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SUSTAINABLE DEVELOPMENT OF CLUSTER MODELS OF INNOVATIVE ENTREPRENEURSHIP IN THE FACE OF CYBER THREATS: ACCOUNTING, FINANCIAL AND MARKETING MANAGEMENT SUPPORT

Zakhar Pakhniuk
PhD Student, Interregional Academy of Personnel Management, Kyiv, Ukraine;
ORCID: 0009-0009-7929-9562

Tetyana Tsalko
Candidate of Economic Sciences, Associate Professor of the Department of Management, Kyiv National University of Technology and Design, Kyiv, Ukraine;
ORCID: 0000-0002-4609-8846

Svitlana Nevmerzhytska
Candidate of Technical Sciences, Associate Professor of the Department of Management, Kyiv National University of Technology and Design, Kyiv, Ukraine;
ORCID: 0000-0001-5392-9030

Iryna Biletska
D.Sc. in Economics, Professor, Head of Department of International Economics, Marketing and Management, Ivano-Frankivsk Research and Educational Institute of Management, West Ukrainian National University, Ivano-Frankivsk, Ukraine;
ORCID: 0000-0002-6906-7161

Yuliia Rusina
Candidate of Economic Sciences, Associate Professor of the Department of Finance, Kyiv National University of Technologies and Design, Kyiv, Ukraine;
ORCID: 0000-0001-9540-0899

Nataliia Buhas
Candidate of Economic Sciences, Associate Professor of the Department of Management, Kyiv National University of Technology and Design, Kyiv, Ukraine;
e-mail: bugas.nv@knutd.edu.ua
ORCID: 0000-0002-5858-0285
(Corresponding author)

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ABSTRACT

The modern approaches to managing innovation clusters do not sufficiently take into account the complex interaction of accounting and analytical, financial, marketing, innovation, and cybersecurity support, which reduces the effectiveness of strategic management and management decision-making. The purpose of the study is to develop an integrated methodology for managing the sustainable development of cluster models of innovative entrepreneurship based on a combination of accounting and analytical, financial, marketing, and cybersecurity support. An author's model of comprehensive assessment is proposed, which involves normalization of indicators, determination of partial integral indices for individual functional components, calculation of the basic integral index of sustainable development, assessment of synergistic interaction between functional subsystems, determination of the integral index of cyber risk, and formation of the final integral indicator of sustainable development of the cluster model. The testing of the methodology was carried out on the example of five food industry enterprises of Vinnytsia region, which were considered as a potential production core of the regional agro-food cluster model. The results of the study confirmed the effectiveness of the proposed integrated model for comprehensive assessment of the level of sustainable development of enterprises, taking into account financial stability, accounting and analytical support, marketing activity, innovative development, synergistic interaction and cyber resilience. The calculations made it possible to rank enterprises by the level of the integrated index of sustainable development and establish that, along with financial indicators, the level of synergy between functional subsystems and the scale of cyber risks have a significant impact on the results of the cluster model. The practical significance of the proposed methodology lies in the possibility of its use by enterprises, cluster organizations, state authorities and local governments to assess the level of sustainable development of innovation clusters, justify management decisions, increase the efficiency of innovation activities, strengthen cyber resilience and ensure the long-term competitiveness of business structures.

Keywords: sustainable development, innovative entrepreneurship, cluster models, accounting and analytical support, financial support, marketing support, cyber threats, cyber resilience, integrated assessment, management

JEL Classification: L26, O31, O32, M41, G32, C43

INTRODUCTION

In the current conditions of global digital transformation of the economy, innovative entrepreneurship is becoming a key factor in ensuring the competitiveness of states, regions, and business entities. At the same time, increasing geopolitical instability, increasing the level of digitalization of business processes, and the active implementation of artificial intelligence technologies are creating fundamentally new challenges for enterprise management systems. Cyber threats are becoming especially important; they are no longer limited to information security, but directly affect financial stability, investment attractiveness, continuity of business processes, the reliability of accounting

information, the effectiveness of marketing activities, and the sustainability of the functioning of innovation ecosystems. Under such conditions, traditional models of business management are increasingly proving to be insufficiently adaptive to the high speed of technological change. This necessitates the formation of new approaches to managing innovative development, based on the integration of economic, organizational, information, financial and digital tools within a single strategic management system. One of the most effective organizational forms of innovation economy development is cluster business models that ensure the concentration of intellectual capital, financial resources, production potential, scientific developments and entrepreneurial competencies. The interaction of enterprises, scientific institutions, government bodies, investors, financial institutions, and innovation infrastructure creates a synergistic effect that significantly increases the speed of creation, dissemination, and commercialization of innovations. Along with the advantages of digital integration, the vulnerability of cluster entities to cyber threats also increases significantly. Modern cyberattacks can disrupt the functioning of accounting information systems, corporate financial platforms, logistics networks, electronic document management systems, marketing platforms, production processes, and management decision-making mechanisms. As a result, even a local incident can cause large-scale economic losses for all participants in cluster interaction.

The problem becomes particularly relevant in the context of the digitalization of the Ukrainian economy, its integration into the European economic space and the need for post-war recovery, when innovative entrepreneurship should become one of the key drivers of the structural modernization of the national economy. The effective functioning of cluster models requires not only the activation of innovative activity, but also the formation of a comprehensive management system that ensures a high level of financial stability, reliability of accounting and analytical information, the effectiveness of marketing support, and cyber resilience of all participants in cluster interaction. In this regard, there is an objective need to form a new methodology for managing the sustainable development of cluster models of innovative entrepreneurship, which will be based on the integration of accounting and analytical, financial, and marketing support, taking into account the impact of cyber threats. Such a methodology should provide a comprehensive assessment of the state of the cluster system, quantitative measurement of the relationships between its structural elements, determination of the level of resilience to external and internal risks, as well as the formation of scientifically sound management decisions to increase the efficiency of the functioning of innovative clusters.

LITERATURE REVIEW

Analysis of modern scientific literature shows that the issues of sustainable development, economic clustering, innovative entrepreneurship, digital transformation, cybersecurity, accounting, financial management, and marketing support are being researched quite actively. However, the vast majority of scientific works consider these areas in isolation. The issues of managing sustainable development of cluster models of innovative entrepreneurship are widely covered in the works of foreign and domestic scientists.

