sustainability

MDPI

Article

Integration as a Driver of Enterprise Sustainability: The Russian Experience

Nadezhda Shmeleva [1,*], Tatyana Tolstykh [1] and Olga Dudareva [2]

[1] Department of Industrial Strategy, National University of Science & Technology (MISIS), 119049 Moscow, Russia; tt400@mail.ru

[2] Department of Economics Security, Voronezh State Technical University (VSTU), 394071 Voronezh, Russia; dudarevaov@mail.ru

* Correspondence: nshmeleva@misis.ru; Tel.: +7-9036297636

Abstract: The current geopolitical map, facing challenges and disruptions to industrial-technological relations, requires transformation the processes of interaction between economic agents and the building of collaborative links through the implementation of ecosystem models. The aim of the article is to assess the resilience of industrial ecosystems by determining the collaborative maturity, resource stability and technological resilience of actors. The article presents a typology of integration forms between industrial enterprises based on symbiotic relationships. The concept of ecosystem symbiosis is introduced. The authors propose a methodology for assessing industrial ecosystem sustainability, distinguished by the approach to the formation of an integral indicator consisting of three components: stability (invulnerability), resilience (reliability) and ecosystem (coherence). The composite index method, fuzzy sets method, preference ordering by similarity to the ideal solution, rank sum method, fuzzy k-means clustering method, least squares method, Gaussian method, and variance and multiple regression analyses were used in developing the methodology for stability assessment. The approach is demonstrated by the example of three industrial ecosystems in the Voronezh, Belgorod and Lipetsk regions of the Russian Federation. As a result of the analysis, it was found that ecosystem's sustainability was achieved, primarily due to the factors of resilience and reliability, which had the maximum impact on the integrated sustainability indicator. The propositions arising from this analysis provide information on the industrial integrations with the highest and the lowest sustainability, to provide academics, policymakers and industrial enterprises with a more adequate understanding of the practical mechanisms that help trigger sustainable development.

Keywords: industrial ecosystems; integration; symbiotic relationships; sustainable development

Citation: Shmeleva, N.; Tolstykh, T.; Dudareva, O. Integration as a Driver of Enterprise Sustainability: The Russian Experience. *Sustainability* **2023**, *15*, 9606. https://doi.org/10.3390/su15129606

Academic Editor: Grigorios L. Kyriakopoulos

Received: 26 April 2023
Revised: 6 June 2023
Accepted: 12 June 2023
Published: 15 June 2023

1. Introduction

The paradigm shifts in global development, leading to a more globalized and networked world, are radically changing the nature of production and competitive processes [1]. The focus of global competition is shifting to the meso level (territories, cities), following product chains and value added. Today, national competitiveness depends not only on the macroeconomic situation in the country, but also on the maturity of regions and the sustainable development of territories [2,3]. Based on technological sovereignty, the localization of production and production chains will lead to further regionalization of industry. Accordingly, the role of microeconomic factors is increasingly prominent. New models of sustainable development for territories, industries and industrial enterprises are considered as key to future industrialization. The advantages of network forms of organization of economic interactions are manifested in the mutual interest of specialized economic units in each other (collective value creation for all parties involved, distribution of resources and effects), combining two opposing principles—competition and cooperation. The variability of inter-organizational interaction forms implies the use of various tools for establishing integration links. However, networking is currently the dominant form of integration with total coverage [4,5]. At the same time, the undeniable advantages of networks include predicting the further spread of integration. Network structures taking various organizational forms are widely used in business practice, including clusters, industrial networks, techno parks, networks of technology transfer centers, industrial symbioses, ecosystems, etc. Each of these models has its own advantages and limitations and requires clarification of the key concepts.

The definition of industrial networks is treated ambiguously in the scientific literature. Korovin [6] proposes a classification of networking according to institutional, resource, attitudinal or managerial criteria. In fact, these criteria cover all types of lateral structures (clusters, symbioses, ecosystems, etc.). According to Anjos [7], “the primary approach to integration is the resource criterion approach, which consists in combining companies to create additional value”. Gulati, Lavie and Madhavan believe that “a company’s inclusion in a network is determined by the extent to which a company can obtain or present access to network resources by channeling them through inter-organizational channels” [4]. The value that companies’ integration creates can be both “tangible and intangible” [8,9]. However, the academic community has not sufficiently addressed the issues of integration typology using key criteria such as the life-cycle stage of industrial integration and the level of collaborative maturity, operationalizing the models to assess the sustainability and maturity of integration networks, and identifying the key factors underlying the complex interactions.

In the article, the authors propose a classification of network integration of companies according to the degree of technological and environmental maturity. From this perspective, industrial networks belong to the initial immature level of network integration, where the goal is defined solely by resource benefits for the companies. More mature, but still quite “young”, are companies whose integration is in the form of industrial parks and clusters. Three types of integration can be distinguished for industrial enterprises:

- “young” (eco-techno parks)—a type of industrial integration where enterprises are integrated into a single value-added chain;
- “combined” (industrial symbiosis)—a type of industrial integration of enterprises with signs of circularity;
- “mature” (ecosystem symbiosis)—a type of industrial integration of enterprises characterized by both the circularity of resources and the exchange of innovative technologies and knowledge.

The innovative industrial ecosystem refers to an approach that integrates both industrial systems of different types and individual actors (financial, scientific, educational, and public institutions) based on the exchange of materials, energy, resources, knowledge, and technology, creating economic, technological, and environmental benefits for all participants in the ecosystem and society.

This article proposes an approach to assess the sustainability of ecosystem symbiosis when integrated into innovative industrial ecosystems based on the integral indicators of stability, resilience and ecosystem (coherence). By coherence, the authors imply long-term collaboration or collaborative maturity. “The level of collaborative maturity is expressed in the ability to build mutually beneficial trusting relationships with partners, to resolve conflicts, to be guided by long-term goals and to take care of one’s reputation” [10].

The article is organized as follows. Section 2 provides a theoretical overview of an innovation industrial ecosystem, industrial symbiosis, and an ecosystem approach to foster the implementation of ecosystem symbiosis and sustainable business models in economic practice. Section 3 presents a new methodology for the evaluation of industrial ecosystems’ sustainability. Assessment of an ecosystem’s sustainability is carried out based on blocks of indicators, including stability, resilience and coherence. Section 4 focuses on the implementation of the proposed methodological approach. The authors illustrate their assumptions with an empirical case study of three industrial ecosystems located in the Voronezh, Belgorod and Lipetsk regions (Russia). Finally, in Section 5, the authors discuss propositions arising from the conducted analysis to determine the self-organization features of innovation industrial ecosystems and their implications in terms of sustainability. Additionally, the authors highlight the key findings of the study and present the theoretical contribution and practical significance of the study.

2. Literature Review

Academics have researched the network forms of cooperation between sectors and industries and the development of inter-sectoral network relations in the following studies. Bolshakov, Badenko and Yadykin explore the reliability of industrial integration to provide a digital transformation strategy. The researchers' hypothesis is that "by applying a single standardized approach to digital transformation, companies can achieve greater reliability and sustainability" [11]. The approach is to develop common cross-industry principles that are recommended as a practical guide for enterprises to develop their digitalization strategies. By following such principles, organizations can create resource synergies by benefiting from collective industry knowledge and expertise. Ma, Zhao and Yin believe that it is necessary to improve industrial integration to develop the economy using the "Intelligent industrial structure change prediction method and sustainable adjustment strategy for regional policy optimization and adjustment". When analyzing the sustainability of networked industrial structures in the region, the strategy of complex linkage adjustment based on the authors' proposed linkage prediction algorithm leads to carbon emission reduction and is in line with the green development philosophy [12]. An alternative hypothesis of vertical enterprise integration was presented by Nogueira, Pereira et al. They analyzed the impact of resource synergies in the form of information on the level of efficiency of operational integration. The hypothesis of their study was that integrated companies are leaders in product innovation and that companies that have developed integration capabilities (i.e., have collaborative maturity) are more robust [13].

