	0.35	1.77
Odesa	-0.54	0.87	0.22	-0.07	-1.49	-0.51	1.52	-1.08	-0.63	-0.19	-0.91	0.98	1.41	0.21
Poltava	-1.57	-0.92	-0.32	0.21	1.00	0.54	1.06	-0.21	-0.95	-1.68	0.72	0.30	0.86	0.78
Rivne	-0.69	0.16	0.81	1.77	-0.56	-1.01	-0.48	0.21	-0.36	-0.92	-0.58	-0.75	1.77	0.77
Sumy	-1.23	-1.22	-0.07	1.40	0.95	-0.04	0.23	0.20	-0.44	-1.08	-0.11	-1.13	1.28	1.26
Ternopil	-0.74	-0.49	0.48	1.15	-1.59	0.24	0.97	1.88	0.71	-0.47	-0.16	-0.35	-0.85	-0.91
Kharkiv	-1.31	-1.01	-0.57	0.38	0.29	0.86	1.37	-0.27	-0.66	-1.06	0.96	-0.66	1.55	0.35
Kherson	-1.02	-0.72	-0.03	1.52	0.94	0.31	-1.00	-0.31	-0.51	-0.72	1.17	0.42	0.47	-1.36
Khmelnyskyi	-1.77	-0.93	0.44	0.86	0.37	0.88	0.17	-1.45	-1.00	-0.55	0.57	0.42	0.50	1.16
Cherkasy	-0.87	-1.55	-0.36	0.63	0.09	0.82	1.23	-0.23	-0.59	-0.96	-1.02	0.41	1.68	0.67
Chernivtsi	0.19	0.96	0.10	0.15	-1.74	-0.78	1.12	-1.01	-0.58	-0.15	1.60	0.99	-0.25	-0.75
Chernihiv	-1.33	-0.83	-0.61	0.00	0.55	0.75	1.47	1.69	0.83	-0.02	0.07	-3.21	-0.81	-1.12
Region	Capital investments in industrial economic activities, $normX_{4(i,t)}^{idr}$							Capital investments in scientific activities, $normX_{5(i,t)}^{idr}$						
	2018	2019	2020	2021	2022	2023	2024	2018	2019	2020	2021	2022	2023	2024
Vinnitsia	0.02	-0.63	-1.28	1.50	0.32	0.58	-0.88	0.01	-0.39	-0.77	-0.93	0.04	0.17	2.05
Volyn	1.00	0.02	-0.96	-0.83	0.64	0.35	-1.03	-0.53	0.72	1.98	-0.53	-0.04	-0.53	-0.53
Dnipropetrovsk	-0.02	-0.28	-0.52	0.39	0.14	-1.08	-0.49	0.70	0.70	0.70	0.70	0.30	-1.40	-1.40
Donetsk	-0.10	-0.49	-0.87	0.24	0.21	-0.35	-0.53	-1.00	-0.92	-0.84	-0.02	0.06	1.61	0.71
Zhytomyr	-0.42	-0.47	-0.50	0.83	0.39	-1.29	0.14	-0.50	-0.50	-0.50	0.38	0.02	-0.50	-0.50
Zakarpattia	-0.80	-0.52	-0.25	0.27	-0.48	0.65	1.77	-0.13	0.79	1.72	-0.13	-0.02	-1.06	-0.13
Zaporizhzhia	0.70	0.74	0.78	0.39	0.03	-1.04	-1.72	1.55	0.46	-0.63	0.24	0.02	-0.78	-1.37
Ivano-Frankivsk	-1.44	-0.42	0.61	-0.03	-0.26	0.26	1.66	-0.13	-0.13	-0.13	1.72	0.01	-1.06	-1.06
Kyiv	1.13	0.34	-0.45	-1.90	0.16	0.31	-0.16	-0.74	-0.29	0.16	1.97	0.01	-0.51	-0.97
Kirovohrad	-1.23	-0.75	-0.28	-0.47	0.46	0.34	0.68	1.88	1.78	1.77	1.74	1.72	1.71	-1.71
Luhansk	1.93	0.48	-0.97	-0.49	-0.75	-0.55	0.24	-1.10	-0.60	-0.12	-0.12	0.20	1.19	-0.77
Lviv	-1.83	-0.35	1.15	0.45	-0.04	0.89	-0.07	1.28	0.94	0.61	-0.93	-0.59	-0.49	-1.37
Mykolaiv	-1.49	-0.84	-0.19	-0.17	0.48	0.39	0.91	-0.26	-0.06	0.15	1.37	0.89	0.55	-1.89
Odesa	0.07	-0.40	-0.86	-0.74	-0.21	0.45	1.99	0.47	-0.62	-1.70	1.34	0.01	0.47	-0.41
Poltava	-0.07	-0.60	-1.13	-0.77	0.24	-0.05	1.60	1.61	0.95	0.29	-0.38	-0.61	-0.82	-1.05
Rivne	1.95	0.45	-1.06	-0.49	-0.19	-0.48	0.16	0.48	-0.19	-0.85	1.79	0.01	-0.85	-0.85
Sumy	-1.15	-0.13	0.90	1.19	-0.09	0.90	-1.05	0.85	0.19	-0.48	-1.79	0.01	-0.48	0.85
Ternopil	-1.70	-0.83	0.04	0.63	0.09	1.33	0.25	0.68	-0.54	-1.77	-0.14	0.02	1.23	-0.14
Kharkiv	0.30	-0.24	-0.78	0.10	-0.33	0.03	1.87	1.71	0.48	-0.75	0.15	0.20	-0.75	-1.20
Kherson	-0.93	-0.58	-0.25	0.48	0.96	0.50	-0.99	1.34	0.69	0.05	0.69	-0.31	-1.24	-1.24
Khmelnyskyi	-1.11	-0.61	-0.12	1.24	0.73	-0.59	-0.32	-0.67	-0.84	-1.00	0.31	0.05	-0.35	1.60
Cherkasy	-0.48	-0.77	-1.08	1.15	0.54	-0.56	0.28	-0.94	0.16	1.26	-0.94	0.00	1.26	-0.94
Chernivtsi	-1.29	-0.66	-0.04	-0.22	-0.19	1.05	1.56	1.78	0.74	-0.30	-0.30	-0.01	-0.30	-1.34
Chernihiv	1.22	0.68	0.14	0.46	-0.88	-0.06	-0.61	-0.97	-0.51	-0.07	1.74	0.01	-0.07	-0.97

