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Approach to the Formation of an Innovation Portfolio in Industrial Ecosystems Based on the Life Cycle Concept

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Abstract: The innovation ecosystem concept has been widely used as a framework to explain innovation activities within different industries. Despite the usefulness of this approach, the concept is under-theorized, especially with regard to the methodological issues. This article presents a new approach in assessing the effectiveness of innovation industrial ecosystems, allowing to take into account the peculiarities of the life cycle stages of individual innovative projects and an ecosystem as a whole. We illustrate our assumptions on the example of two industrial ecosystems' projects assessments with appropriate explanations, which help from the academicians, researchers, and readers to receive a comprehensive understanding on how to form a knowledge-intensive ecosystem project portfolio and make managerial decisions on further actions of ecosystem actors regarding project development. The presented methodology has been tested on the example of projects implemented by research centers and laboratories of National University of Science and Technology (MISIS; Moscow, Russia). The propositions arising from this analysis provide information to help academics, policymakers, government, and individual enterprises with a more adequate understanding of the practical mechanisms and tools that help implement the ecosystem model for industrial development.

Keywords: industrial ecosystem; innovation ecosystem; innovative projects; life cycle; projects selection; innovation portfolio; ecosystem potential; fuzzy set method

1. Introduction

New concepts in the development of economic systems at micro, macro, and meso levels are primarily related with collaboration processes. It cardinally changes the existing relations between market entities, leads to blurring the boundaries between industries and territories, imposes new requirements for business, and forms competitive advantages. The use of a “platform” approach to create new business processes allows actively developing the ecosystem of enterprise partners, building new intersectoral relationships, and expanding the range of offered services.

The Davos Manifesto 2020 published by Klaus Schwab, claims that current capitalism is the capitalism of stakeholders: “The purpose of a company is to engage all its stakeholders in shared and sustained value creation. In creating such value, a company serves not only its shareholders, but

all its stakeholders—employees, customers, suppliers, local communities and society at large” [1]. Currently, the market is won not by those market participants who fight alone for competitive advantages, relying on their own resources, abilities, and knowledge, but those who build their strategies on the basis of “networkization”, partnership, resource sharing, and knowledge transfer. The key strategic direction in these conditions should be the interaction of different economic sectors through the creation of new business models and end-to-end digital processes based on the intersections of industries and through cross-border cooperation. In these conditions, there is a need in new organizational models and mechanisms for companies to serve its customers and to communicate with other stakeholders. One of the most promising models is an ecosystem approach as a conceptual framework whose goal is to address the need to balance social, economic, and environmental issues through a network of dynamic relationships between actors (individuals as well as institutions and infrastructures) implementing innovative activities. Despite the increased interest of the scientific community to the problem of innovation ecosystems formation and development, one should admit the weak methodological elaboration of this theory, which complicates its application in practice.

The growing significance of ecosystem thinking for both practitioners and academics has led to the emergence of different research directions, which aim “to enhance our understanding of what innovation ecosystems are and how they change over time” [2]. To answer these questions there is a need to link the ecosystem concept with the life cycle approach.

The authors present an innovation ecosystem as an open coevolving system of innovative projects that emerges in this system and then successively goes through all life cycle phases. The formation of ecosystem’s project portfolio involves an assessment of their potential and must be inseparably linked with the goals, life cycle stages, and characteristics of the ecosystem as a whole. It is assumed that the ecosystem dynamics is provided directly by those innovative projects that are implemented by the actors of the ecosystem. The authors suggest there is a need to take into consideration the life cycle of innovative projects when forming the ecosystem’s project portfolio. Such an approach makes it possible to increase the efficiency of innovation processes in the industrial ecosystem by optimizing the project portfolio. Basically, the use of the life cycle concept allows the building of effective strategies at each stage of ecosystem development, taking into account the peculiarities of the life cycle phases, the problems inherent in this phase—the set goals—with the use of all available resources.