Another alternative hypothesis relates to issues of transformational adaptation of national economies. The authors' hypothesis is that "the degree of correlation between the level of involvement of national economies in the transformation of global value chains on the principles of sustainable development and the dynamics of green innovation implementation is differentiated for different countries depending on both the level of wealth and the sectoral structure of the national economy". A particular feature of the study is the identification of groups of factors that influence the implementation of innovation not in a single company, but in a chain of interconnected companies [1].

Research Hypothesis. Networked enterprise integration based on the principles of sustainability, collaboration and open innovation provides ecosystem-based resource synergy, long-term stability and resilience for each actor.

The evolution of industrial enterprise integration forms is summarized in Figure 1.

Porter, who is considered the founder of the cluster theory, outlined its essence in his work "Competitive Advantages of Nations" [14]. A major contribution to the formation of the cluster theory was made by Marshal, who, in his work "Principles of Economics", empirically proved the relationship between productivity and geographic proximity of economic agents. The author himself called clusters "localized industry". The current theoretical approaches to the understanding of clusters and their role in the socio-economic development of regions have been formed and are continuously adjusted under the influence of several areas of scientific thought.

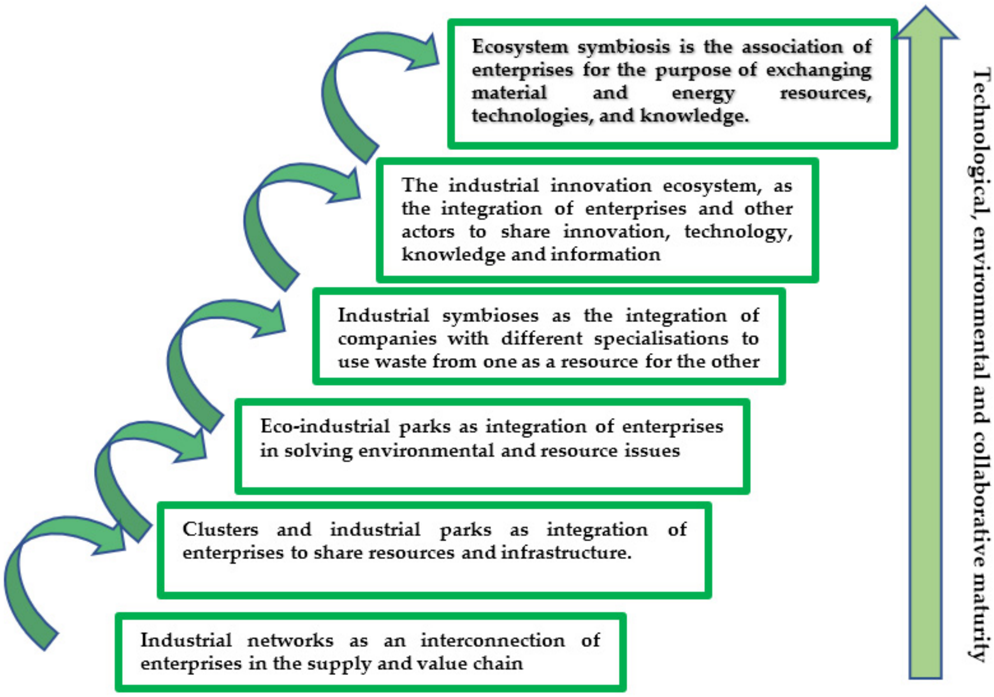

Figure 1. Types of industrial enterprise integration.

The research in [15] provides a large-scale analysis of the literature on the main research areas of industrial clusters. Clustering implies not only resource exchange, but also the creation of cognitive value in the form of new technologies, knowledge and materials. The limitation of clusters according to the criterion of environmental maturity is their pronounced production specialization; the environmental policy of the cluster member is not a significant factor [16]. The principal rationale for establishing an industrial park is to enable "industry to settle and develop at a specific location that is planned and improved to that effect". The United Nations Industrial Development Organization (UNIDO) defines an industrial park as "a tract of land developed and subdivided into plots according to a comprehensive plan with the provision of roads, transportation and public utilities, sometimes also with common facilities, for use by a group of manufacturers" [17]. Industrial parks are understood as a "networked integration of companies that combine industrial and economic resources to create an innovative and technological environment" [18]. Festel and Würmseher define an industrial park as a "specialized production area, which is provided with necessaries for activities, from energy resources to logistics" [19]. The park is managed by a specialized company. On the territory of the complex, activities are carried out by several enterprises that are not legally linked but, as a rule, are integrated into a single value-added chain.

The integration of companies in the form of eco-industrial parks (EIPs) represents a much more advanced network, as in this case, the aim is to build up technological interaction between production facilities through the exchange of resources (interchange) and recyclable materials [20,21]. That is, unlike industrial parks, eco-industrial parks (EIPs) promote not only technological development, but also the coordination of economic development and environmental protection [22]. The formation of eco-industrial parks is not the initiative of the companies themselves and not a product of their self-organization, but instead a decision of local and state authorities. Therefore, the limitations of eco-industrial parks include social barriers such as underdeveloped cooperation in technological, logistical and cognitive areas [23]. The creation of the EIP leads to the scaling and expansion of activities aimed at the introduction of resource-efficient and environmentally friendly industries with the prospect of going beyond eco-industrial parks to their inclusion in the system of "sustainable cities", in which economic and social symbiosis can be achieved in all aspects of sustainable urban planning [24]. Eco-industrial parks improve the integration of industries in territories by creating a common economic environment and increasing innovative business opportunities. Thus, eco-industrial parks provide a triple benefit: environmental, social and economic:

- modern eco-industrial parks are designed to drastically reduce the negative environmental impact of industrial operations through environmentally efficient management and the implementation of pollution prevention systems;
- eco-industrial parks provide social benefits, including improved local living standards, as a result of the development of common infrastructure and improved quality of education through the introduction of new curricula, as well as the introduction of higher standards of health and safety for employees of enterprises;
- the creation of eco-industrial parks leads to an increase in the competitiveness of companies, a decrease in resource consumption and increasing sales through green and segment marketing.

The limitation of eco-industrial parks in the form of lack of self-organization overcomes the association of enterprises in the form of industrial symbioses, representing a new business model that uses materials previously considered as waste, allowing new markets to be formed [25].

Industrial symbiosis is a concept that came from the field of industrial ecology and is interpreted as "a set of intercompany relations in which the waste of one enterprise becomes a resource or energy for another enterprise" [26]. Industrial symbiosis is often described as a model for sustainable development and a tool for the circular economy [27]. Industrial ecology includes some specialized tools and techniques that can be used within industrial symbiosis. The network of physical processes and relationships between companies that transform raw materials and energy into finished products and waste is known as the "industrial metabolism" [28–30]. The industrial metabolism, in addition to biological systems, is based on the use of by-products to form closed cyclic systems that produce minimal waste and consume fewer natural resources and energy.

The networking of enterprises based on the principles of the circular economy allows companies to form joint strategies to achieve sustainability and to derive synergies from integration. Bijon, Wassenaar, Junqua and Dechesne evaluated the nature of synergy and its impact on sustainability [31]. From the perspective of technological and ecological maturity, pro-industrial symbiosis has the potential to evolve into an industrial ecosystem. This experience of a symbiotic trajectory with social and economic aspects, using the example of Tampico-Altamira, was described by Morales, Manuel, Diemer, Arnaud and Cervantes in [32]. The article reports that industrial symbiosis can become an ecosystem in which interconnections lead to cooperative actions, and the biophysical and social aspects of symbiosis can be viewed as a breakthrough in ecosystem development.