**Table 2.** Integral indices of innovative development of regions, 2018–2024

Region	Years						
	2018	2019	2020	2021	2022	2023	2024
Vinnitsia	0.347	0.383	0.376	0.589	0.069	0.708	0.545
Volyn	0.330	0.171	1.185	0.579	0.138	0.188	1.046
Dnipropetrovsk	0.416	0.385	0.608	0.491	0.649	1.023	0.903
Donetsk	0.472	0.466	0.458	0.132	0.047	0.559	0.843
Zhytomyr	0.611	0.692	0.468	0.620	0.144	0.573	0.411
Zakarpattia	0.572	0.677	0.452	0.444	0.168	0.434	1.010
Zaporizhzhia	0.756	0.679	0.511	0.424	0.051	0.420	1.374
Ivano–Frankivsk	0.461	0.407	0.545	0.637	0.068	0.373	1.125
Kyiv	0.611	0.486	0.236	1.327	0.116	0.666	0.446
Kirovohrad	0.846	0.699	0.874	0.982	0.495	0.499	0.963
Luhansk	0.457	0.458	0.359	0.732	0.247	0.691	0.703
Lviv	0.875	0.822	0.649	0.339	0.130	0.509	0.889
Mykolaiv	0.767	0.409	0.360	0.366	0.268	0.670	0.838
Odesa	0.480	0.751	0.792	0.662	0.095	0.356	0.952
Poltava	0.465	0.305	0.583	0.549	0.162	0.793	0.947
Rivne	0.621	0.631	0.651	0.398	0.291	0.582	0.446
Sumy	0.929	0.253	0.651	0.889	0.053	0.486	1.051
Ternopil	0.974	0.415	0.410	0.377	0.132	1.292	0.522
Kharkiv	0.667	0.409	0.400	0.597	0.170	0.183	1.150
Kherson	0.942	0.637	0.246	0.376	0.169	0.333	1.092
Khmelnyskyi	0.483	0.825	0.482	0.490	0.132	0.810	1.005
Cherkasy	0.627	0.435	0.531	0.537	0.123	0.774	0.717
Chernivtsi	0.767	0.723	0.351	0.100	0.174	0.751	1.314
Chernihiv	0.637	0.526	0.238	0.781	0.144	0.378	1.104

For 2018–2024, the lowest value of the average for Ukraine of the IIIRD was in 2022, and the highest value was observed in 2024.

Clustering of regions based on their contribution to the total value added indicator is carried out using equation 3, which allows us to assess the relative contribution of individual regions to Ukraine's economic output during 2018–2024. The share of the contribution of regions to the added value is given in Table 3, which allows us to identify regions with a high, medium, and low level of contribution to the macroeconomic result and use these data for further clustering and more accurate formation of the integral index.

The results show a very high discrepancy in the share of the regions' contribution to the value added indicator. Thus, the city of Kyiv accounts for the average for the period under study 43.6%; this value is 82 times higher than the share of the contribution of the Chernivtsi region or 132 times more than the contribution of the Luhansk region. Such a discrepancy in variation gives grounds for excluding the city of Kyiv from further studies

and grouping the regions for further careful determination of innovative development. The discrepancy between Dnipropetrovsk and Luhansk regions in terms of the geometric average share in the total value added index is 28.15 times.

Table 4 groups regions into clusters, which minimizes statistical errors associated with the high heterogeneity of the data set and ensures more accurate formation of regional groups.

As a result, 4 clusters with approximately the same share of regions (from 12.4% to 14.67%) were obtained in the resulting indicator for the period 2018–2024, namely value added, but with a different number of regions. Cluster 1 has the largest number of regions – 13, cluster 2 – 6 regions (Mykolaiv, Cherkasy, Vinnitsia, Zaporizhzhia, Poltava, and Donetsk), cluster 3 – 3 (Odesa, Kharkiv, and Lviv) and cluster 4 – 2 regions (Kyiv and Dnipropetrovsk).

The obtained results are quite heterogeneous and demonstrate significant changes in time, therefore, to obtain more accurate calculations, further calculations are carried out by clusters of regions (Table 5).