Bakhmat et al. (2022) investigated approaches to quality management in the context of sustainable development, some principles of which were used in the formation of conceptual foundations of enterprise management in the context of digital transformation. Balanovska et al. (2021) substantiated the role of marketing management in ensuring the competitiveness of enterprises, which allowed for taking into account the relationship between marketing and management processes in the proposed approach. Bazaluk et al. (2022) analyzed the impact of international integration processes on the economic development of states, some provisions of which were used to characterize the external environment of the functioning of enterprises. Bilan et al. (2017) proposed approaches to effective management of resource potential, some elements of which were taken into account in the justification of a systemic approach to enterprise management. Bosniuk et al. (2021) revealed the importance of human capital and professional competencies in ensuring the effectiveness of organizations, which allowed the personnel component to be taken into account in the author's concept of management. Chikov et al. (2023) proposed a methodological approach to the use of neural network models for assessing the performance of enterprises, some provisions of which were used in substantiating the use of modern digital analytical tools.

Gebhardt and Pohlmann (2013) investigated the influence of entrepreneurial competencies and management skills on the development of clusters, which became the basis for taking into account organizational factors of effective management. Gryshchenko et al. (2023) substantiated the features of managing the development of innovative entrepreneurship in integrated structures, some provisions of which were used in forming the organizational mechanism of the study. Gryshko et al. (2018) proposed the integration of BSC and KPI systems to improve management efficiency, the principles of which were taken into account when developing a comprehensive performance assessment system. Hnatenko et al. (2024) investigated the transformation of financial and economic processes in the context of the development of the renewable energy market, which allowed the use of separate approaches to assessing the impact of digital economic processes on the activities of enterprises. Horák et al. (2023) substantiated the role of investment support for the development of

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bioenergy projects, some provisions of which were used in the characterization of the financial and investment component of ensuring the sustainable development of enterprises.

The next group of authors, Kalinichenko and Lesyuk (2021), proposed approaches to assessing the level of financial security of the state, some provisions of which were used in substantiating the security component of the enterprise management system. Kubitskyi et al. (2023) investigated the directions of development of higher education institutions in modern conditions, some organizational principles of which were taken into account in the formation of conceptual foundations of effective management. Kulyk et al. (2026) analyzed the patterns of formation of the effectiveness of production processes and their energy efficiency, which allowed the use of separate methodological approaches to assessing the effectiveness of the functioning of economic systems. Lai et al. (2014) investigated the impact of knowledge management in cluster associations on the innovative performance of enterprises, some provisions of which became the basis for taking into account the information component of management. Lutkovska et al. (2025) substantiated financial and economic mechanisms for increasing production efficiency in the smart development system, which allowed us to take into account the possibilities of using modern digital technologies in the enterprise management system. Mazur et al. (2021) proposed directions for improving control in the financial management of enterprises, some provisions of which were used in developing the author's approach to information and analytical support for management decisions. Martens and Carvalho (2017) identified key factors for ensuring sustainability in project management, which allowed us to take into account the principles of long-term efficiency of enterprise management. Mousavi and Bossink (2017) investigated the capabilities of enterprises to implement sustainable innovations, some conclusions of which were used in substantiating the innovative component of enterprise development. Mykhailichenko et al. (2021) considered competitive HR management strategies in the context of digitalization of business processes, which became the basis for taking into account the personnel support for the digital transformation of enterprises. Plakhonik et al. (2024) proposed modern approaches to the formation of effective management systems, some principles of which were used in building a conceptual model of the study. Prokopenko et al. (2021) substantiated models of public management by clustering, marketing, and the labor market, which allowed us to take into account the institutional mechanisms of enterprise development in modern conditions.

The last group of authors, Proyer et al. (2008), studied strategies for sustainable development of industrial parks based on industrial symbiosis, some provisions of which were used in substantiating the principles of interaction between participants of integrated structures and ensuring their long-term development. Pu and Shao (2019) proposed a classification of strategies for implementing a circular economy in manufacturing companies, which allowed taking into account modern approaches to increasing the efficiency of resource use and ensuring sustainable development of enterprises. Prylipko et al. (2021) developed models of regional management of innovative activities, some provisions of which were used in the formation of an organizational and economic mechanism for managing enterprises. Purdenko et al. (2023) studied modern approaches to financial management of innovative eco-entrepreneurship, which became a methodological basis for taking into account the financial and analytical component of management and modern tools for making managerial decisions. Rowan and Casey (2021) substantiated the model of interaction "university - business – government" in the context of the implementation of the Sustainable Development Goals, some principles of which were used in the characterization of the partnership interaction of economic entities. Semenov et al. (2021) investigated the management of energy- and resource-saving innovation projects, which allowed us to take into account modern approaches to the implementation of innovative management solutions. Shumilova et al. (2023) considered the system of formation of professional competencies of managers in conditions of transformational changes, some provisions of which were used in substantiating the role of management personnel in ensuring the effective functioning of enterprises. Sunny and Shu (2019) investigated the impact of investments, innovations, and territorial clustering on the development of sustainable entrepreneurship, which allowed us to take into account the relationship between innovative activity and the competitiveness of enterprises. Voznyuk et al. (2022) proposed a synergistic approach to modeling management processes, some principles of which were used in building the author's conceptual model of the study. Wallner (1999) substantiated the role of network interaction and eco-clusters in ensuring sustainable development, which became the basis for taking into account a systemic approach to the development of integrated structures. Zhyvko et al. (2024) investigated the impact of the stock market on the institutional security of innovative development management, some provisions of which were used in substantiating the institutional component of modern enterprise management mechanisms.

Despite the significant contribution of the above authors to the development of the theory of sustainable development, clustering, innovative entrepreneurship, financial management, marketing support, and digital transformation, the issues of managing the sustainable development of cluster models of innovative entrepreneurship in the context of cyber threats based on the integration of accounting and analytical, financial, and marketing support remain insufficiently studied. Most of the existing research considers individual components of this issue, while the formation of a comprehensive mechanism that would combine the tools of cyber resilience, digital security, accounting and analytical support, financial management,

and marketing management in a single system for ensuring the sustainable development of clusters requires further scientific substantiation.

Thus, the analysis of modern literature indicates the absence of an integrated methodological approach that would simultaneously combine accounting and analytical, financial, and marketing support for the management of cluster models of innovative entrepreneurship with the assessment of their resilience to cyber threats. Most existing models examine these components in isolation, which complicates a comprehensive assessment of the effectiveness of the functioning of innovation clusters in the digital economy. It is this scientific gap that determines the need to develop an author's integrated model of sustainable development management of cluster models of innovative entrepreneurship, which is based on the synchronization of accounting and analytical, financial, marketing, and cybersecurity support in a single system of support for strategic management decisions.