The definition of industrial and business ecosystems has been the subject of many articles in the scientific literature. Espina-Romero and Guerrero-Alcedo define the ecosystem as "the integration of companies united around innovation to develop innovative products and meet customer needs" [33]. The ecosystem approach to the development of economic systems is described by the concept formed to date, which systematizes the main scientific achievements and trends in the development, synergistic interaction and co-evolution of ecosystems of various etymologies. The ecosystem concept allows for presenting a scientific understanding of the problems and solutions in the practical implementation of ecosystem development. The ecosystem concept includes ontology, conceptual apparatuses, principles, laws, regularities, theories, algorithms, methods, technologies and levers, as used in formal and informal models. The proponents of the first approach are Frosch and Gallopoulos [34] who defined the industrial ecosystem as a "model of industrial activity in which individual production processes consume raw materials and generate products to be sold and waste to be recycled". In traditional industrial systems, every processing operation consumes raw materials, delivers products, and generates waste that is stored. It is necessary to replace this simplified method with a more integrated model: the industrial ecosystem.

An industrial ecosystem can function like a biological ecosystem. Naturally, it will never be possible to create a perfect industrial ecosystem; however, producers and consumers must change their habits if they want to maintain or improve living standards in the face of from environmental degradation [35]. Localized socio-economic formations that ensure sustainable development through the circulation of resources in the target, environmental, technological and project subsystems were presented in [36,37]. The second approach is described in the work by Wareham, Fox, Cano and Giner [5]. Industrial ecosystems are a set of interacting economic entities that are not managed hierarchically and adapt to each other using professional communication platforms created by an industrial architect [5,36]. A set of components is created by the owner of the product platform and innovations are developed by independent actors outside the platform. Eco-platforms are created in which resource management and business processes tend to be more environmentally friendly and safe for humans and the environment [37,38]. The concept of ecosystems that are an evolutionary development of industrial networks, industrial and eco-industrial parks, clusters, and symbioses is substantiated in a series of publications [2,3,39–41]. The industrial ecosystems formed on the principles of self-organization and self-regulation, partnership and trust, sustainability and open innovation form a special innovative technological environment, allowing implementation of ambitious projects associated with new technologies and resource efficiency. The ecosystem can include as actors not only individual companies or organizations, but also clusters and symbioses [33]. Thus, the essence of the industrial ecosystem should be considered as an emergent model of industrial activity, based on a localized evolving coherent network of multiple actors, not controlled hierarchically, acting simultaneously using the logic of autonomy and interconnectedness, self-organization, and homeostasis, and differing in their beliefs and decision-making principles [42,43]. The purpose is to achieve sustainability and create additional value for each actor of the current and future generations based on the principles of industrial symbiosis and recycling.

Ecosystem integration for companies is not limited to territory or industry, allowing for technological and ecological maturity. The highest point of technological, ecological, and collaborative maturity can be considered as an ecosystem symbiosis that includes industrial ecosystems as actors, covering entire regions and industries. Although such ecosystem symbioses may be regarded as the future, attempts to describe them have been made in scientific articles [44].

3. Materials and Methods

According to the UN, if unsustainable patterns of traditional production and business continue, by 2050, humanity will require three times the Earth's resources. Under these circumstances, the sustainable development paradigm takes on new convergent features associated with humanity's ever-increasing collective strain on natural resources and the transition to new geochronological and technological patterns. These features need to be considered when designing a sustainable development toolkit to ensure the values of both current and future generations, as well as obtaining balanced ESG effects (environmental, social, governance). Industrial ecosystems can make a significant contribution to overall sustainable industrial development through eco-efficient management and production patterns, improved local livelihoods, and reduced consumption and resource dependency.

The study applied a set of general scientific methodological approaches. The dialectical approach allowed considering the philosophical aspects, factors and conditions of the sustainable development of industrial ecosystems. Based on the critical (evaluative) approach, the contradictions, critical aspects and paradoxes of sustainable development were identified. The application of the systemic and synergetic approaches made it possible to form a holistic view of the industrial ecosystem, to highlight the relationships between the actors, levels, components and structural elements of the industrial ecosystem. A meta-systemic approach allowed us to highlight the objects, subjects, categories and terms, goals, objectives of research, and interdisciplinary elements, including the essence, connections, structure, composition, characteristics (qualitative, quantitative, temporal), functions, properties, specifics, principles, concepts, stages, forms, directions, and methods of sustainable development of industrial ecosystems under conditions of technological transformations.

Existing studies on the assessment of the sustainability of industrial ecosystem symbioses are characterized by several limitations. First, they are often limited to a system of indicators for assessing the sustainability of ecosystems. Integral indicators describe ecosystem symbioses from different research projections, but do not give a general idea of the sustainability of the industrial ecosystem. This can lead to industrial ecosystems having different resilience scores. In addition, the sustainability assessment should have a predictive function and answer three key questions:

- What is the degree of sustainability of industrial ecosystem symbioses?
- Which actors in the industrial ecosystem are characterized by minimum and maximum sustainability?
- What are the sources of sustainability?

The main objectives of this study are as follows: identification of industrial ecosystems with the highest and lowest resilience; benchmarking of industrial ecosystems within three groups (high, medium, low resilience); development of a predictive function to define resilience in relation to the ecologically, socially, managerially and economically acceptable level of ESG outcomes.

The research strategy used involves assessing the composite indicator using the components of stability (invulnerability), resilience (reliability) and ecosystems (coherence) rather than by type of sustainability.

The method for assessing the stability of industrial ecosystem symbioses is implemented using the RS-TOPSIS (Rough Set and Technique for Order Preference by Similarity to Ideal Solution), PyTOPS-3 software tool. Achieving the sustainability of industrial ecosystems can be formalized as:

$$S = f(S_t = I_v = 1, R = Rl, E = C) \tag{1}$$

where

S—stability of the industrial ecosystem;
S_t—stability, expressed through the invulnerability index (I_v) and the inverse of the vulnerability index (v);
R—vitality of industrial ecosystems, expressed through the reliability index (Rl);
E—ecosystem, expressed through the coherence (C) of the industrial ecosystem.

Wang D. [45] defines vulnerability as a conditional probability of loss of stability by an industrial ecosystem under the influence of a disturbance and identifies four projections for assessing the vulnerability of an industrial ecosystem, classified as follows:

- risk of economic fluctuations;
- sensitivity of the industrial ecosystem;
- resilience of the industrial ecosystem;
- stability of the industrial ecosystem.

The authors propose assessment of the vulnerability of an industrial ecosystem as the probability that the final state of the ecosystem will go beyond the boundaries of a given region of the state space of the industrial ecosystem because of an initiating impact. Then, the stability of the industrial ecosystem can be assessed as the opposite of vulnerability. It is recommended to select tools and indicators by evaluating their relative levels of feasibility, reliability and usefulness in accordance with the given scale of the industrial ecosystem. The concept of resilience is defined as “the amount of perturbation that can be absorbed before the system changes its structure by changing the variables and processes that govern behavior”. Vitality can be thought of as “the rate at which a system returns to equilibrium after a disturbance” [46–50].

The methodology for assessing the sustainability of industrial ecosystems under technological and economic fluctuations is presented in Figure 2.