**Table 3.** The share of the regions’ contribution to the “value added” indicator, 2018–2024

Region	Contribution of regions to value added by production costs of business entities, $d_{reg,i}^t$ . for the period 2018–2024, %							The average value of the share of the regions’ contribution to value added, $\overline{d_{ger,i}^t}$ for the period 2018–2024, %
	2018	2019	2020	2021	2022	2023	2024	
Vinnitsia	1.92	1.88	2.01	2.33	2.28	2.46	2.35	2.18
Volyn	1.56	1.54	1.67	1.37	1.64	2.20	1.90	1.70
Dnipropetrovsk	9.70	9.64	10.07	10.97	8.28	8.21	8.17	9.29
Donetsk	4.25	3.44	3.63	3.81	1.61	1.21	1.40	2.76
Zhytomyr	1.29	1.28	1.50	1.23	1.41	1.36	1.38	1.35
Zakarpattia	0.82	0.76	0.94	0.69	0.91	0.85	0.87	0.83
Zaporizhzhia	3.05	2.46	2.89	3.36	2.30	1.70	1.98	2.53
Ivano–Frankivsk	0.95	0.99	1.37	1.28	1.31	1.16	1.23	1.18
Kyiv	5.68	5.70	6.63	5.37	5.03	5.67	5.30	5.63
Kirovohrad	1.11	1.09	1.28	1.25	1.33	1.17	1.24	1.21
Luhansk	0.47	0.55	0.61	0.50	0.10	0.01	0.06	0.33
Lviv	3.70	4.44	4.88	4.49	6.94	7.24	7.02	5.53
Mykolaiv	1.71	1.72	1.93	1.59	0.98	1.18	1.07	1.45
Odesa	3.77	3.81	4.40	4.01	4.09	4.29	4.15	4.07
Poltava	2.65	2.64	3.38	2.55	3.03	2.82	2.90	2.85
Rivne	0.77	0.82	1.02	0.89	1.01	0.90	0.95	0.91
Sumy	1.26	1.26	1.72	1.33	1.13	1.10	1.11	1.27
Ternopil	0.88	1.48	1.09	0.95	1.08	1.04	1.05	1.08
Kharkiv	3.89	4.07	4.82	4.23	3.68	4.14	3.86	4.10
Kherson	0.88	0.86	1.05	1.10	0.55	0.13	0.34	0.70
Khmelnyskyi	1.33	1.21	1.65	1.49	1.49	1.34	1.41	1.42
Cherkasy	1.81	1.91	1.70	1.60	2.17	2.05	2.09	1.90
Chernivtsi	0.40	0.39	0.47	0.47	0.67	0.64	0.65	0.53
Chernihiv	0.86	0.72	1.51	4.11	1.09	0.89	0.98	1.45
Kyiv city	45.31	45.35	37.77	39.02	45.90	46.26	45.57	43.60
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

**Table 4.** Clustering of regions by the indicator of the average share of contribution to the resulting sign Y of value added, 2018–2024

Clustering Options	Cluster 1 Interval boundaries $[d_{reg,i}^{t(min)} \leq d_{reg,i}^t \leq 1,529]$		Cluster 2 Interval boundaries $[1,529 \leq d_{reg,i}^t \leq 3,889]$		Cluster 3 Interval boundaries $[3,889 \leq d_{reg,i}^t \leq 5,461]$		Cluster 4 Interval boundaries $[5,461 \leq d_{reg,i}^t \leq d_{reg,i}^{t(max)}]$	
	$d_{reg,i}^{t(max)}$ 9,291	Luhansk	0.36	Mykolaiv	1.57	Odesa	4.04	Kyiv
	Chernivtsi	0.46	Cherkasy	1.79	Kharkiv	4.09	Dnipropetrovsk	9.05
	Kherson	0.71	Vinnitsia	2.05	Lviv	4.40		
$d_{reg,i}^{t(min)}$ 0.334	Zakarpattia	0.84	Zaporizhzhia	2.74				
	Rivne	0.87	Poltava	2.91				
Number of groups according to the Sturges formula $m = 4$	Ternopil	1.03	Donetsk	3.40				
	Ivano-Frankivsk	1.18						
	Kirovohrad	1.19						
Spacing Width $h = 1.573$	Chernihiv	1.24						
	Zhytomyr	1.25						
	Sumy	1.28						
Multiplicity of intervals $k = 1.5$	Khmelnyskyi	1.35						
	Volyn	1.49						
	Total, %	13.21		14.45		12.40		14.67