AIMS AND OBJECTIVES

The purpose of the study is to develop an integrated methodology for managing the sustainable development of cluster models of innovative entrepreneurship in the context of cyber threats based on a comprehensive combination of accounting and analytical, financial, marketing, innovation, and cybersecurity support, as well as its practical testing for assessing the level of sustainable development of food industry enterprises as a potential core of a regional innovation cluster.

To achieve this goal, the following research tasks have been defined:

1. To investigate the theoretical principles of managing the sustainable development of cluster models of innovative entrepreneurship in the context of digital transformation of the economy and the growth of cyber threats.
2. To generalize modern scientific approaches to the formation of systems of accounting and analytical, financial, marketing, and cybersecurity support for the innovative development of enterprises.
3. To develop an integrated economic and mathematical methodology for comprehensive assessment of the sustainable development of cluster models of innovative entrepreneurship using a system of integral indices.
4. To substantiate a methodological approach to determining partial integral indices of accounting and analytical, financial, marketing, innovative support, and cyber resilience of enterprises.
5. To propose a model for assessing the synergistic interaction of functional components of the cluster system and the integral impact of cyber risks on the results of its functioning.
6. To form an integral indicator of sustainable development of the cluster model of innovative entrepreneurship taking into account the interaction of functional subsystems and the level of cyber risk.
7. To conduct practical testing of the proposed methodology on the example of food industry enterprises of Vinnytsia region, to rank them by the level of sustainable development and to identify key factors for increasing the efficiency of the cluster model.
8. To develop practical recommendations for improving the management of sustainable development of cluster models of innovative entrepreneurship by integrating accounting and analytical, financial, marketing, and cybersecurity support.

METHODS

The research methodology is based on a comprehensive economic and mathematical approach to assessing the sustainable development of cluster models of innovative entrepreneurship in the context of cyber threats. It is based on the integration of accounting and analytical, financial, marketing, innovation support, and cyber resilience into a single assessment system, which allows taking into account the interconnection of the functional subsystems of the enterprise and their impact on the results of activity. The methodology involves the formation of a system of quantitative indicators for each functional component, bringing them to a single comparative scale through normalization, determining partial integral indices and their further aggregation into the basic integral index of sustainable development. To ensure the comparability of indicators, normalization procedures are used for both stimulants and de-stimulators, which makes it impossible for individual indicators to dominate in the structure of the integrated assessment.

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Unlike traditional integral models, the proposed methodology takes into account not only the aggregate level of development of individual functional blocks, but also the effect of their interaction. To do this, after calculating the integral indices of accounting and analytical, financial, marketing, innovative support, and cyber resilience, the coefficient of synergistic interaction is determined, which characterizes the consistency of the functioning of all subsystems. At the same time, the integral index of cyber risk is calculated, which reflects the possible negative consequences of digital threats for the activities of the enterprise. The combination of the positive effect of synergy and the negative impact of cyber risks provides a more objective assessment of the real level of sustainable development compared to traditional additive models.

The practical testing of the methodology was carried out on the example of five food industry enterprises of Vinnytsia region, which are considered as a potential production core of the regional agro-food cluster model. The financial component was estimated according to the data from open financial reporting of enterprises using indicators of asset profitability, sales profitability, autonomy coefficient, and asset turnover. Indicators of accounting and analytical, marketing, innovation support, and cyber resilience were determined by the method of expert assessment with subsequent transformation into normalized indices. Based on the results obtained, the basic integral index, synergy coefficient, cyber risk index, and final integral indicator of sustainable development were calculated, which allowed ranking enterprises by their level of readiness to function as part of an innovation cluster and to identify the most problematic functional components that require improvement.

The purpose of the proposed methodology is to form a comprehensive toolkit for assessing the sustainable development of cluster models of innovative entrepreneurship in the context of cyber threats. Unlike existing approaches, which are mainly focused on the analysis of individual financial or innovative characteristics, the proposed methodology integrates accounting and analytical, financial, marketing, innovative, and cybersecurity support into a single assessment system. The research methodology consists of six interrelated stages: formation of a system of indicators, normalization of initial data, determination of partial integral indices, calculation of the basic integral index, assessment of synergistic interaction and cyber risk, as well as determination of the final integral indicator of the sustainable development of the cluster model.

RESULTS

Let us move on to the implementation of the proposed methodology for assessing the sustainable development of cluster models of innovative entrepreneurship in the face of cyber threats.

1. Formation of a system of indicators and their normalization

In the first stage, a system of indicators is formed, which characterizes five functional blocks of the study (Figure 1).

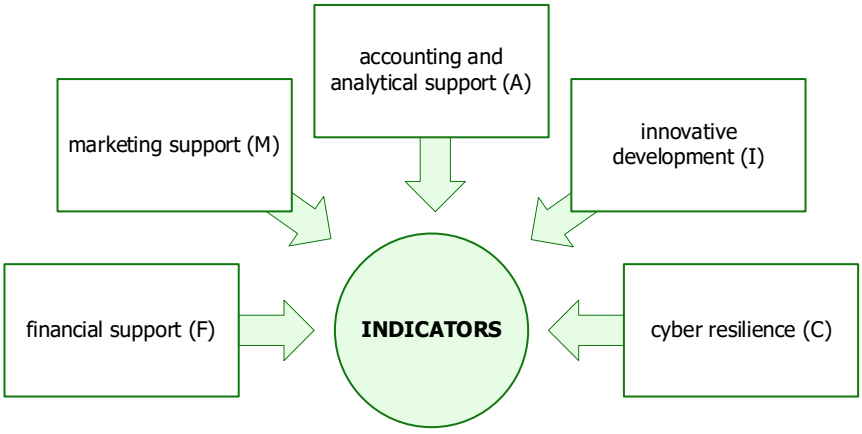

Figure 1. System of indicators characterizing the activities of an entrepreneurial entity.

Each block includes quantitative indicators that can be obtained from enterprise reporting or determined by expert methods. The use of indicators with different units of measurement requires their reduction to a single scale.