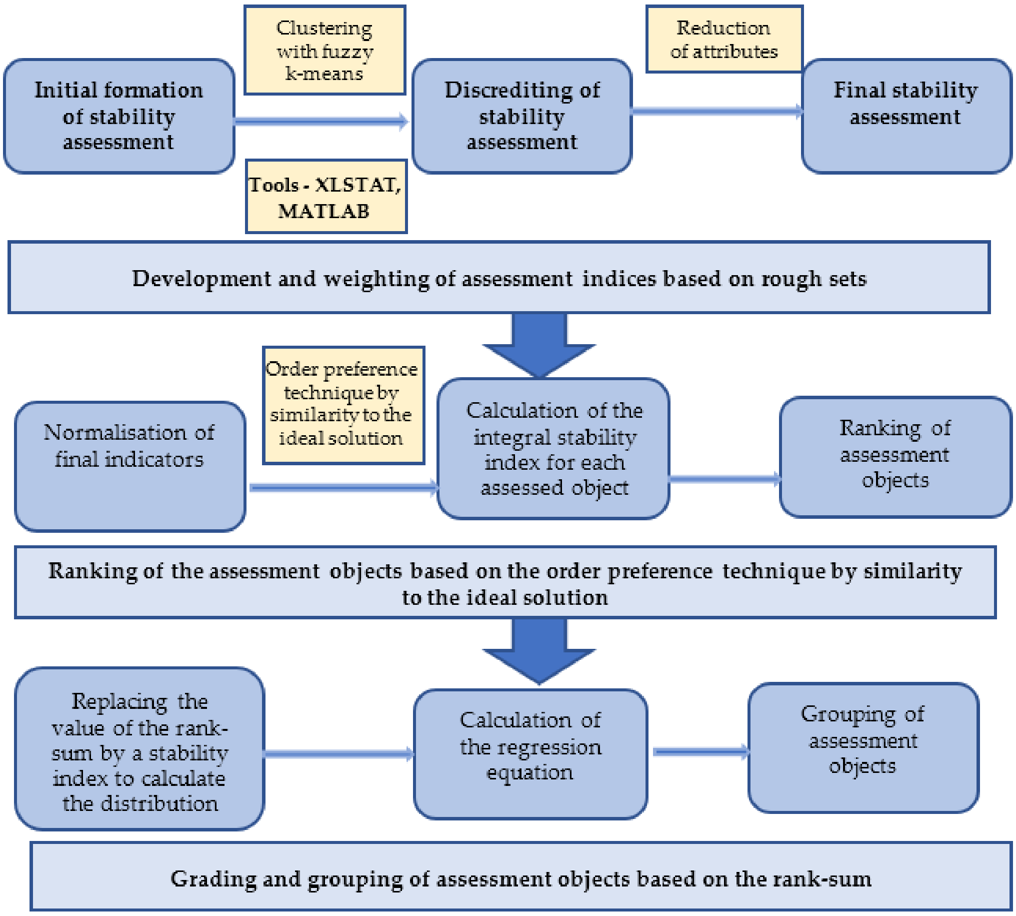

Figure 2. Methodology for assessing the sustainability of industrial ecosystems under technological and economic fluctuations.

The composite index method, fuzzy sets method, preference ordering by similarity to the ideal solution, rank-summing method, fuzzy k-means clustering method, least squares method, Gaussian method, and variance and multiple regression analysis were used in developing the resilience assessment methodology.

At the first stage of the methodology for assessing the sustainability of industrial ecosystems under the conditions of technological and economic fluctuations, it is necessary to form a system of indicators. The initial scorecard includes 29 indicators for assessing the sustainability of the industrial ecosystem. All indicators of the initial assessment system correspond to those presented in the work of Wang et al. on indicators for assessing the vulnerability of industrial ecosystems [45,51]. The sources of initial data for the formation of a system of indicators include Rosstat, the Higher School of Economics, the Association of Industrial Parks of Russia, and the Ministry of Industry and Trade of the Russian Federation [52–56]. At the second and the third stages of the assessment of the sustainability of industrial ecosystems under conditions of technological and economic fluctuations, the attributes are reduced, and the sustainability assessment indicators are weighted based on the fuzzy set method. Since the 29 variables chosen to assess the sustainability of industrial ecosystems are mostly continuous attributes, and the fuzzy set can only work with discrete data, the clustering algorithm must be applied to discretize continuous data. For this, the clustering method with fuzzy k-means is used. According to the theory of fuzzy sets, the weights of indicators can be obtained by calculating the importance of an attribute, which is determined by the amount of information contained in it. In the k-means clustering algorithm, the number of clusters must be known in advance. In this case, we are interested in clustering according to three components of sustainability—stability (invulnerability), resilience (reliability) and ecosystem (coherence). So, the number of clusters is 3. Clustering was carried out using XLSTAT, an add-in for Excel data analysis. As a result of fuzzy clustering by the k-means method, the following data were obtained (Table 1).

Table 1. Results of fuzzy clustering of variables by the k-means method.

Cluster	Size	Intraclassness	Minimum Distance to Centroid	Maximum Distance to Centroid	Average Distance to Centroid
Cluster 1	10	4.905	0.377	0.958	0.739
Cluster 2	15	3.590	0.142	0.919	0.629
Cluster 3	4	6.331	0.359	0.939	0.757

The final system of indicators for assessing the three components of sustainability included 13 indicators, of which 5 indicators assessed the stability (invulnerability) component of the industrial ecosystem, 7 assessed the resilience (reliability) component of the industrial ecosystem, and one indicator assessed the ecosystem (coherence) component of the industrial ecosystem (Table 2). At the fourth stage of assessing the sustainability of industrial ecosystems, indicators were normalized. Normalization was carried out according to the minimax criterion. For some indicators, higher values indicate a higher level of industrial ecosystem resilience, and these indicators are considered positive (X1.1, X1.2, X1.5, X2.4, X2.5, X2.6, X2.7, X3.1). However, for some other indicators, higher values indicate a lower level of sustainability in the industrial ecosystem, and these indicators are considered negative (X1.3, X1.4, X2.1, X2.2, X2.3). In the case of negative indicators, their reciprocal values should be used during normalization. At the fifth stage, the integral stability index is calculated for each object of assessment (for each industrial ecosystem) based on the method of ordering preferences by similarity to the ideal solution:

- The object of assessment with the greatest stability (ideal solution) and the object of assessment with the least stability (negative solution) are determined.
- The Euclidean distance between the object of assessment with the greatest (least) stability and other objects of assessment is calculated.
- The relative proximity of each assessment object to the assessment object with the greatest stability is calculated.

Table 2. System of indicators for assessing the sustainability of industrial ecosystems in four projections.

Components	Assessment Indicators	Method of Calculation	Characteristic
1. Stability (invulnerability)	X1.1 Industry elasticity coefficient	Growth rate of industrial production in the industrial ecosystem/GDP growth rate in the country, %	Relationship between development of industrial ecosystems and economic growth
	X1.2 Industrial output per capita in the region	The production output of industrial ecosystem actors/Population in the region	The economic basis for the development of industrial ecosystems
	X1.3 Standard deviation of local commodity price growth rates	$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{av})^2}{n-1}}$ where S—the standard deviation; n—number of observation periods; x_i—the rate of growth in the price of raw materials in the region of presence at time i, %; x_{av}—arithmetic mean of price growth rates in the region of presence, %	Raw material price risk
	X1.4 Standard deviation of gross regional output (GRP) growth rate	$S = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - x_{cf}\right)^2}{n-1}}$ where x_i—GRP growth rate in the region of presence at time i, %; x_{cf}—arithmetic mean of GRP growth rates, %	Risk of regional economic fluctuations

Table 2. *Cont.*

Components	Assessment Indicators	Method of Calculation	Characteristic
1. Stability (invulnerability)	X1.5 Share of investment in environmental management in GRP	Investments in environmental management in the industrial ecosystem/GRP of the region	The ability of the economy to support environmental recovery
2. Vitality (reliability)	X2.1 Share of unprofitable actors	Number of unprofitable actors in the industrial ecosystem × 100%/Total number of actors	The current state of the industrial ecosystems
	X2.2 Share of resource-oriented industrial products in total industrial production (%)	Production output of resource-oriented industrial products in industrial ecosystem/Total industrial production output in industrial ecosystem	Dependency of the industrial ecosystem on resources
	X2.3 Foreign trade dependence	The total volume of imports and exports in the industrial ecosystem/GRP of the region of presence	Dependency of the industrial ecosystem on foreign market
	X2.4 Share of dominant industrial output in total output	The production output of the dominant industrial products in the industrial ecosystem/Total industrial production output in the industrial ecosystem	Diversity of the industrial ecosystem
	X2.5 Share of non-primary industrial output in total industrial products	The production output of non-primary industrial products in the industrial ecosystem/Total industrial production output	Diversity of the industrial ecosystem
	X2.6 Inventory production ratio	Productive reserves in industrial ecosystem + Costs in work in progress/Finished products	Resource utilization rate
	X2.7 Share of investment in fixed assets	Investments in fixed assets in the industrial ecosystem/Total investment in the industrial ecosystem	Investment capacity of the industrial ecosystem to external change
3. Ecosystem (coherence)	X3.1 Degree of correlation between actors	The number of connections between actors in an industrial ecosystem/The number of actors	

At the sixth stage, the objects of assessment are ranked based on the integral sustainability indicator. The seventh stage implies a transition to rank-summation. The rank-sum coefficient is determined for each assessment. At the eighth stage of the methodology for assessing the sustainability of industrial ecosystems under the conditions of technological and economic fluctuations, the regression equation is calculated. At the ninth stage, the objects of assessment (industrial ecosystems) are grouped. The number of groupings is selected depending on the number of ecosystems being assessed. Finally, an analysis of variance should be performed to ensure that the grouping is statistically significant.