**Table 5.** Dynamics of integral index of innovative development by regional clusters

Region	Years						
	2018	2019	2020	2021	2022	2023	2024
<b>Cluster 1</b>							
Kirovohrad	0.846	0.699	0.874	0.982	0.495	0.499	0.963
Volyn	0.330	0.171	1.185	0.579	0.138	0.188	1.046
Khmelnyskyi	0.483	0.825	0.482	0.490	0.132	0.810	1.005
Sumy	0.929	0.253	0.651	0.889	0.053	0.486	1.051
Zhytomyr	0.611	0.692	0.468	0.620	0.144	0.573	0.411
Luhansk	0.457	0.458	0.359	0.732	0.247	0.691	0.703
Chernihiv	0.637	0.526	0.238	0.781	0.144	0.378	1.104
Ivano–Frankivsk	0.461	0.407	0.545	0.637	0.068	0.373	1.125
Zakarpattia	0.572	0.677	0.452	0.444	0.168	0.434	1.010
Rivne	0.621	0.631	0.651	0.398	0.291	0.582	0.446
Kherson	0.942	0.637	0.246	0.376	0.169	0.333	1.092
Ternopil	0.974	0.415	0.410	0.377	0.132	1.292	0.522
Chernivtsi	0.767	0.723	0.351	0.100	0.174	0.751	1.314
<b>SRGEOM <math>\overline{I_{X_{1,t}}^{idr}}</math></b>	0.632	0.505	0.481	0.505	0.155	0.513	0.854
<b>Cluster 2</b>							
Vynnytsia	0.347	0.383	0.376	0.589	0.069	0.708	0.545
Mykolaiv	0.767	0.409	0.360	0.366	0.268	0.670	0.838
Cherkasy	0.627	0.435	0.531	0.537	0.123	0.774	0.717
Donetsk	0.472	0.466	0.458	0.132	0.047	0.559	0.843
Zaporizhzhia	0.756	0.679	0.511	0.424	0.051	0.420	1.374
Poltava	0.465	0.305	0.583	0.549	0.162	0.793	0.947
<b>SRGEOM <math>\overline{I_{X_{2,t}}^{idr}}</math></b>	0.550	0.433	0.463	0.391	0.098	0.640	0.843
<b>Cluster 3</b>							
Lviv	0.875	0.822	0.649	0.339	0.130	0.509	0.889
Odesa	0.480	0.751	0.792	0.662	0.095	0.356	0.952
Kharkiv	0.667	0.409	0.400	0.597	0.170	0.183	1.150
<b>SRGEOM <math>\overline{I_{X_{3,t}}^{idr}}</math></b>	0.654	0.632	0.591	0.512	0.128	0.322	0.991
<b>Cluster 4</b>							
Dnipropetrovsk	0.416	0.385	0.608	0.491	0.649	1.023	0.903
Kyiv	0.611	0.486	0.236	1.327	0.116	0.666	0.446
<b>SRGEOM <math>\overline{I_{X_{4,t}}^{idr}}</math></b>	0.504	0.433	0.378	0.807	0.274	0.826	0.635

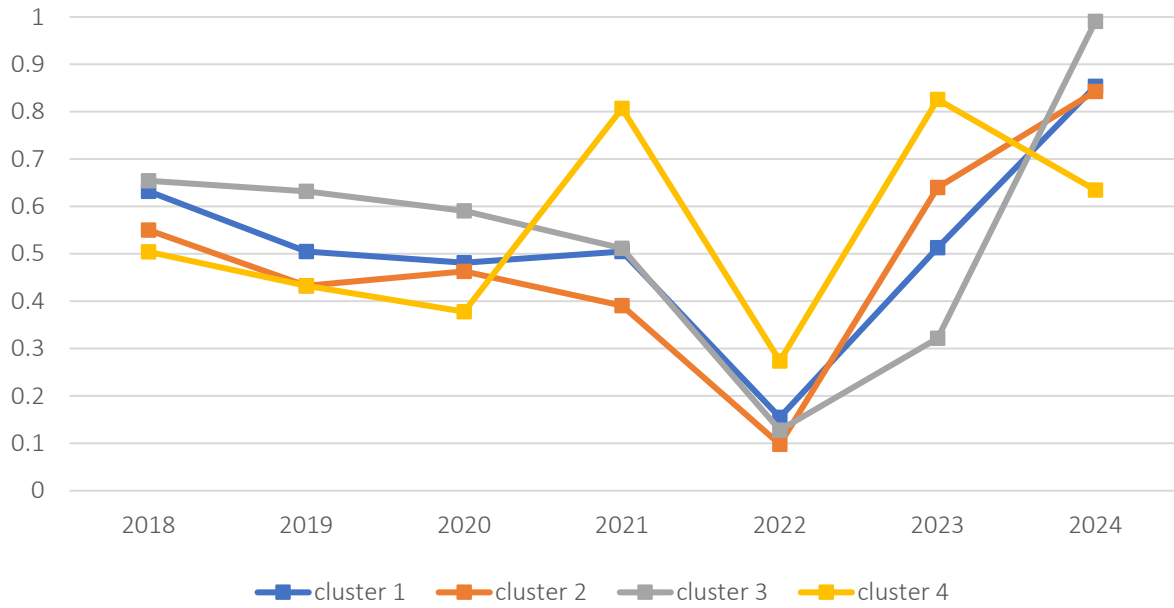
The dynamics of average cluster integral indices of innovative development ( $\overline{I_{X_{i,t}}^{idr}}$ ) is presented in Figure 2.