Stage 1. *Normalization of indicators*

The following dependence is used for incentive indicators:

$$Zij = \frac{Xij - X\frac{min}{j}}{X\frac{max}{j} - X\frac{min}{j}}, \quad (1)$$

where: Zij *– normalized value of the jth indicator for the ith enterprise;* Xij *– actual value of the indicator;* $Xjmin$ *– the minimum value of the indicator in the sample;* $Xjmax$ *– the maximum value of the indicator in the sample.*

For disincentive indicators (e.g., depreciation rate of fixed assets, level of cyber incidents, debt burden), the inverse relationship is used:

$$Zij = \frac{X\frac{max}{j} - Xij}{X\frac{max}{j} - X\frac{min}{j}}, \quad (2)$$

Normalization ensures that all indicators are brought to the interval from 0 to 1, which makes it impossible for individual indicators to dominate when constructing an integral index and ensures their comparability regardless of the units of measurement.

2. Determination of partial integral indices

After normalization, five integral indices are formed, each of which characterizes a separate functional component of the cluster model.

Stage 2. *Integral index of accounting and analytical support:*

$$IA = \sum_{j=1}^{mA} wAjZAj, \quad (3)$$

where: IA *– integral index of accounting and analytical support;* wAj *– weight coefficient of the jth indicator;* ZAj *– normalized value of the indicator;* mA *– the number of indicators characterizing the accounting and analytical system.*

This block may include the following indicators:

- level of accounting automation;
- efficiency of management reporting;
- completeness of information support;
- integration of ERP systems;
- quality of analytical support for management decisions.

The IA index characterizes the level of readiness of the enterprise's information system to support the management of innovative activities and strategic decision-making.

Stage 3. *Integral index of financial security:*

$$IF = \sum_{j=1}^{mF} wFjZFj, \quad (4)$$

where: IF *– integral index of financial security;* wFj *– weighting factors of financial indicators;* ZFj *– normalized financial indicators;* mF *– number of financial indicators.*

The following indicators are included in the calculation of the integral index of financial support: autonomy coefficient, return on assets, return on sales, and asset turnover.

A high index value indicates a sufficient level of financial stability of the enterprise, its ability to provide financing for innovative projects and support the long-term development of the cluster model.

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Stage 4. *Integral index of marketing support:*

$$IM = \sum_{j=1}^{mM} wMjZMj, \quad (5)$$

where: IM *– integral index of marketing support;* wMj *– weighting factors of marketing indicators;* ZMj *– normalized values of marketing indicators.*

This block includes:

- product sales growth rate;
- market share;
- consumer satisfaction level;
- efficiency of digital marketing channels;
- intensity of promotion of innovative products.

The resulting index characterizes the competitiveness of the enterprise, its ability to adapt to changes in the market environment and effectively commercialize the results of innovative activities.

Stage 5. *Integral index of innovative development*

Innovative development determines the ability of the enterprise to create, implement, and commercialize new technologies, products, and management solutions. It is proposed to use the integral index to assess it:

$$Ii = \sum_{j=1}^{\mathrm{mI}} \mathrm{wI}jZij, \quad (6)$$

where: Ii *– integral index of innovative development;* wIj *– weight coefficient of the jth indicator;* Zij *– normalized value of the indicator;* mI *– number of innovation indicators.*

The indicators of innovative development should include:

- the share of costs for innovative activities in the total costs of the enterprise;
- the number of innovations implemented;
- the share of sales of innovative products;
- the intensity of digital transformation of production;
- the level of technological renewal of fixed assets.

A high value of the integral index characterizes the ability of the enterprise to maintain long-term competitiveness through continuous implementation of innovations and technological development.

Stage 6. *Integral index of cyber resilience.*

In the conditions of digitalization of the economy, an important component of sustainable development is the level of cyber resilience of the enterprise. To assess it, it is proposed to use the integral index:

$$Ic = \sum_{j=1}^{\mathrm{mc}} \mathrm{wC}jZCj, \quad (7)$$

where: Ic *– integral cyber resilience index;* wCj *– weighting coefficients of indicators;* ZCj *– normalized indicator values;* mc *– number of cybersecurity indicators.*

It is recommended to include in this block:

- level of information system security;
- regularity of information backup;
- share of automated protection systems;
- level of cybersecurity personnel training;
- compliance with international information security standards.

The index characterizes the ability of the enterprise to ensure the continuity of business processes, protect information resources, and minimize the negative consequences of cyber incidents.

3. Construction of an integral index of sustainable development

After determining the partial indices, they are aggregated into a single integral indicator. This allows for a comprehensive assessment of the level of sustainable development of the enterprise, taking into account all functional components.

Stage 7. *Basic integral index of sustainable development:*

$$ISD = \alpha IA + \beta IF + \gamma IM + \delta II + \lambda IC, \quad (8)$$

where: ISD *– basic integrated index of sustainable development;* IA *– accounting and analytical support index;* IF *– financial security index;* IM *– marketing support index;* II *– innovative development index;* IC *– cyber resilience index;* $\alpha, \beta, \gamma, \delta, \lambda$ *– weight coefficients of the corresponding components for which the condition is met:*

$$\alpha + \beta + \gamma + \delta + \lambda = 1 \quad (9)$$

Weighting factors can be determined by the expert assessment method, the analytic hierarchy process (AHP) method, or the entropy method. In further testing, expert assessment was used with the involvement of specialists in the fields of management, finance, marketing, accounting, and cybersecurity. The basic integral index reflects the potential for sustainable development of the enterprise without taking into account the interaction between individual functional subsystems.

4. Taking into account the synergistic effect

In modern cluster models, the development of individual subsystems is interdependent. Strengthening financial support without developing marketing or digital security does not provide the maximum economic effect. To take this phenomenon into account, a synergistic interaction coefficient is introduced.

Stage 8. *Synergistic interaction coefficient:*

$$SCSI = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij}}{n(n-1)}, \quad (10)$$

where: $SCSI$ *– synergistic interaction coefficient;* r_{ij} *– expert assessment of the strength of interaction between functional subsystems;* n *– number of functional blocks.*

The value of the coefficient varies from 0 to 1. The closer the indicator is to one, the higher the consistency of the work of the accounting and analytical, financial, marketing, innovation, and cybersecurity components.

5. Cyber risk assessment

Along with the positive impact of synergy, it is necessary to take into account the negative impact of digital threats on the results of the enterprise's functioning.