Thus using the ecosystem’s projects life cycle phases (anticipation, birth, growing up, adulthood, transfer of experience and knowledge, new life) the authors pose the following research question: how to select the innovation projects to include them into an ecosystem’s project portfolio in order to provide positive synergistic effects from the interaction of participants, and allow the formation of effective sustainable ecosystems?

To solve this problem the authors develop a methodological approach in forming an innovation portfolio of an industrial ecosystem. The approach is based on a fuzzy set method that is relevant in group decision-making and is aimed at solving practice-oriented tasks of multicriteria optimization. The ability of taking into account a large number of both quantitative and qualitative criteria for optimality are among the main advantages of this method. The simplicity and versatility of its use formed the basis for mass application in solving tasks of the optimal allocation of resources according to established priorities among many alternatives. The advantage of the method is the ability to reasonably compare heterogeneous factors.

The research results are useful for academic researchers and policymakers in emerging economies to adopt and consider so to improve the contribution of innovation ecosystems to the country’s economic development.

The article is organized as follows. Section 2 provides a theoretical overview of an innovation ecosystem and discusses the previous works on the research problem. Section 3 is devoted to theoretical foundations of our research introducing the authors’ conceptual assumptions and chosen approaches. Section 4 presents research methodology for forming innovative project portfolio based on the assessment of their potential taking into consideration different projects life cycle phases. This

methodological approach is based on a fuzzy set method. Section 5 focuses on the implementation of the proposed methodological approach. We apply this methodology to the case study of National University of Science and Technology (MISIS; Moscow, Russia) engaging with local economies for launching new industries, fostering entrepreneurship, and strengthening cross-industry ecosystems. In Section 6, the authors discuss propositions arising from the conducted analysis. Additionally, some limitations of the research and future research perspectives are proposed. Section 7 highlights the key findings of the study and presents some managerial insights on the received results and the theoretical significance of the study.

2. Literature Review

Innovation and ecosystem are now much sought after, but not always well defined, and even less often well measured. A system that amalgamates and integrates the interests of stakeholders is known as an ecosystem in the scientific literature. As is known, today there are “business ecosystems” [3], “innovation ecosystems” [4], “digital ecosystems” [5], “university ecosystems” [6,7], and “financial ecosystems” [8]. Our research interest lies primarily with the innovation ecosystem concept.

In the current era of active creation of collaborations and alliances, rapid development of open innovations has started to affect enterprises and the whole ecosystem. Entrepreneurial sustainability is relying more and more on collaboration through dynamic and open platforms. With the development of the concept of “open innovation,” the management of companies is increasingly focused on results, regardless of the place of their creation and the origin of the resources involved. Within the paradigm of open innovation, large companies dominate, forming innovative markets and networks. Small and medium-sized companies, including start-ups, have more limited financial and human resources, are focused on a shorter time horizon, and experience difficulties in implementing innovative strategies. Such enterprises are faced with the need to either allocate significant costs for attracting highly qualified personnel, initiating and implementing projects, or dependence on external sources of information, knowledge, competencies, and technologies [9].

Typical actors of an ecosystem are suppliers, producers, competitors, and other stakeholders (educational and research institutions, communities, public sector actors, etc.). In this regard, the question of innovation in sustainable development needs to be analyzed at the level of the whole value chain, not just the firm. Thus, the study of the problem of sustainable enterprise development is possible through an ecosystem approach.

We agree with authors who criticize the inconsistent use and vague wording of the term “ecosystem” in scientific research [10]. Often there is a substitution of concepts: an ecosystem is represented by cluster formations (network innovative ecosystems of a special class) or a triple helix model based on a university–business–state partnership [11]. Gamidullaeva and co-authors [12] argue that “regional entrepreneurial ecosystems offer a set of formal and informal institutions for the institutional environment at the national and regional level”. According to Bruns et al. [13], the “ecosystem” metaphor reflects a tendency in scientific studies to describe the well-known phenomenon of agglomeration effects of regions (urban, regional, national ecosystems) and industries (agriculture, chemical industry, manufacturing, mass media, financial ecosystems) associations of firms (business ecosystems, entrepreneurial ecosystems) or activities (services, innovations, digital ecosystems). As a result, today we have “business ecosystems” [3], “innovation ecosystems” [14], “digital ecosystems” [15], and “university ecosystems” [16,17] or “financial ecosystems” [18,19].