Figure 2 shows that there is not a single regional cluster that would be a clearly defined leader or outsider during the period under study. At the same time, there is a general trend that can be clearly traced, namely, a decrease in the value of the average IIIRD of regional clusters in 2022. The largest dynamic changes were observed in the values of the average IIIRD of the fourth cluster (which includes Kyiv and Dnipropetrovsk regions), since in 2021 from the lowest positions of the middle IIIRD regional

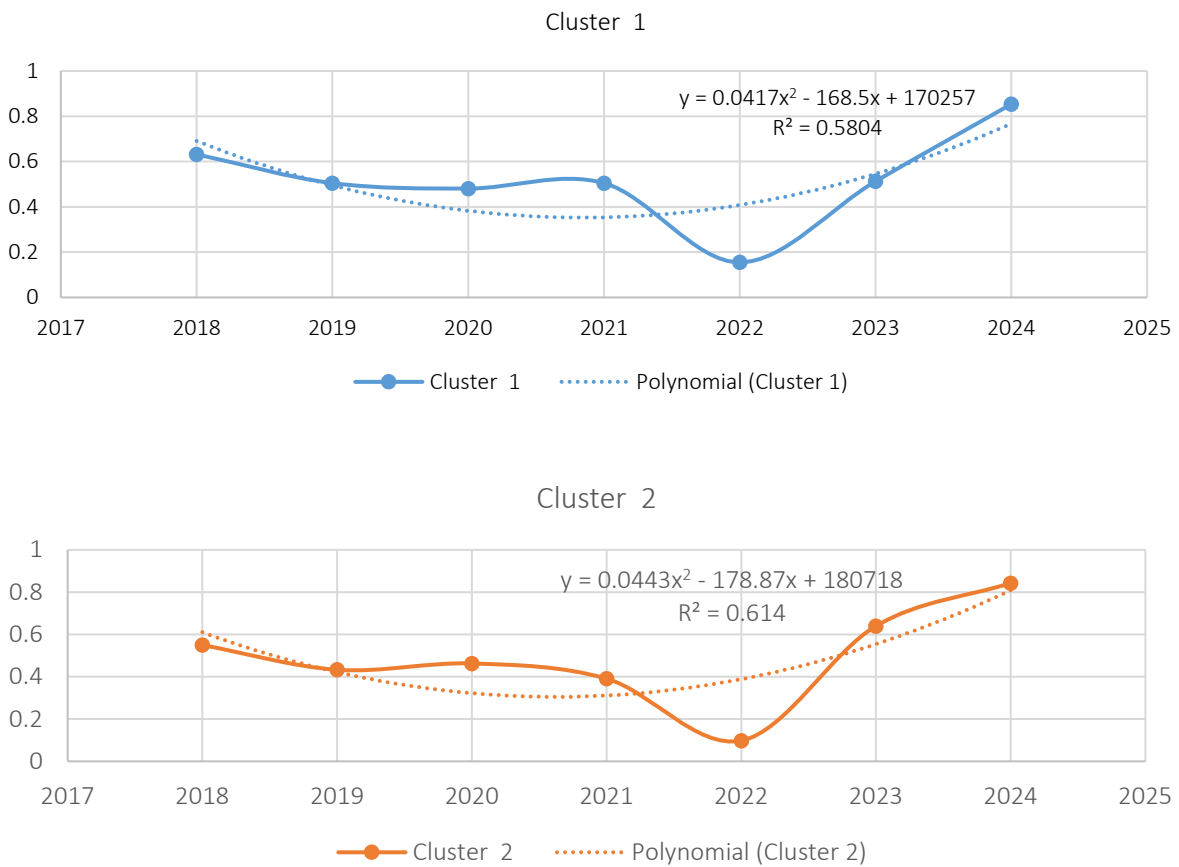
clusters demonstrated a significant rise and separation from the average values of other regional clusters. However, in 2022, the fourth cluster in terms of the average value of the IIIRD had a general downward trend.

Figure 3 shows the point of minimum average values of the integral indices of innovative development of clusters and their inflection (first derivative = 0), which falls on all clusters in 2022.

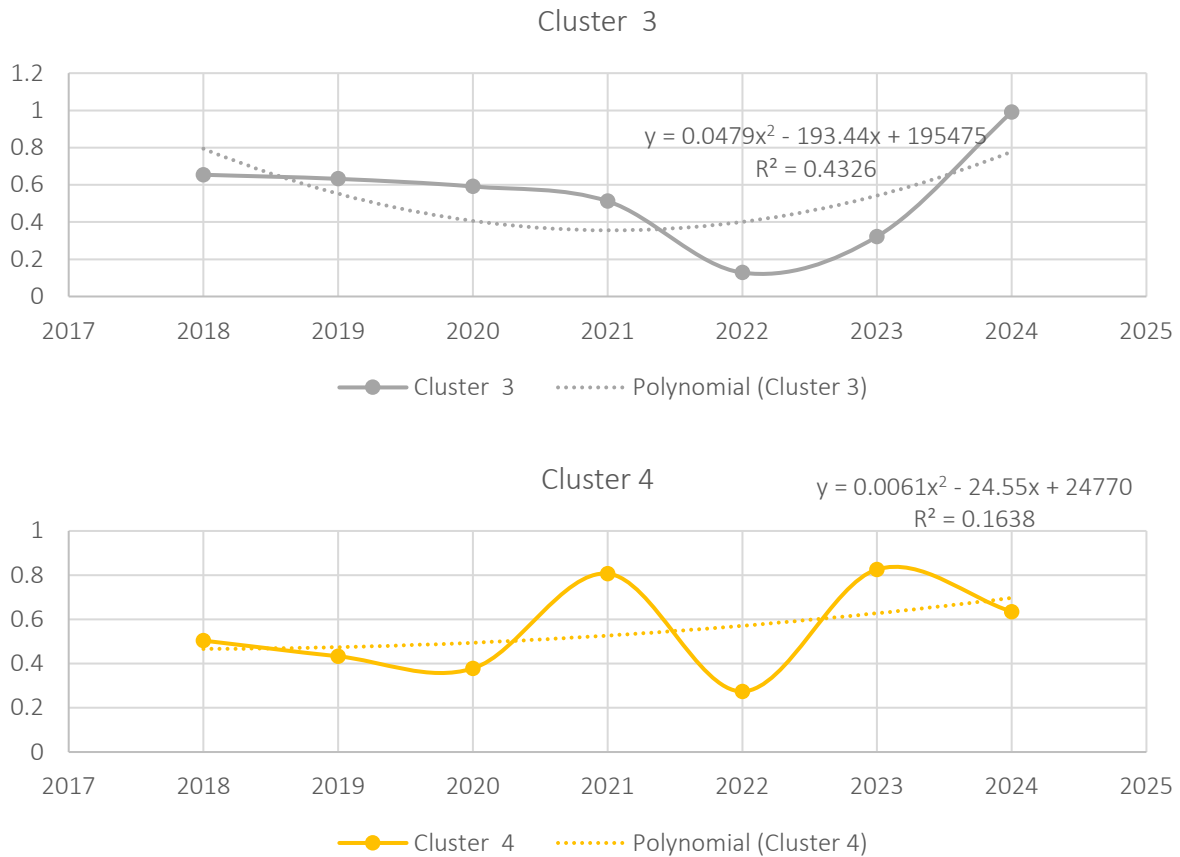
Figure 3 shows the point of minimum average values of the integral indices of innovative development of clusters and their inflection (first derivative = 0), which falls on all clusters in 2022.