Stage 9. *Integral cyber risk index:*

$$CRI = \sum_{j=1}^{\mathrm{mR}} v_j Ri_j, \quad (11)$$

where: CRI *– integral cyber risk index;* R_j *– normalized value of the cyber risk indicator;* v_j *– weighting factor of the corresponding indicator;* mR *– number of cyber risk indicators.*

It is advisable to include the following indicators:

- number of cyber incidents;
- average recovery time after an incident;
- frequency of data loss;

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- number of identified critical vulnerabilities;
- level of financial losses from cyber threats.

The higher the index value, the more cyber risks reduce the potential for sustainable development of the enterprise.

6. Formation of the final integral index

At the final stage of the study, all components are integrated into a single indicator that characterizes the actual level of sustainable development of the enterprise.

Stage 10. *Final integral index of sustainable development:*

$$ISDI = ISD \times SCSI \times (1 - CRI), \quad (12)$$

where: $ISDI$ *– integrated index of sustainable development of the enterprise;* ISD *– basic integral index;* $SCSI$ *– synergistic interaction coefficient;* CRI *– integral cyber risk index.*

The economic content of the proposed model is that the level of sustainable development is determined not only by the internal potential of the enterprise, but also by the efficiency of interaction between its functional subsystems and the level of protection against digital threats. This approach allows you to avoid overestimating the effectiveness of enterprises, which is typical for traditional additive models.

Testing methodological approaches

The practical testing of the methodology was carried out on the example of five food industry enterprises of Vinnytsia region, which are considered as a potential production core of the regional agri-food cluster model. The choice of enterprises is due to their industry affinity, territorial concentration, and potential for the formation of joint innovation, logistics, marketing, and information ties.

The sample includes: PrJSC "Vinnytsia Food and Flavor Factory"; PrJSC "Vinnytsia Dairy Plant "Roshen""; LLC "Tulchyn Butter and Cheese Factory"; PrJSC "Mohyliv-Podilskyi Cannery Plant"; PrJSC "Vinnytsia Confectionery Factory." To calculate the financial component, data from the open financial statements of enterprises for 2024 were used. In particular, net income, net financial result, and the value of assets and liabilities were taken into account. Open data confirm the availability of financial statements for 2024 for all five enterprises. Indicators of accounting and analytical, marketing, innovation, and cybersecurity support are not disclosed in standard financial reporting. Therefore, for demonstration testing, they were evaluated on a ten-point scale with subsequent reduction to the interval from 0 to 1. Four indicators were used to form the integral index of financial support:

1. Return on assets.
2. Return on sales.
3. Autonomy coefficient.
4. Asset turnover.

Return on assets is defined as the ratio of net profit to total asset value:

$$ROAi = \frac{NPi}{Ai}, \quad (13)$$

Sales profitability is calculated using the formula:

$$ROSi = \frac{NPi}{Ri}, \quad (14)$$

where NPi *is the net profit of the enterprise;* Ai *is the value of assets;* Ri *is the net income.*

The autonomy coefficient is defined as the share of equity in assets:

$$Kauti = \frac{Ai - Li}{Ai}, \quad (15)$$

where Li *– obligations of the enterprise.*

Asset turnover is calculated as:

$$Kturni = \frac{Ri}{Ai}. \quad (16)$$

Table 1. Calculated financial ratios of enterprises.

Enterprise	ROA	ROS	$Kaut$	$Kturn$
PJSC "Vinnytsia Food and Flavor Factory"	0.148	0.105	0.749	1.409
PJSC "Vinnytsia Dairy Plant "Roshen"	0.186	0.052	0.809	3.537
LTD "Tulchyn Butter and Cheese Plant"	0.006	0.033	0.989	0.196
PJSC "Mohyliv-Podilsky Canning Plant"	–0.034	–0.127	–0.007	0.272
PJSC "Vinnytsia Confectionery Factory"	0.002	0.003	0.884	0.615

As an example, for "Vinnytsia Food and Flavor Factory" PJSC, the calculations look like this:

$$ROA1 = \frac{33{,}954}{229{,}329} = 0{,}148;$$

$$ROS1 = \frac{33{,}954}{323{,}173} = 0{,}105;$$

$$Kaut1 = \frac{229{,}329 - 57.618}{229{,}329} = 0{,}749;$$

$$Kturn1 = \frac{323{,}173}{229{,}329} = 1{,}409.$$

For PJSC "Vinnytsia Dairy Plant "Roshen"":

$$ROA2 = \frac{226{,}772}{1221{,}755} = 0{,}186;$$

$$ROS2 = \frac{226{,}772}{4321{,}559} = 0{,}052;$$

$$Kaut2 = \frac{1221{,}755 - 233{,}776}{1221.755} = 0{,}809;$$

$$Kturn2 = \frac{4321{,}559}{1221{,}755} = 3{,}53.$$

The results obtained show that the highest return on assets and the highest asset turnover are for PrJSC "Vinnytsia Dairy Plant "Roshen"". At the same time, the greatest autonomy is characteristic of LLC "Tulchyn Butter and Cheese Plant", which is explained by the extremely low value of its liabilities compared to assets. The worst financial values were obtained for PrJSC "Mohyliv-Podilskyi Cannery Plant": negative return on assets, negative return on sales, and a negative value of the autonomy coefficient due to the excess of liabilities over assets.

After normalizing the indicators according to formula (1), the integral index of financial security is determined as the arithmetic mean of four normalized coefficients:

$$IF = \frac{(ZROAi + ZROSi + Zauti + Zturni)}{4}. \quad (17)$$

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Table 2. Normalized financial indicators and integral index of financial security.

Enterprise	$ZROA$	$ZROS$	$Zaut$	$Zturni$	IF
PJSC "Vinnytsia Food and Flavor Factory"	0.830	1.000	0.760	0.364	0.738
PJSC "Vinnytsia Dairy Plant "Roshen""	1.000	0.772	0.820	1.000	0.898
LTD "Tulchyn Butter and Cheese Plant"	0.186	0.689	1.000	0.000	0.469
PJSC "Mohyliv-Podilsky Canning Plant"	0.000	0.000	0.000	0.023	0.006
PJSC "Vinnytsia Confectionery Factory"	0.165	0.558	0.895	0.126	0.436

As an example, for "Vinnytsia Food and Flavor Factory" PJSC, the financial index is:

$$IF1 = \frac{(0{,}830+1{,}000+0{,}760+0{,}364)}{4} = 0{,}738.$$

For PJSC "Vinnytsia Dairy Plant "Roshen"":

$$IF2 = \frac{(1{,}000+0{,}772+0{,}820+1{,}000)}{4} = 0{,}898.$$

Thus, the financial block of the model clearly differentiates enterprises with high performance and financially problematic business entities.