4. Results

The proposed methodology for assessing the stability of an industrial ecosystem under the conditions of technological and economic fluctuations was implemented using the example of industrial ecosystems in the Lipetsk, Belgorod and Voronezh regions. Information databases used included statistical and analytical data of the geo-information system "Ecoindustrial parks, techno parks, clusters", the ISID operational platform and the UNIDO analytical industrial platform. The time horizon was 2020. The characteristics of the selected objects for assessing the level of stability are presented in Table 3.

The results of the normalization of indicators for assessing the stability of the objects of assessment are presented in Table 4. The calculation of the integral sustainability index for each object of assessment (for each industrial ecosystem) is presented in Table 5. Based on the method of ordering preferences by similarity to the ideal solution.

Table 3. The industrial ecosystems in the Lipetsk, Belgorod and Voronezh regions.

Industrial Ecosystems	Actors	Area, ha
Voronezh	1. Maslovsky Industrial Park	378
	2. Industrial Production Center	220.2
	3. Industrial Park Perspectiva	146.3
Lipetsk	4. Industrial Park Rozhdestvo	420
	5. Industrial Park Sozidatel	8.65
	6. Industrial Production SEZ Lipetsk, site "Gryazinskaya"	1024.5
	7. Industrial Production SEZ Lipetsk, site "Eletskaya"	1273.8
Belgorod	8. Industrial Park Volokonovsky	12.8
	9. Industrial Park Kombinat	68
	10. Industrial Park Severny	58.1
	11. Industrial Park Fabrika	24.2

Table 4. Initial data for calculating the level of sustainability of industrial ecosystems.

Index	Actor Numbers According to Table 3										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
X1.1	0.9	0.8	1.1	0.89	0.56	1.1	1.1	1.08	1.12	0.87	0.92
X1.2	1	1	1	0.6	0.6	0.6	0.6	0.8	0.8	0.8	0.8
X1.3	30	30	30	32	32	32	32	29	29	29	20
X1.4	35	35	35	40	40	40	40	39	39	39	39
X1.5	5	7	10	7	14	11	11	5	5	3	11
X2.1	10	13	15	12	5	7	10	3	12	13	5
X2.2	20	15	11	8	14	14	12.7	11	8	9	16
X2.3	15	20	13	19	15	15.3	13	11	10	14	15
X2.4	0.6	0.7	0.6	0.4	0.8	0.7	0.6	0.7	0.4	0.6	0.4
X2.5	80	85	89	92	86	86	83	89	92	91	84
X2.6	0.2	0.3	0.3	0.1	0.2	0.3	0.1	0.3	0.1	0.32	0.21
X2.7	5	7	10	7	14	11	7	5	5	3	6
X3.1	43	25	32	37	45	45	45	32	36	56	23

Table 5. Sustainability indicators for the three components in the form of a heat map for the assessed objects in 2020.

Industrial Area	Stability (Invulnerability)	Vitality (Reliability)	Ecosystem (Coherence)	Integrated Stability Index	Rank	Stability Group
Industrial Park Perspektiva	0.7424	0.5542	0.2727	0.6049	1	High
Industrial Park Volkonovsky	0.3925	0,7078	0.2727	0.5530	2	Medium
IP SEZ Center	0.5807	0.3857	0.0606	0.4357	3	Medium
Industrial Park Severny	0.2811	0.5284	1.0000	0.4695	4	Medium
Industrial Park Kombinat	0.4067	0.4635	0.3939	0.4363	5	Medium
IP SEZ Lipetsk, site "Gryazinskaya"	0.3383	0.5384	0.6667	0.4713	6	Medium
Industrial Park Sozidatel	0.2000	0.5819	0.6667	0.4416	7	Medium
Industrial Park Maslovsky	0.5800	0.2278	0.6061	0.3924	8	Low
Industrial Park Rozhdestvo	0.1906	0.3541	0.4242	0.3382	11	Low
Industrial Park Fabrika	0.6099	0.3009	0.0000	0.3966	9	Low

– the object of assessment with the greatest stability was determined (ideal solution) to be the Industrial Park Perspektiva;
– the object of assessment with the least stability (worst solution) was determined to be the Industrial Production SEZ Lipetsk, site “Eletskaya”.

A comparison can be made between all industrial ecosystems as a single group. However, it should be considered that there are differences between each of these regarding the current state of the actors, environmental variables, etc. Therefore, it is more appropriate to compare industrial ecosystems with similar conditions.

Next, sustainability indicators were calculated by component (stability, resilience, ecosystem) for each of the assessed objects (Table 6). An integrated stability indicator for each assessed object was determined. Based on the integrated sustainability indicator, each object was assigned a rank: from 1 for the maximum sustainability indicator to 11 for the minimum sustainability indicator.

Table 6. Correlation coefficients of the three components and the integral indicators of sustainability.

	Integrated Sustainability Index	Stability (Invulnerability)	Vitality (Reliability)	Ecosystem (Coherence)
Integrated sustainability indicator	1			
Stability (invulnerability)	0.4280	1		
Vitality (reliability)	0.7552	−0.2330	1	
Ecosystem (coherence)	−0.1095	−0.6106	0.1268	1

The data were analyzed using the StatPlus Pro 7.6.5.0 software package developed by AnalystSoft for basic univariate and multivariate statistical analysis, as well as time series analysis, nonparametric statistics, survival rate analysis and statistical charts, including control charts.

Based on the stability indicators for three components in the form of a heat map for the assessed objects, a correlation analysis was carried out (Table 6). The values of the pair correlation coefficient indicate a weak linear relationship between X_1 stability (invulnerability) and the Y integrated stability index (r = 0.428). The values of the paired correlation coefficient indicate a strong linear relationship between X_2 resilience (reliability) and the Y integrated sustainability indicator (r = 0.7552). The values of the paired correlation coefficient indicate a low linear relationship between X_3 ecosystem (coherence) and the Y integrated indicator of sustainability (r = −0.1095). The values of the pair correlation coefficient indicate a low linear relationship between X_2 resilience (reliability) and X_1 stability (invulnerability) (r = −0.233). The values of the pairwise correlation coefficient indicate a moderate linear relationship between X_3 ecosystem (coherence) and X_1 stability (invulnerability) (r = −0.6106). The values of the pair correlation coefficient indicate a low linear relationship between X_3 ecosystem (coherence) and X_2 resilience (reliability) (r = 0.1268).

The main econometric model in the developed methodology is a multiple regression model. The multiple regression equation can be represented as:

$$Y = f(\beta, X) + \varepsilon \tag{2}$$

where $X = X\ (X_1, X_2, \ldots, X_m)$—vector of independent (explanatory) variables; β—vector of parameters (to be determined); ε—random error (deviation); Y—dependent (explanatory) variable. The theoretical linear multiple regression equation is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_m X_m + \varepsilon$$

where β_0 is an intercept term that determines the value of Y when all explanatory variables X_j are 0.