**Figure 2.** Dynamics of the average values of the IIRD in the context of clusters



**Figure 3.** Dynamics of the average values of integral indices of innovative development by clusters of regions



**Figure 3 (cont.).** Dynamics of the average values of integral indices of innovative development by clusters of regions

For the development of strategies for innovative development of regions, it is important to determine which indicators affect the IIIRD (the next sixth stage of assessing the innovative development of regions). The results obtained for the first cluster of factor economic and mathematical modeling of the dependence of the IIIRD

on natural variables of indicators of innovative development are presented as an example in Table 6.

The reliability of the approximation of statistical data by the model for the IIIRD is  $R^2 = 0.903$ , and confirms the validity of economic modeling.

**Table 6.** Input data for factor economic and mathematical modeling of the IIIRD from natural variables of indicators of innovative development of regions for cluster 1

Year	Array of indicators for modeling (cluster 1)					Estimates of relationship parameters and basic statistics					
	$I_{X_{i,t}}^{idr(1)}$	$X_{1(i,t)\Sigma}^{idr(1)}$	$X_{3(i,t)\Sigma}^{idr(1)}$	$X_{4(i,t)\Sigma}^{idr(1)}$	$X_{5(i,t)\Sigma}^{idr(1)}$	Test	b5	b4	b3	b1	b0
2018	0.634	452.291	4826.993	359.469	7.524		-0.361	0.003	0.000	0.000	<b>1.640</b>
2019	0.505	512.741	3675.811	344.174	6.980		0.098	0.005	0.000	0.000	1.118
2020	0.485	625.799	2524.619	328.878	6.435	R <sup>2</sup>	0.894	0.112	#N/D	#N/D	#N/D
2021	0.505	773.537	5635.427	368.280	7.920		4.613	1.980	#N/D	#N/D	#N/D
2022	0.158	598.099	4444.298	386.694	8.613		0.236	0.026	#N/D	#N/D	#N/D
2023	0.515	705.128	5179.512	370.062	7.326	HCMC	-3.644	0.705	2.084	-0.844	1.452
2024	0.851	776.932	4647.416	374.517	6.633	D:1	TRUE	FALSE	TRUE	FALSE	<b>TRUE</b>
						$E_x$	-5.613	2.465	1.356	<b>-0.515</b>	

Note: #N/D – no data.

**Table 7.** Determination of the weights of integral indices of innovative development by clusters

Indicator	Regional clusters			
	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Entropy $E_j$	0.951	0.934	0.930	0.957
Divergence Ratio $D_j$	0.039	0.056	0.060	0.033
Weight $w_j$	0.205	0.296	0.316	0.172

The results of calculations according to equation (7) for determining the weights of the IIIRD by regional clusters are presented in Table 7.

Table 7 demonstrates that the highest entropy value (0.957) was obtained for cluster 4, which indicates a lower weight of this cluster in the weighted integral index of innovative development of Ukraine (0.172). The lowest value of entropy (0.930) was obtained for cluster 3, which is reflected in its highest weight in the weighted integral index of innovative development (0.3196).