“An innovation ecosystem refers to a loosely interconnected network of companies and other entities that coevolve capabilities around a shared set of technologies, knowledge, or skills, and work cooperatively and competitively to develop new products and services” [3]. According to Moore [3] ecosystems are understood as an economic community supported by a basis of interacting economic units that are the organisms of the entrepreneurial world, which also does not clarify the goals and principles of their formation. Adner and Kapura [20] and Autio and Thomas [21] consider an ecosystem as a network of interconnected organizations connected around a coordinating firm

or platform, which again is similar to network models and contradicts the principle of self-organization, being the basis of the analogy of natural and socioeconomic ecosystems. Proskurnin [22] believes that an innovation ecosystem is a self-organizing, self-regulating, and self-developing open system, characterized by input flows of ideas, value, people, information, and resources. In general, the theory of the innovation ecosystem is a continuation of the previous economic studies on innovation systems, the foundations of which were laid by B. Lundvall, R. Nelson, and K. Freeman [23–25], distinguished by the increased attention of researchers to dynamic network interactions in the process of creating innovations. According to N. V. Smorodinskaya, the ecosystem approach focuses on the interactions of participants (collaborations), which ensure the generation and dissemination of knowledge with subsequent transformation into innovation [26].

The concept of an ecosystem is associated with a natural ecosystem in which living organisms and their habitats are united, harmonious, and balanced [27]. According to the authors, innovation ecosystem is “the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors” [27]. In our opinion, the nature of an innovation ecosystem, as an analogue of a natural one, is that the vertical hierarchy of administration is completely absent in this model [9]. First of all, this concerns the process of assessing and selecting new actors to participate in ecosystem projects, which should be as objective and independent as possible.

Ecosystems bring together and integrate the interests of cooperating or competing businesses that offer different products and services.

In the context of our study, it is necessary to emphasize the importance of such characteristics of the ecosystem as the complementarity and coordination of enterprises of different industries, united according to the principle of joint specialization. As rightly noted in [28], “the key element of the ecosystem is an innovative project, since the most important indicator of its efficiency is the success of the implemented innovative projects”. The rest of the elements are needed to generate, maintain and develop these projects. Consequently, the innovation ecosystem can be represented “in the form of an area of growth of an innovative project that emerges in this system and then successively goes through all phases of its development” [28]. Of particular difficulty is the implementation of a continuous selection of innovative projects that provide positive synergistic effects from the interaction of participants, and allow the formation of effective sustainable ecosystems [29]. The selection of projects involves an assessment of their potential and must be inseparably linked with the goals and characteristics of the development of the entire ecosystem.

Moore [3] suggests that innovation ecosystems progress through four life cycle phases with distinct characteristics: birth, expansion, leadership, and self-renewal (or death). The authors in this article propose the following ecosystem phases: conceptual design; ecosystem building; operation and maintenance; succession. After succession, there are two possible reactions to the challenges: self-sustaining growth or retrenchment.

Life cycle approach has gained significant popularity in the last two decades, having emerged as an analogue of processes occurring in living organisms. Typical stages are always present in full life cycle of any system, each of which has objectives specific only to it and contributes to the full life cycle. The need for such models is caused by the problem of building efficient strategies at each stage of development, taking into account the problems and objectives inherent to this stage and accumulating all the resources available at this stage.

The current literature is lacking a theoretical foundation that addresses the development and change of innovation ecosystems over time and does not consider the inherent dynamics of innovation ecosystems that lead to their conceptual design, building, operation and maintenance, and succession.

In the article, the authors attempt to develop a methodology for the formation and assessment of ecosystems in terms of solving the problem of assessment the potential of innovative projects using the example of an innovation industrial ecosystem. Taking an ecosystem lifecycle perspective, this paper addresses this research gap by elaborating a methodology for the formation of innovation ecosystems.