For our example (Table 5), the regression equation (estimation of the regression equation) is as follows:

$$Y = 8.5 \times 10^{-5} + 0.3846X_1 + 0.5383X_2 + 0.07692X_3$$

The interpretation of the regression coefficients is as follows. The constant estimates the ag-regulated effect of factors other than x_i on Y such that Y would be 8.5×10^{-5} in the absence of x_i. The coefficient b_1 indicates that as x_1 increases by 1, Y increases by 0.3846. The coefficient b_2 indicates that as x_2 increases by 1, Y increases by 0.5383. The coefficient b_3 indicates that as x_3 increases by 1, Y increases by 0.07692.

4.1. Multicollinearity Analysis

A multicollinearity is a linear relationship between two or more explanatory variables; it may appear in a functional (explicit) or stochastic (implicit) form. If the factor variables are related by strict functional dependence, then it is complete multicollinearity. In this case, there are linearly dependent columns among the columns of the matrix of factor variables X, and by the property of the determinants of the matrix, det (XTX = 0).

The type of multicollinearity in which factor variables are related by some stochastic relationship is known as partial. If there is a high degree of correlation between the factor variables, the matrix (XTX) is close to degenerate, i.e., det ($XTX \geqq 0$) (the closer to 0 the determinant of the inter-factor correlation matrix, the stronger the multicollinearity of the factors and the more unreliable the results of the multiple regression).

If there is inter-factor correlation coefficient $r_{xjxi} > 0.7$ in the matrix, then there is multicollinearity in this multiple regression model.

In our case, for all pairwise correlation coefficients $|r| < 0.7$, indicating the absence of the multicollinearity of factors.

According to the results of the analysis, it can be stated that the second factor (resilience, reliability) has the maximum impact on the integrated sustainability indicator. In second place is the factor of stability (invulnerability). Ecosystem (coherence) has little effect on the stability of the considered industrial zones. For each component of stability, residual and selection plots were compiled; the component ecosystem (coherence) is presented in Figure 3. Then, the hypothesis of overall significance was verified—the hypothesis that all regression coefficients are simultaneously equal to zero for the explanatory variables:

$\mathbf{H0}: R2 = 0; \beta_1 = \beta_2 = \ldots = \beta_m = 0$

$\mathbf{H1}: R2 \neq 0$

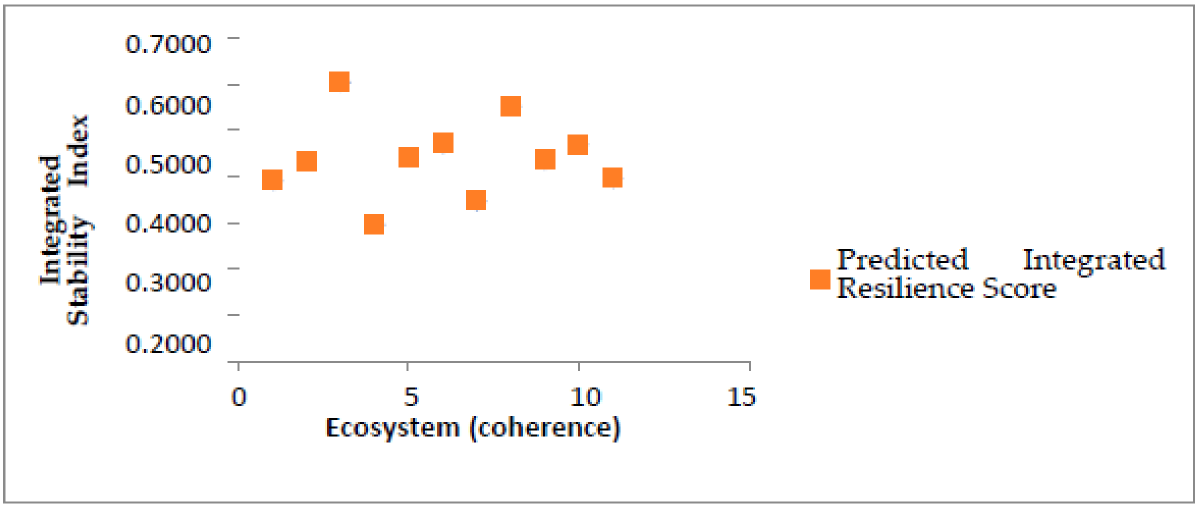

Figure 3. Selection plot for the ecosystem (coherence) component.

This hypothesis is tested using the Fisher distribution F-statistic (right-hand test).

If $F < F_{kp} = F_{\alpha}; n - m - 1$, there is no reason to reject hypothesis H0.

$F = 17{,}344{,}183.815$, $F_{kp}(3;7) = 4.35$

Since the actual value of $F > F_{kp}$, the coefficient of determination is statistically significant, and the regression equation is statistically robust (i.e., the bi-coefficients are jointly significant).

4.2. Assessment of the Significance of the Additional Factor Inclusion (Partial F-Criterion)

The need for such estimation is related to the fact that not every factor included in the model can significantly increase the share of explained variation of the result indicator. This may be due to the consistency of input factors (as there is a correlation between the factors themselves). A measure of the significance of the improvement in the quality of the model, once factor x_j is included, is the partial F-criterion, F_{xj}. If the observed value of F_{xj} is greater than F_{kp}, then the additional introduction of factor x_j into the model is statistically justified. The partial F-criterion estimates the significance of the "proper" regression coefficients (b_j). There is a relationship between the partial F-criterion, F_{xj}, and the t-criterion used to estimate the significance of the regression coefficient.

$$F_{x1} = 17{,}848{,}715.792.$$

$$R^2(x_3,x_n) = \sum \beta_j r_j = 0.9083 \times 0.7552 + 0.2645 \times (-0.1095) = 0.657$$

$$F_{kp}(k1 = 2;\ k2 = 7) = 4.74$$

An economic interpretation of the model parameters is as follows:

- increasing the stability indicator by 1 leads to an average increase in stability of 0.385;
- increasing the vitality by 1 leads to an average increase in stability of 0.538;
- an increase in X_3 of 1 leads to an average increase in Y of 0.0769.

Based on the maximum coefficient $\beta_2 = 0.908$, it was concluded that the vitality (invulnerability) factor has the greatest impact on stability.

The developed method of assessing the sustainability of industrial ecosystems under conditions of technological and economic fluctuations is based on the compilation of three methods, the fuzzy sets method, the method of ordering preferences by similarity with the ideal solution, and the rank-summing method, and includes nine stages. The essence of the method comes down to the assumption that the level of sustainability of industrial ecosystems can be assessed using stability, expressed through the indicator of invulnerability; the resilience of industrial ecosystems, expressed through the indicator of reliability; and ecosystem, expressed through the coherence of industrial ecosystem.

5. Discussion and Conclusions

The article proposes a methodical approach to assessing the sustainability of industrial ecosystems by determining the collaborative maturity, resource stability and technological resilience of actors. The criteria for defining the stability of an industrial ecosystem under conditions of technological and economic fluctuations is proposed, based on the components of stability (invulnerability), vitality (reliability) and ecosystem (coherence). These criteria make it possible to identify industrial ecosystems with the highest and lowest sustainability, comparing the assessed industrial ecosystems within three groups (high, medium, and low sustainability). The developed methodology for assessing the sustainability of industrial ecosystems under conditions of technological and economic fluctuations is based on the compilation of three methods, the fuzzy sets method, the method of preference ordering by similarity with the ideal solution, and the method of rank-summing, and includes nine stages. The methodology allows determination of the potential for technological, environmental and collaborative maturity of enterprises. The proposed method has some limitations in practical use: (1) the labor-intensive approach, (2) the high volatility of estimates, and (3) the high susceptibility to the ranking method and parameter values. The method was illustrated using the example of industrial ecosystems of the Belgorod, Lipetsk and Voronezh regions. Industrial Park Perspektiva had the highest level of stability. The least stable was the Industrial Park Rozhdestvo, which had a ranking of 10 in terms of sustainability. The highest resilience was demonstrated by the Industrial Park Volokonovsky (ranked second in the assessment of the integrated sustainability index). Industrial Park Maslosky was characterized by the lowest resilience, having a ranking of eight. The Industrial Park Severny had the highest ecosystem content (coherence) and was ranked fourth. Based on the analysis of the results of the industrial ecosystem resilience assessment, the ecosystem integration of enterprises was predicted based on the principles of self-organization and trust, stability, and open innovation. It is recommended to select tools and indicators by assessing their relative levels of feasibility, reliability and usefulness according to the given scale of the industrial ecosystem. The research hypothesis that industrial enterprise integration based on the principles of sustainability, collaboration and open innovation provides ecosystem-based resource synergy, long-term stability and resilience for each actor was confirmed.