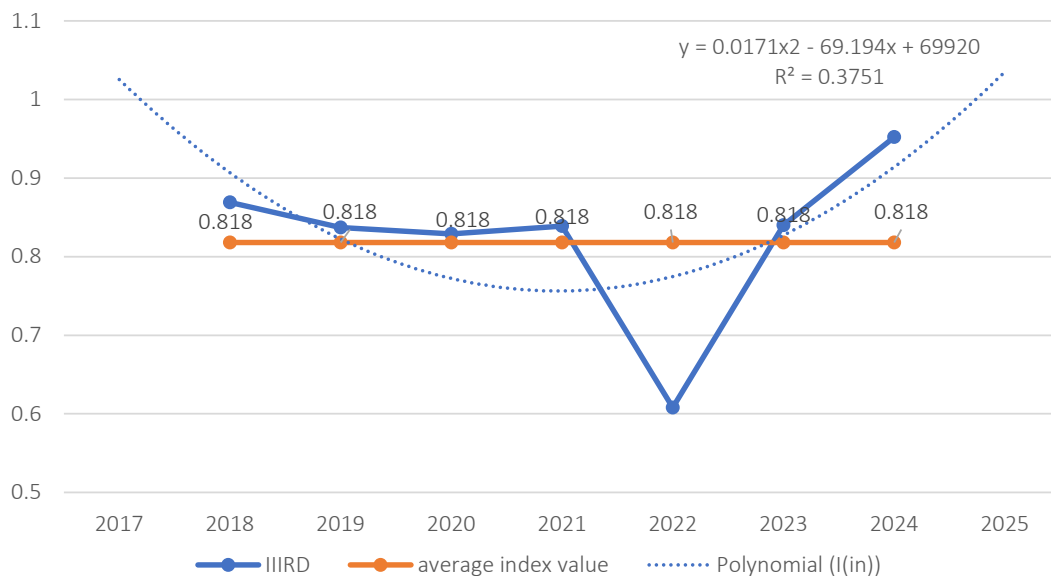
Table 8 shows the calculated weighted integral indices of innovative development of Ukraine for 2018–2024.

The dynamics of the average value of the weighted integral index of innovative development of Ukraine are presented in Figure 4. The minimum value (0.614) is found in 2022, and the maximum value for the study period 2018–2024 is observed in 2024.

**Table 8.** Weighted integral index of innovative development of Ukraine, 2018–2024

Year	$I_t^{Ukr}$	Weighted average of the Integral Innovation Index
2018	0.869	0.818
2019	0.837	
2020	0.829	
2021	0.839	
2022	0.608	
2023	0.840	
2024	0.952	

Integral Innovation Index of Ukraine for 2018–2024 is characterized by unstable dynamics: a significant decline in 2022, and the absence of a trend. This proves the sensitivity of innovative development to adverse transformative factors, such as hostilities. But despite the significant deterioration in the values of the integral innovation index in 2022, which is explained by the beginning of large-scale war on the territory of Ukraine, the situation is improving in the following period.



**Figure 4.** Dynamics of the average value of the weighted integral index of innovative development of Ukraine

Despite the continuation of hostilities on the territory of Ukraine, due to the introduction of various tools to stimulate innovation activity, in most regions in 2024, there is an increase in the integral index of innovative development. This positive trend is confirmed by international calculations. For example, according to the Global Startup Ecosystems Index (2025), after a significant drop in the steps of this index to 50th place in 2022, already in 2025, there is an increase in Ukraine to 42nd place in the rating, which is definitely a positive trend. For the innovative development of territories, both state bodies of regional government and local self-government should pursue a stimulating policy based on a system of flexible regulators and incentives for business entities to innovate through financial, organizational, tax, and advisory support. It is important to create favorable conditions for innovation activity in the regions, to support access to international markets with competitive products, to minimize the risks of innovation activity, and to strengthen motivation for research activities. The instruments of the stimulating policy of innovative development of regions are tax benefits, subsidies, grants, development of innovation infrastructure, ensuring and stimulating effective interaction between state and regional authorities, business, scientific institutions, and higher education institutions. The stimulating policy of innovative development of regions should be flexible to transformative changes in the environment, and is of great importance for stimulating innovation activity in the regions.

## 4. DISCUSSION

The results demonstrates significant variability of the IIIRR both in time and in space. The lowest index values were recorded in 2022 (average for Ukraine – 0.608–0.614), which is directly related to the full-scale Russian invasion and its negative impact on the economy, innovation infrastructure, and investments. All four regional clusters experienced a synchronous decline, which confirms the systemic nature of the shock. At the same time, a clear recovery is observed in 2024: the weighted national IIIRR reached a maximum value of 0.952, and the average cluster indices increased by 40–70% compared to 2022. This indicates the high resilience of Ukraine’s regional innovation systems even in the

context of the ongoing war. The positive dynamics are explained by the introduction of state support instruments (tax breaks, grants, and development of innovation infrastructure) and the adaptation of business to new realities, in particular through the relocation of enterprises and strengthening international cooperation.

Special attention in the study is paid to the identification of regional clusters, which is based on determining the geometric mean share of the contribution of regions to the formation of added-value. This approach is consistent with the concept of regional innovation systems and the cluster theory of territorial development (Ključnikov et al., 2020; Krasnostanova et al., 2021).

Clustering of regions by average share of contribution to value added revealed clear differentiation: cluster 4 (Dnipropetrovsk and Kyiv regions) demonstrates the greatest volatility and potential for recovery, while cluster 1 (13 regions, mostly less industrialized) is characterized by a more stable but lower level. The absence of a clear “leader” or “outsider” among the clusters emphasizes that innovative development is nonlinear and depends on external shocks, and not only on the initial economic potential. Factor modeling (using the example of cluster 1) confirms the significant influence of natural indicators (expenditures on R&D, volume of innovative products, capital investments), with a high  $R^2 = 0.903$ . The elasticities of independent variables allow management bodies to determine priority levers of stimulation – primarily investments in scientific activities and commercialization of products.