3. Conceptual Framework

Innovation is considered to be a crucial factor, which can improve the competitiveness of firms and ensure sustainability. Collaborations have become a trend in regard to enabling long-term business growth [29]. An ecosystem usually includes economic actors at micro, meso, and macro levels, and it is aimed to initiate and develop innovative projects based on the principles of sharing intellectual, technological and material resources. Hence, it is necessary to consider the concept of a life cycle as applied to the ecosystem. Then, the classification of projects implemented in ecosystems can be represented from the viewpoint of:

- ✓ The ecosystem level;
- ✓ Complexity of the ecosystem structure, which will depend on the number and scale of actors, digital and intellectual potential.

For example, projects for technology transfer, recycling, additive production, and design of new technologies and materials have a complex structure and can be implemented at the regional, national, and international levels. Projects related to cross-industry cooperation, energy efficiency, digital modeling, and creation of intellectual property are being implemented at the meso level. At the micro level, it is advisable to implement engineering and educational projects.

Since the ecosystem formation strategy is the efficiency of the implementation of development processes, and introduction and promotion of innovative projects, the authors propose an approach to the concept of an ecosystem life cycle based on the classification of projects (Figure 1).

The life cycle of any project includes four main phases: initiation, development, implementation, and control. There are more phases of ecosystem projects because such projects include processes of generating knowledge, developing and constructing, training, knowledge spillover between actors, and knowledge spillover between ecosystems. Moreover, life cycles of ecosystems can differ in levels (micro, macro, and meso), and the phases differ in the structure of actors participating therein. Figure 1 presents six possible phases of an industrial ecosystem life cycle.

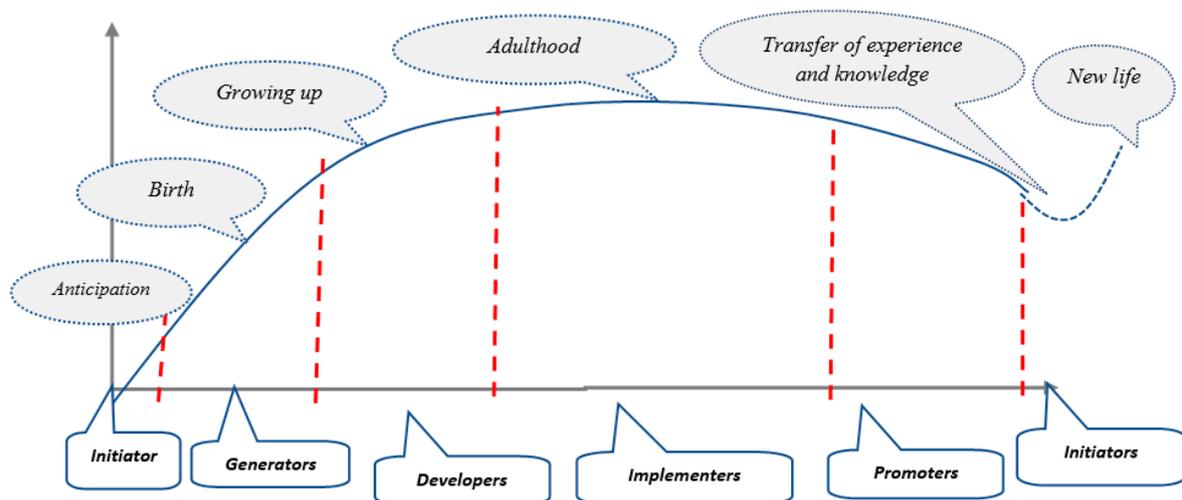


Figure 1. Project's life cycle in the ecosystem [29].

Here are the phases of project life cycle in the industrial ecosystem:

1. *Anticipation.* At this phase, there is awareness of the need for change. This is just a reference of the idea. This stage of the ecosystem involves the activities of actors-initiators. Large industrial complexes which need transformation processes, as well as universities that accumulate and generate domestic and world experience can become such actors.