Ecosystems are widely discussed nowadays. Researchers from Taiwan assessed the sustainability of industrial integrations in the form of industrial parks from the following aspects: industrial structure, regional development framework, enterprise competitiveness and public administration system. The hypothesis of their study was that a diversified industrial structure is the main factor in increasing regional economic sustainability [57]. The authors Zhukovskiy, Koshenkova, Vorobeva, Rasputin and Pozdnyakov evaluate the fuel and energy sector through selected properties: sustainability, affordability, efficiency, adaptability and reliability. Their hypothesis was that an effective design of sustainable development strategies requires an assessment of external challenges and their impact on technological development, allowing for the identification of underdeveloped areas with high potential [58]. The authors believe that the effectiveness of industrial enterprises integration primarily depends on the level of collaborative maturity and trust of each actor, the sustainability of the ecosystem stability, and the quality of the innovation environment. The development of industrial ecosystems requires a detailed study of the processes of interorganizational interaction, conflict theory, and synergistic and spillover effects.

In future research, the authors plan to investigate the mechanism for industrial ecosystem actors to capture value through the network effect and focus on the analysis of ecosystem integration, based not only on the benefits of ecosystems, but also from the position of competition and conflict theory. The authors will also pursue development of a model that allows a comprehensive spatial–temporal analysis of the functioning and interaction of objects, processes and environments within an ecosystem and assessment of the impact of external (geopolitical) factors and possible scenario analysis.

Author Contributions: Conceptualization, formal analysis, writing—original draft preparation, data collection, data validation, and supervision, T.T.; writing—original draft preparation, data collection, data validation, first data analysis, and funding acquisition, N.S.; writing—original draft preparation, data collection, data validation, first data analysis, and funding acquisition, O.D. All authors have read and agreed to the published version of the manuscript.

Funding: The study was supported by the grant of the Russian Science Foundation No. 23-28-01548 "Integration of enterprises into innovative industrial ecosystems for the formation of windows of opportunity for development and implementation of import-independence policy".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Shelomentsev, A.G.; Goncharova, K.S.; Stepnov, I.M.; Kovalchuk, J.A.; Lan, D.H.; Golov, R.S. Strategic Innovation as a Factor of Adaptation of National Economies to the Development of Global Value Chains. *Sustainability* **2021**, *13*, 9765. [CrossRef]
2. Coombes, P.H.; Nicholson, J.D. Business models and their relationship with marketing: A systematic literature review. *Ind. Mark. Manag.* **2013**, *42*, 656–664. [CrossRef]
3. Tolstykh, T.; Gamidullaeva, L.; Shmeleva, N.; Woźniak, M.; Vasin, S. An Assessment of Regional Sustainability via the Maturity Level of Entrepreneurial Ecosystems. *J. Open Innov. Technol. Mark. Complex.* **2021**, *7*, 5. [CrossRef]
4. Gulati, R.; Lavie, D.; Madhavan, R. How do networks matter? The performance effects of interorganizational networks. *Res. Organ. Behav.* **2011**, *31*, 207–224. [CrossRef]
5. Wareham, J.; Fox, P.B.; Cano Giner, J.L. Technology ecosystem governance. *Organ. Sci.* **2014**, *25*, 1195–1215. [CrossRef]
6. Korovin, G.B. Network structures in the regional industry. *Econ. Reg.* **2020**, *16*, 1132–1146. [CrossRef]
7. Anjos, F. Resource configuration, inter-firm works, and organizational performance. *Math. Soc. Sci.* **2016**, *82*, 37–48. [CrossRef]
8. Wang, G.; Yang, J.; Xu, F. Analyzing Express Revenue Spatial Association Network's Characteristics and Effects: A Case Study of 31 Provinces in China. *Sustainability* **2023**, *15*, 276. [CrossRef]
9. Abbott, A.; Collins, D. A Theoretical and Empirical Analysis of a 'State of the Art' Talent Identification Model. *High Abil. Stud.* **2002**, *13*, 157–178. [CrossRef]
10. Kreibich, L.-M. Improving Inter-Agency Collaboration in International Devel-Opment Analysis of Conditions under Which to Enter, Develop and Sustain Successful Partnerships. Ph.D. Thesis, Hertie School, Berlin, Germany, 2013; 64p.
11. Bolshakov, N.; Badenko, V.; Yadykin, V.; Tishchenko, E.; Rakova, X.; Mohireva, A.; Kamsky, V.; Barykin, S. Cross-Industry Principles for Digital Representations of Complex Technical Systems in the Context of the MBSE Approach: A Review. *Appl. Sci.* **2023**, *13*, 6225. [CrossRef]
12. Ma, Y.; Zhao, R.; Yin, N. Application of an Improved Link Prediction Algorithm Based on Complex Network in Industrial Structure Adjustment. *Processes* **2023**, *11*, 1689. [CrossRef]
13. Nogueira, P.; Pereira, L.; Simões, A.; Dias, A.; Lopes da Costa, R. Vertical Integration Dynamics to Innovate in Technology Business. *Informatics* **2023**, *10*, 25. [CrossRef]
14. Porter, M. The competitive Advantage of Nations. *Harv. Bus. Rev.* **1990**, 73–93.
15. Cruz Sara, C.S.; Teixeira Aurora, A.C. The Evolution of the Cluster Literature: Shedding Light on the Regional Studies-Regional Science Debate. In *Regional Studies*; Routled Taylor & Francis Group: Abingdon, UK, 2009; pp. 1–26. [CrossRef]
16. Lataifa, S.B.; Rabeau, Y. Too close to collaborate? How geographical proximity could impede entrepreneurship and innovation. *J. Bus. Res.* **2013**, *66*, 2071–2078. [CrossRef]
17. United Nations Industrial Development Organization (UNIDO). International Guidelines for Industrial Parks. Available online: https://www.unido.org/sites/default/files/files/2020-05/International_Guidelines_for_Industrial_Parks_EN.pdf (accessed on 25 April 2023).
18. Yan, X.; Wang, L.; Fang, M.; Hu, J. How Can Industrial Parks Achieve Carbon Neutrality? Literature Review and Research Prospect Based on the CiteSpace Knowledge Map. *Sustainability* **2023**, *15*, 372. [CrossRef]
19. Festel, G.; Würmseher, M. Benchmarking of industrial park infra-structures in Germany. *Benchmark. Int. J.* **2014**, *21*, 854–883. [CrossRef]
20. Maalouf, A.; Maryev, V.; Smirnova, T.; Mavropoulos, A. *Current Waste Management Status and Trends in Russian Federation: Case Study on Industrial Symbiosis*; Springer: Singapore, 2021. [CrossRef]
21. Kowalski, Z.; Kulczycka, J.; Makara, A.; Mondello, G.; Salomone, R. Industrial Symbiosis for Sustainable Management of Meat Waste: The Case of Śmiłowo Eco-Industrial Park, Poland. *Int. J. Environ. Res. Public Health* **2023**, *20*, 5162. [CrossRef]
22. Xu, Q.; Cao, K.; Dai, J.; Zhu, Y.; Dai, Y. Nonlinear Effects of Eco-Industrial Parks on Sulfur Dioxide and Carbon Dioxide Emissions—Estimation Based on Nonlinear DID. *Sustainability* **2023**, *15*, 1988. [CrossRef]
23. Ceglia, D.; de Abreu, M.C.; Da Silva Filho, J.C. Critical elements for eco-retrofitting a conventional industrial park: Social barriers to be overcome. *J. Environ. Manag.* **2017**, *187*, 375–383. [CrossRef]
24. Eco-Industrial Parks: Ensuring Shared Prosperity and Protecting the Environment. UNIDO. 2017. Available online: https://www.unido.org/news/eco-industrial-parks-creating-shared-prosperity-and-safeguarding-environment (accessed on 14 November 2022).
25. Castellet-Viciano, L.; Hernández-Chover, V.; Bellver-Domingo, Á.; Hernández-Sancho, F. Industrial Symbiosis: A Mechanism to Guarantee the Implementation of Circular Economy Practices. *Sustainability* **2022**, *14*, 15872. [CrossRef]
26. Yeo, Z.; Masi, D.; Low, J.; Ng, Y.; Tan, P.; Barnes, S. Tools for Promoting Industrial Symbiosis: A Systematic Review. *J. Ind. Ecol.* **2019**, *23*, 1087–1108. [CrossRef]
27. Dorokhina, E.Y.U. Industrial and eco-industrial parks as a means for the resolution of regional conflicts in the use of natural resources. *Probl. Reg. Ecol.* **2018**, *2*, 113–118. [CrossRef]
28. Chertow, M.R. "Uncovering" Industrial Symbiosis. *J. Ind. Ecol.* **2007**, *1*, 11–30.
29. Haq, H.; Välisuo, P.; Niemi, S. Modelling Sustainable Industrial Symbiosis. *Energies* **2021**, *14*, 1172. [CrossRef]
30. Cioca, L.-I.; Ciomoş, A.-O.; Şeitoar, D.; Druță, R.M.; David, G.M. Industrial Symbiosis through the Use of Biosolids as Fertilizer in Romanian Agriculture. *Recycling* **2021**, *6*, 59. [CrossRef]