Accounting and analytical, marketing, innovation, and cybersecurity support were assessed on a ten-point scale. Each enterprise was assigned a score based on the following criteria: automation of accounting processes; use of management analytics;

development of digital promotion channels; brand awareness; activity of product updates; use of modern production technologies; availability of backup procedures; training of personnel on cybersecurity issues; security of information systems; formalization of response to cyber incidents. Expert scores were divided by 10, resulting in index values ranging from 0 to 1.

Table 3. Expert indices of functional support of enterprises.

Enterprise	IA	IM	II	IC
PJSC "Vinnytsia Food and Flavor Factory"	0.82	0.76	0.78	0.74
PJSC "Vinnytsia Dairy Plant "Roshen""	0.94	0.92	0.95	0.93
LTD "Tulchyn Butter and Cheese Plant"	0.64	0.58	0.55	0.59
PJSC "Mohyliv-Podilsky Canning Plant"	0.52	0.47	0.42	0.45
PJSC "Vinnytsia Confectionery Factory"	0.88	0.89	0.87	0.85

The highest expert ratings were received by PJSC "Vinnytsia Dairy Plant "Roshen"", which, within the model, reflects the development of its accounting and analytical processes, technological support, marketing mechanisms, and digital protection systems. The second place in terms of non-financial components was taken by PrJSC "Vinnytsia Confectionery Factory". The high values of the marketing and innovation indices are explained by the scale of production, the development of the brand, and the possibilities of introducing new products and technologies. The values given are model expert ratings for testing the algorithm. In the final article, it is necessary to indicate the actual number of experts, their professional composition, the coefficient of consistency of opinions and the results of the questionnaire.

A. Calculation of the basic integral index

The following weighting factors were applied when aggregating the components:

$$\alpha=0{,}15;\ \beta=0{,}30;\ \gamma=0{,}15;\ \delta=0{,}20;\ \lambda=0{,}20. \quad (18)$$

The highest weight - 0.30 – was given to financial support, since it is financial stability that determines the real ability of the enterprise to finance innovative, marketing, and cybersecurity measures. Innovative development and cyber resilience received a weight of 0.20 each, and accounting and analytical support and marketing support received 0.15 each.

For "Vinnytsia Food and Flavor Factory" PJSC:

ISD_1=0,123+0,221+0,114+0,156+0,148=0,762.

For PJSC "Vinnytsia Dairy Plant "Roshen"":

$ISD\ 2 = 0{,}141 + 0{,}269 + 0{,}138 + 0{,}190 + 0{,}186 = 0{,}924.$

For LLC "Tulchyn Butter and Cheese Plant":

$ISD\ 3 = 0{,}15 \times 0{,}64 + 0{,}30 \times 0{,}469 + 0{,}15 \times 0{,}58 + 0{,}20 \times 0{,}55 + 0{,}20 \times 0{,}59 = 0{,}552.$

For PJSC "Mohyliv-Podilsky Cannery":

$ISD\ 4 = 0{,}15 \times 0{,}52 + 0{,}30 \times 0{,}006 + 0{,}15 \times 0{,}47 + 0{,}20 \times 0{,}42 + 0{,}20 \times 0{,}45 = 0{,}324.$

For PrJSC "Vinnytsia Confectionery Factory":

$ISD\ 5\ = 0{,}15 \times 0{,}88 + 0{,}30 \times 0{,}436 + 0{,}15 \times 0{,}89 + 0{,}20 \times 0{,}87 + 0{,}20 \times 0{,}85 = 0{,}740.$

B. Calculation of synergy coefficient and cyber risk

According to the results of expert assessment, the synergistic interaction coefficients were:

$SCSI_1$=0,78; $SCSI_2$=0,90; $SCSI_3$=0,62; $SCSI_4$=0,48; $SCSI_5$=0,84.

Cyber risk indices are determined based on an assessment of the probability of cyber incidents, the criticality of information systems, recovery time, risk of data loss, and potential financial consequences:

CRI_1=0,18; CRI_2=0,10; CRI_3=0,28; CRI_4=0,40; CRI_5=0,14.

The increase in CRI means an increase in the negative impact of cyber threats. The lowest risk level is set for PrJSC "Vinnytsia Dairy Plant "Roshen"" and the highest for Mohyliv-Podilskyi Cannery Plant.

C. Calculation of the final integral index

For "Vinnytsia Food and Flavor Factory" PJSC:

$ISDI_1$=0,762×0,78×(1−0,18)=0,488.

For PJSC "Vinnytsia Dairy Plant "Roshen"":

$ISDI\ 2 = 0{,}924 \times 0{,}90 \times (1 - 0{,}10) = 0{,}749.$

For LLC "Tulchyn Butter and Cheese Plant":

$ISDI\ 3 = 0{,}552 \times 0{,}62 \times (1 - 0{,}28) = 0{,}246$

For PJSC "Mohyliv-Podilsky Cannery":

$ISDI\ 4 = 0{,}324 \times 0{,}48 \times (1 - 0{,}40) = 0{,}093.$

For PrJSC "Vinnytsia Confectionery Factory":

$ISDI\ 5 = 0{,}740 \times 0{,}84 \times (1 - 0{,}14) = 0{,}535.$

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Table 4. Final results of the assessment of sustainable development of enterprises.