2. *Birth*. This is the phase of design, logical and technological development, description of the idea, and comparisons of the idea with analogues. Engineering centers, technology parks, venture companies, research structures, startups, consulting companies, and financial institutions can be actors-generators of this stage. At this stage, universities are actors-integrators, determining those who are able to generate ideas.
3. *Growing up*. At this phase, there are teams to implement the project, and additional industrial enterprises are related to the actors of the previous stage.
4. *Adulthood*. This phase is the direct implementation of the project. Industrial enterprises, which introduce projects are actors-implementers taking part in the development of these projects.
5. *Transfer of experience and knowledge*. One of the main problems of the ecosystem is knowledge spillover. Universities, industrial enterprises, industrial exhibitions, and marketing companies are the actors of this stage.
6. *New life*. New challenges require new changes, conversions, and transformations. This is the phase of conversion the experience of past projects into new ones [29].

Thus, at different phases of the life cycle of an individual ecosystem project, different actors can take part in its implementation. There is no universal model for life cycles of ecosystems. Some stages of a life cycle can be absent or present depending on each specific project. Therefore, to assess the ecosystem as a single system that implements an innovative projects portfolio (Figure 2), the authors propose to use a life cycle model consisting of four phases which can be both sequential, and overlap each other in time.

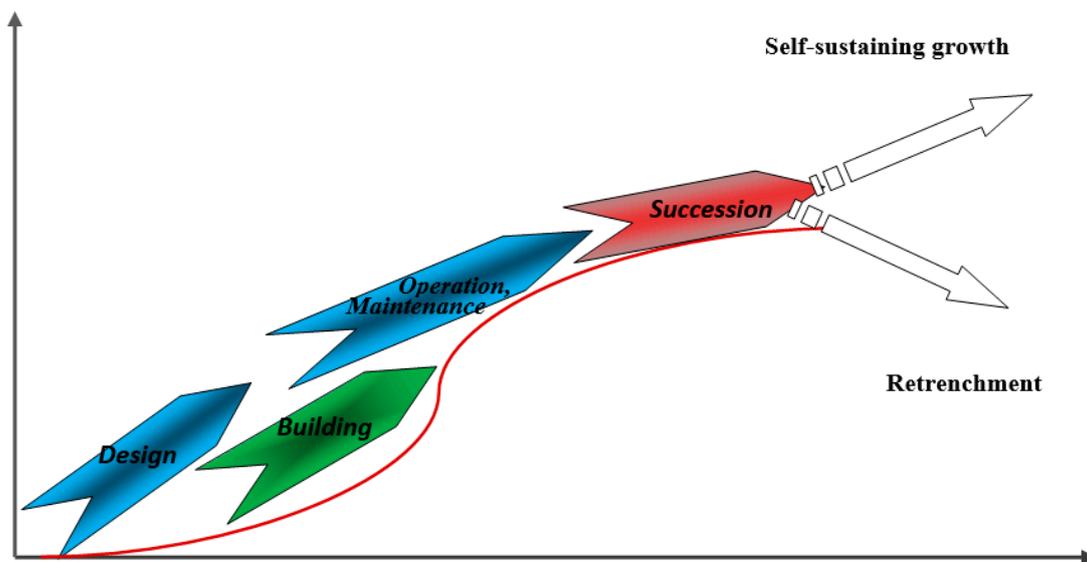


Figure 2. Life cycle of an industrial ecosystem implementing an innovative projects portfolio [29].

(1). *Conceptual Design*

The purpose of the stage for concept development is the analysis of new possibilities in the field of ecosystem application, development of preliminary system requirements, and possible design solutions. The design stage starts with the realization of the need to create a new ecosystem or modify an available one. The stage includes research, planning, and assessment of economic, technical, strategic, and market basics of future actions. A dialogue between potential ecosystem actors, stakeholders, and developers is carried out. This stage ends with the construction of the system architecture.