31. Bijon, N.; Wassenaar, T.; Junqua, G.; Dechesne, M. Towards a Sustainable Bioeconomy through Industrial Symbiosis: Current Situation and Perspectives. *Sustainability* **2022**, *14*, 1605. [CrossRef]
32. Morales, M.; Diemer, A.; Cervantes, G.; Carrillo González, G. By-product synergy changes in the industrial symbiosis dynamics at the Altamira-Tampico industrial corridor: 20 Years of industrial ecology in Mexico. *Resour. Conserv. Recycl.* **2018**, *140*, 235–245. [CrossRef]
33. Tolstykh, T.; Shmeleva, N.; Gamidullaeva, L.; Krasnobaeva, V. The Role of Collaboration in the Development of Industrial Enterprises Integration. *Sustainability* **2023**, *15*, 7180. [CrossRef]
34. Frosch, R.A.; Gallopoulos, N.E. Strategies for manufacturing. *Sci. Am.* **1989**, *261*, 144–153. [CrossRef]
35. Korhonen, J. Industrial Ecosystem: Using the Material and Energy Flow Model of an Ecosystem in an Industrial System. Bachelor's Thesis, University of Jyväskylä, Jyväskylän, Finland, 2000. no. 5.
36. Kleiner, G.B. Industrial ecosystems: A look into the future. *Econ. Revival Russ.* **2018**, *2*, 53–62.
37. Aarikka-Stenroos, L.; Ritala, P.; Thomas, L.D.W. Circular economy ecosystems: A typology, definitions, and implications. In *Handbook of Sustainability Agency*; Edward Elgar: Cheltenham, UK, 2021.
38. Mason, K.; Spring, M. The sites and practices of business models. *Ind. Mark. Manag.* **2011**, *40*, 1032–1041. [CrossRef]
39. Miles, R.E.; Snow, C.C. Causes of failure in network organizations. *Calif. Manag. Rev.* **1992**, *34*, 53–72. [CrossRef]
40. Kloth, C.; Applegate, B. Inter-Organization Collaboration & Partnerships: A Critical Analysis. OD Network Annual Conference. 2004. [Electronic Resource]. Available online: https://ru.scribd.com/document/156397997/Inter-organization-Collaboration-and-Partnerships-A-Critical-Analysis (accessed on 20 February 2023).
41. Tolstykh, T.; Gamidullaeva, L.; Shmeleva, N. Approach to the Formation of an Innovation Portfolio in Industrial Ecosystems Based on the Life Cycle Concept. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 151. [CrossRef]
42. Grumadaitė, K.; Jucevičius, G. Strategic Approaches to the Development of Complex Organisational Ecosystems: The Case of Lithuanian Clusters. *Sustainability* **2022**, *14*, 15697. [CrossRef]
43. Riesener, M.; Dölle, C.; Kuhn, M. Innovation ecosystems for industrial sustainability. *Procedia CIRP* **2019**, *80*, 27–32. [CrossRef]
44. Maier, M.W. Architecting principles for systems-of-systems. *Syst. Eng. J. Int. Counc. Syst. Eng.* **1998**, *1*, 267–284. [CrossRef]
45. Wang, D.; Zheng, J.; Song, X.; Ma, G.; Liu, Y. Assessing industrial ecosystem vulnerability in the coal mining area under economic fluctuations. *J. Clean. Prod.* **2017**, *142*, 4019–4031. [CrossRef]
46. Batrancea, L.; Rathnaswamy, M.K.; Batrancea, I. A Panel Data Analysis on Determinants of Economic Growth in Seven Non-BCBS Countries. *J. Knowl. Econ.* **2022**, *13*, 1651–1665. [CrossRef]
47. Moret, W. *Vulnerability Assessment Methodologies: A Review of the Literature*; FHI: Washington, DC, USA, 2014; Volume 360.
48. Dudareva, O.V. Vulnerability management of industrial ecosystems for sustainable development. *Organ. Prod.* **2021**, *29*, 77–84.
49. Holling, C.S. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.* **1973**, *4*, 1–23. [CrossRef]
50. Holling, C.S.; Gunderson, L.H. Resilience and adaptive cycles. In *Panarchy: Understanding Transformations in Human and Natural Systems*; Island Press: London, UK, 2002; pp. 25–62.
51. Barile, S.; Bassano, C.; D'Amore, R.; Piciocchi, P.; Saviano, M.; Vito, P. Insights of Digital Transformation Processes in Industrial Symbiosis from the Viable Systems Approach (vSa). *Sustainability* **2021**, *13*, 9696. [CrossRef]
52. Goals of Sustainable Development. Rosstat. Available online: https://rosstat.gov.ru/sdg/data (accessed on 14 November 2022).
53. Ministry of Industry and Trade of the Russian Federation. Available online: https://minpromtorg.gov.ru (accessed on 14 November 2022).
54. Industrial Parks and SEZs of Russia. Available online: https://indparks.ru (accessed on 14 November 2022).
55. Department of Economic and Social Affairs. Sustainable Development. [Electronic Resource]. Available online: https://sdgs.un.org (accessed on 14 November 2022).
56. SDG Global Database. Available online: https://unstats.un.org/sdgs/unsdg (accessed on 14 November 2022).
57. Lee, Y.-H.; Kao, L.-L.; Liu, W.-H.; Pai, J.-T. A Study on the Economic Resilience of Industrial Parks. *Sustainability* **2023**, *15*, 2462. [CrossRef]
58. Zhukovskiy, Y.; Koshenkova, A.; Vorobeva, V.; Rasputin, D.; Pozdnyakov, R. Assessment of the Impact of Technological Development and Scenario Forecasting of the Sustainable Development of the Fuel and Energy Complex. *Energies* **2023**, *16*, 3185. [CrossRef]