An important element of the study is the factorial economic and mathematical modeling of the dependence of the integral index of innovative development on the system of natural indicators. This approach allows us to determine the strength and direction of the influence of individual factors on the resulting indicator (Kurmanov et al., 2023; Liu et al., 2024).

Comparison of the results with previous studies indicates their consistency and at the same time the novelty of the proposed approach. Thus, according to Korenyako and Maltsev (2021) and the European Commission (n.d.), a decrease in the aggregate inno-

vation index of Ukraine by 5.3% in 2014–2021 was recorded (to 29.8% of the EU average), which correlates with our identification of structural weaknesses (low innovation infrastructure). Similar regional disparities and the impact of the war are reflected by Irtyshcheva and Nosar (2021) and Irtyshcheva et al. (2018), who emphasize the need for a multi-level assessment taking into account clusters.

The national level is confirmed by international rankings: according to the Global Innovation Index (GII) (WIPO, 2025), Ukraine in 2024 took 60th place (4th among countries with income below the average), demonstrating advanced development relative to GDP, especially in knowledge and technology. An even more striking positive trend is recorded by the Global Startup Ecosystem Index: after falling to 50th place in 2022, Ukraine rose to 46th in 2024 and 42nd in 2025, entering the top 10 in Eastern Europe. This fully corresponds to the calculations of the IIIRD growth in 2024 and indicates the real effectiveness of the stimulating policy.

The final stage of the study is the determination of the weighted integral index of innovative development of the country, which is formed based on the weight coefficients of regional integral indices. This approach allows us to take into account the contri-

bution of each region to the formation of national innovative potential (Mordovtsev et al., 2025; Tsonkov & Zlatev, 2025; Shvydkyi et al., 2026).

The proposed approach outperforms previous methods (e.g., simple sum weighting or ranking approaches of L. Bezzubko and B. Bezzubko (2017)) due to the mandatory multicollinearity check, the use of geometric mean, and entropy weighting at the national level. This approach also develops the ideas of regional innovation ecosystems of Tkachuk et al. (2023) and Pilko et al. (2024), offering a practical tool for monitoring and strategic planning.

The results obtained are of important practical importance for regional and local governments. For further innovative development, a flexible incentive policy is needed: tax breaks, grants, infrastructure development (science parks, clusters), increased interaction between business, science, and government, as well as support for entering international markets. Particular attention should be paid to regions of clusters 1 and 2, where the growth potential is the greatest, but resources are limited. Such an approach will contribute not only to the restoration, but also to Ukraine's transition to the model of "innovative leadership", which is key for post-war reconstruction and European integration.

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## CONCLUSION

The aim of this study was to assess the level of innovative development of regions of Ukraine in the context of modern socio-economic and military challenges. The paper determined the integral index of innovative development of regions. The results are characterized by unstable dynamics during the seven years under study. The full-scale Russian invasion led to a pronounced asymmetric decline in regional innovative development in 2022, and then to an uneven recovery in different regions, which confirms the persistent influence of wartime factors. The highest value of the weighted identifier of Ukraine for the studied period was in 2024 (0.962), and the lowest – in 2022 (0.608).

The practical significance of the study lies in the possibility of obtaining high-quality information and analytical content on the innovative development of regions. This allows assessing the current state of innovative development, identifying existing imbalances, analyzing dynamic changes, identifying the most influential factors on the innovative development of regions, assessing their elasticity, which will contribute to increasing the efficiency of management decision-making. The above will allow outlining strategic priorities for the innovative development of regions for the state regional administration and local governments in order to substantiate decisions on the allocation of resources to ensure innovative development.

Further research requires improving the methodological approach to assessing the impact of management factors on the innovative development of regions of Ukraine.

## AUTHOR CONTRIBUTIONS

Conceptualization: Svitlana Tulchynska, Olha Popelo, Artur Zhavoronok, Marta Derhaliuk, Anna Pohrebniak, Olena Kostiuunik.

Data curation: Svitlana Tulchynska, Olha Popelo, Artur Zhavoronok.

Formal analysis: Svitlana Tulchynska, Olha Popelo, Artur Zhavoronok, Marta Derhaliuk, Anna Pohrebniak, Olena Kostiuunik.

Investigation: Marta Derhaliuk, Anna Pohrebniak, Olena Kostiuunik.

Methodology: Svitlana Tulchynska, Olha Popelo, Artur Zhavoronok, Marta Derhaliuk, Anna Pohrebniak, Olena Kostiuunik.

Project administration: Artur Zhavoronok.

Resources: Svitlana Tulchynska, Olha Popelo, Artur Zhavoronok.

Supervision: Olha Popelo, Artur Zhavoronok.

Validation: Svitlana Tulchynska, Marta Derhaliuk, Anna Pohrebniak, Olena Kostiuunik.

Visualization: Svitlana Tulchynska, Olha Popelo, Artur Zhavoronok, Marta Derhaliuk, Anna Pohrebniak, Olena Kostiuunik.

Writing – original draft: Svitlana Tulchynska, Olha Popelo, Artur Zhavoronok, Marta Derhaliuk, Anna Pohrebniak, Olena Kostiuunik.

Writing – review & editing: Svitlana Tulchynska, Olha Popelo, Artur Zhavoronok.

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