Enterprise	*IA*	*IF*	*IM*	**II**	*IC*	*ISD*	*SCSI*	*CRI*	*ISDI*	Place
PJSC "Vinnytsia Dairy Plant "Roshen""	0.94	0.898	0.92	0.95	0.93	0.924	0.90	0.10	0.749	1
PJSC "Vinnytsia Confectionery Factory"	0.88	0.436	0.89	0.87	0.85	0.740	0.84	0.14	0.535	2
PJSC "Vinnytsia Food Flavor Factory"	0.82	0.738	0.76	0.78	0.74	0.762	0.78	0.18	0.488	3
LTD "Tulchyn Butter and Cheese Plant"	0.64	0.469	0.58	0.55	0.59	0.552	0.62	0.28	0.246	4
PJSC "Mohyliv-Podilsky Cannery"	0.52	0.006	0.47	0.42	0.45	0.324	0.48	0.40	0.093	5

The highest value of the integral index was received by PrJSC "Vinnytsia Dairy Plant "Roshen"" – 0.749. The enterprise is characterized by a high level of sustainable development, which is ensured by a combination of a strong financial position, developed innovative activity, a high level of marketing support, significant synergistic interaction, and relatively low cyber risk. The second place was taken by PrJSC "Vinnytsia Confectionery Factory" with a value of 0.535. The enterprise has high non-financial indices, but its final result is limited by relatively low profitability of assets and sales. PrJSC "Vinnytsia Food and Flavor Factory" received a value of 0.488. Despite the higher financial index compared to the Vinnytsia Confectionery Factory, lower assessments of marketing, innovation, and cybersecurity support led to third place. LLC "Tulchyn Butter and Cheese Plant" is characterized by a low level of sustainable development – 0.246. Its advantage is a high autonomy coefficient; however, low asset turnover, insignificant profit, and insufficiently developed non-financial components significantly reduce the final assessment. The critical value of the index was obtained by PrJSC "Mogilev-Podilskyi Cannery Plant" – 0.093. Negative financial result, excess of liabilities over assets, low synergy of functional subsystems, and high cyber risk indicate the need for comprehensive financial, technological, and managerial restructuring.

The results obtained confirm the effectiveness of the proposed integrated methodology for assessing the sustainable development of cluster models of innovative entrepreneurship, which provides a comprehensive analysis of financial, accounting and analytical, marketing, innovation and cybersecurity components of enterprise activities. The use of the integral index allows us to objectively determine the level of sustainable development of cluster interaction participants, identify the most problematic functional areas, and form scientifically based management decisions to increase their competitiveness, innovative activity, and cyber resilience. The practical application of the proposed approach will contribute to increasing the efficiency of the functioning of innovation clusters, ensuring their long-term sustainable development and strengthening economic resilience in the context of digital transformation and the growth of cyber threats.

DISCUSSION

The obtained results develop the scientific provisions of Proyer et al. (2008) on the formation of models of industrial interaction and sustainable development of cluster systems, Pu and Shao (2019) on the implementation of circular economy principles and increasing the efficiency of resource use in production systems, Prylipko et al. (2021) on the modeling of regional management of innovation activities based on comprehensive consideration of personnel, financial and external economic factors, Purdenko et al. (2023) on the integration of financial management and innovative entrepreneurship as a tool for ensuring sustainable development of enterprises, Rowan and Casey (2021) on the development of partnership between universities, business and the state in the process of forming innovation ecosystems, as well as Semenov et al. (2021), who substantiated the need for integrated management of innovative and resource-saving projects in modern economic systems. Unlike the above studies, the proposed work has developed an integrated methodology that combines accounting and analytical, financial, marketing, innovation support, and cyber resilience within a single model for assessing the sustainable development of cluster business models.

However, the practical application of the proposed methodology has certain limitations. The testing was carried out on a sample of enterprises from one industry and one region, which requires additional verification of the model for other sectors of the economy. In addition, some non-financial indicators were determined using expert assessment, so their values may vary depending on the completeness of the information base and the composition of the expert group. The proposed system of weighting coefficients may also need adaptation, taking into account the industry specifics, the level of digital transformation of enterprises and the features of the functioning of cluster formations. In this regard, promising areas of further research include expanding the empirical base, testing the methodology at enterprises of other types of economic activity, using actual data from functioning clusters, as well as comparing alternative methods of integral assessment and determining weighting coefficients.

CONCLUSIONS

The study substantiates the need to form an integrated approach to managing the sustainable development of cluster models of innovative entrepreneurship in the context of digital transformation and increasing cyber threats. It has been established that modern cluster formations function as complex open systems, the effectiveness of which is determined not only by the level of innovative activity of individual participants, but also by the quality of their financial, information, marketing, technological and organizational interaction. Under such conditions, an isolated assessment of individual aspects of the activities of enterprises does not provide sufficient completeness of analytical information and may lead to an overestimated or distorted assessment of the actual level of their sustainable development. It has been proven that cyber threats within cluster models are systemic in nature, since a violation of the security of the information infrastructure of one participant can cause negative consequences for the entire interaction network. This necessitates the transition from local management of cybersecurity of individual enterprises to the formation of a comprehensive system of cyber resilience of the cluster ecosystem. Such a system should cover the protection of accounting data, financial platforms, logistics systems, digital marketing channels, production technologies, and management communication mechanisms.

The study proposes an integrated methodology for assessing the sustainable development of cluster models of innovative entrepreneurship, which combines five functional components: accounting and analytical support, financial support, marketing support, innovative development and cyber resilience. The proposed toolkit involves the sequential normalization of initial indicators, determination of partial integral indices, formation of a basic integral index of sustainable development, assessment of synergistic interaction between functional subsystems, determination of an integral index of cyber risk, and calculation of the final integral index of sustainable development. Unlike traditional additive models, the proposed approach takes into account not only the internal potential of the enterprise, but also the degree of coherence of its functional subsystems and the negative impact of cyber risks. This avoids the situation in which high financial or marketing results are automatically interpreted as a sign of sustainable development, even if the enterprise has a low level of innovation, insufficient security of information systems, or weak coordination between the main areas of activity. Therefore, the final integral index reflects not only the resource availability of the enterprise, but also the real ability to maintain stability, adaptability and continuity of operation in conditions of uncertainty.

The practical testing of the proposed methodology was carried out on the example of five food industry enterprises of the Vinnytsia region, which are considered as a potential production core of the regional agro-food cluster model. The results of the calculations showed significant differentiation of enterprises in terms of financial, accounting and analytical, marketing, innovation, and cybersecurity support. The highest value of the final integral index of sustainable development was received by PrJSC "Vinnytsia Dairy Plant "Roshen"" – 0.749. This is due to a combination of high financial performance, developed marketing and innovation potential, a significant level of cyber resilience, and high synergy between functional subsystems.

The second place was taken by PrJSC "Vinnytsia Confectionery Factory" with an integral index value of 0.535. The enterprise demonstrated high non-financial characteristics, in particular, developed marketing capabilities, innovative activity, and a sufficient level of cyber resilience; however, its final result was limited by lower indicators of profitability and asset turnover. PrJSC "Vinnytsia Food and Flavor Factory" received a value of 0.488 and took third place. Despite a sufficiently high financial index, the enterprise lost to the leaders in terms of marketing, innovation, and cybersecurity.

LLC "Tulchyn Butter and Cheese Factory" is characterized by a low level of sustainable development, which is confirmed by the integral index value of 0.246. Despite a high autonomy coefficient, its position is weakened due to low asset turnover, insignificant profit, an insufficient level of development of non-financial components, and increased cyber risk. The critical level of sustainable development has been established for PrJSC "Mogilev-Podilskyi Cannery Plant", the integral index of which is 0.093. Negative profitability indicators, excess of liabilities over assets, low level of synergistic interaction, and high cyber risk indicate the need for comprehensive financial, technological, and managerial restructuring of the enterprise.

The results obtained confirmed that financial stability remains a basic condition for sustainable development, but in itself does not guarantee a high integral assessment. Of decisive importance are also the ability of the enterprise to introduce innovations, adapt marketing strategies to changes in the market environment, ensure the reliability and efficiency of accounting and analytical information, maintain an appropriate level of cyber protection, and form effective interaction between functional subsystems. This confirms the feasibility of a comprehensive assessment, in which all components are considered as interconnected elements of a single management system.

The scientific novelty of the results obtained lies in deepening the methodological principles of managing the sustainable development of cluster models of innovative entrepreneurship by developing an integrated economic and mathematical

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model that combines accounting and analytical, financial, marketing, innovation, and cybersecurity support, and also takes into account the synergistic effect and impact of cyber risks. The proposed approach expands the possibilities of multi-criteria assessment of cluster systems and creates a basis for the formation of sound strategic decisions regarding their development. The practical significance of the proposed methodology lies in the possibility of its use by enterprise managers, cluster organizations, investors, financial institutions, state authorities, and local governments. The assessment results can be used to identify problematic functional components, justify investment priorities, form digital transformation programs, develop measures to increase cyber resilience, improve marketing policy, strengthen innovation potential and form regional cluster development strategies. The proposed model can also be used as a tool for comparative analysis of enterprises, selection of potential participants in cluster associations, assessment of readiness of business entities for integration into joint innovation, production, logistics and information platforms. Its use makes it possible to determine not only the current level of sustainable development, but also reserves for increasing the efficiency of interaction between participants in the cluster ecosystem. At the same time, the results of the study have certain limitations. Non-financial indicators, synergistic interaction coefficients, and cyber risk indices within the framework of the testing were determined on the basis of model estimates. Therefore, further research should be directed towards conducting a full-scale expert survey of representatives of the enterprises under study, determining the consistency of expert opinions, specifying weighting coefficients using the method of hierarchy analysis, the entropy method, or combined approaches, as well as expanding the time and industry base of the study.

A promising direction for further scientific developments is the adaptation of the proposed methodology to the assessment of real cluster formations, the inclusion of indicators of environmental responsibility, social sustainability, energy efficiency, digital maturity and institutional support in the system of indicators. It is also advisable to form a dynamic model that will allow assessing the change in the level of sustainable development over time, predict the consequences of cyber incidents, and determine optimal scenarios for the development of cluster ecosystems. Thus, the proposed integrated methodology provides a comprehensive and systematic assessment of the sustainable development of cluster models of innovative entrepreneurship, increases the validity of strategic management decisions and creates a methodological basis for strengthening the competitiveness, innovation and cyber resilience of business structures in the digital economy. Its practical application will contribute to the formation of more adaptive, technologically advanced, and resilient cluster systems to external and internal threats.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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The Authors declare that there is no conflict of interest.

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Пахнюк З., Цалко Т., Невмержицька С., Білецька І., Русіна Ю., Бугас Н.

СТАЛИЙ РОЗВИТОК КЛАСТЕРНИХ МОДЕЛЕЙ ІННОВАЦІЙНОГО ПІДПРИЄМНИЦТВА В УМОВАХ КІБЕРЗАГРОЗ: ОБЛІКОВЕ, ФІНАНСОВЕ Й МАРКЕТИНГОВЕ ЗАБЕЗПЕЧЕННЯ УПРАВЛІННЯ

Сучасні підходи до управління інноваційними кластерами недостатньо враховують комплексну взаємодію обліково-аналітичного, фінансового, маркетингового, інноваційного та кібербезпекового забезпечення, що знижує ефективність стратегічного управління та ухвалення управлінських рішень. Метою дослідження є розробка інтегрованої методології управління сталим розвитком кластерних моделей інноваційного підприємництва на основі поєднання обліково-аналітичного, фінансового, маркетингового та кібербезпекового забезпечення. Запропоновано авторську модель комплексного оцінювання, яка передбачає нормалізацію показників, визначення часткових інтегральних індексів за окремими функціональними складовими, розрахунок базового інтегрального індексу сталого розвитку, оцінювання синергетичної взаємодії між функціональними підсистемами, визначення інтегрального індексу кіберризику та формування підсумкового інтегрального показника сталого розвитку кластерної моделі. Апробацію методики здійснено на прикладі п'яти підприємств харчової промисловості Вінницької області, які розглянуто як потенційне виробниче ядро регіональної агропродовольчої кластерної моделі. Результати дослідження підтвердили ефективність запропонованої інтегрованої моделі для комплексного оцінювання рівня сталого розвитку підприємств з урахуванням фінансової стійкості, обліково-аналітичного забезпечення, маркетингової активності, інноваційного розвитку, синергетичної взаємодії та кіберстійкості. Проведені розрахунки дозволили ранжувати підприємства за рівнем інтегрального індексу сталого розвитку та встановити, що поряд із фінансовими показниками суттєвий вплив на результати функціонування кластерної моделі мають рівень синергії між функціональними підсистемами та масштаби кіберризиків. Практичне значення запропонованої методики полягає в можливості її використання підприємствами, кластерними організаціями, органами державної влади та місцевого самоврядування для оцінювання рівня сталого розвитку інноваційних кластерів, обґрунтування управлінських рішень, підвищення ефективності інноваційної діяльності, зміцнення кіберстійкості й забезпечення тривалої конкурентоспроможності підприємницьких структур.

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Ключові слова: сталий розвиток, інноваційне підприємництво, кластерні моделі, обліково-аналітичне забезпечення, фінансове забезпечення, маркетингове забезпечення, кіберзагрози, кіберстійкість, інтегральне оцінювання, управління

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