The main objectives of the design stage:

- To conduct research, having established what is necessary for new ecosystem, and to evaluate technical and economic feasibility and sustainability of this system.

- To study potential ecosystem concepts, formulate and validate a set of requirements for the efficiency of the system operation.
- To choose the most attractive system concept, determine its functional characteristics, and to develop a detailed plan for the subsequent stages of the design, production, and operational deployment of the system.

(2). *Ecosystem Building*

The building stage implies a process of systems designed for the implementation of functions formulated in the system concept which can be supported and successfully operated in their environment. When determining the ecosystem structure, the authors propose to distinguish levels characterized by the number of connections. Ecosystem participants with the largest number of connections are placed in the core, and the smallest ones are placed in the periphery.

The main goals of the building stage are as follows:

- Building of a system prototype that meets the requirements of efficiency, reliability, and safety.
- Formation of the ecosystem structure.
- Determining the boundaries of the ecosystem and developing a trajectory (strategy) for the development of each actor of system.
- Assessment of the ecosystem state based on the integrated characteristics of network interactions.

(3). *Operation and Maintenance*

As a rule, it is the longest stage of the ecosystem life cycle, during which activities aimed at maintaining and increasing the efficiency of ecosystem functioning are implemented. The search for the optimal system configuration for adaptation to external and internal changes and process management related to ensure system viability is conducted.

(4). *Succession*

It is a successive replacement of one actor by another under the influence of external and internal factors. With the sustainable development of the ecosystem, succession ends with the formation of a sustainable stage of the life cycle. The actors continue to develop within the ecosystem. Life cycle patterns are distinguished depending on the distribution of various risks by the life cycle phases. Each actor of the ecosystem is developing in accordance with its life cycle, with the successive changing phases of development. It is important to distinguish two phases in the life cycle of actors:

- (1) The actor consumes significant resources for its formation and development;
- (2) Upon reaching the growth limit, resources are allocated for transformation.

4. Research Methodology

New knowledge is an energy that provides self-organization of the ecosystem. Considering a great amount of knowledge, this is the ability of the ecosystem to initiate and implement new projects. The knowledge intensity of the ecosystem depends both on the actors included and the projects implemented by them.

In order for an ecosystem to develop in terms of self-organization, it is necessary to know the following in terms of the analysis of project options:

- a. What projects are to be introduced for efficient objectives at minimizing the risk?
- b. What is the sequence of operation for implementing these projects?
- c. Is there intellectual and technological potential for the development and introduction of these projects?
- d. What funds will be required?

e. What are the possible sources of financing?

The methodology for project potential assessment consists of three stages:

- (1) Choosing the criteria for evaluating industrial ecosystem projects.
- (2) Evaluation of project potentials included into the ecosystem.
- (3) Analysis of the resulting evaluations and making managerial decision on the possibility of including projects and actors under consideration into other ecosystems (Figure 3).

By the potential of an ecosystem, we mean a set of sources, opportunities, and means that can be used to achieve a specific goal. Resources are at the core of any potential. For example, material resources are at the core of economic potential, which consists of resource, production and investment potentials. From the set of potentials—integration, circular, technological, financial, intellectual, economic, etc.—for the industrial ecosystem actors, technological and financial potential are the key. Industrial enterprises are capital intensive with a cycle of technological re-equipment (renovation) of 4–5 years. That is why the indicators of technological potential and the rate of increase in value added were chosen to assess the projects of the industrial ecosystem.

Actors are engaged in certain types of activities, the development prospects of which depend on the corresponding potential. In industrial ecosystems, the main actors are developers and suppliers of unique resources (research laboratories and centers, startups, engineering centers, research institutes). The main criteria of efficiency for them are the level of innovation, as well as the qualifications and intellectual potential of the personnel. In this regard, to assess the potential of projects implemented in the industrial ecosystem, the following indicators were selected: creativity, idea elaboration, intellectual activity cash flow.

Indicators for assessing the potential of the innovation ecosystem and industrial symbiosis are given in the articles of the authors [9].

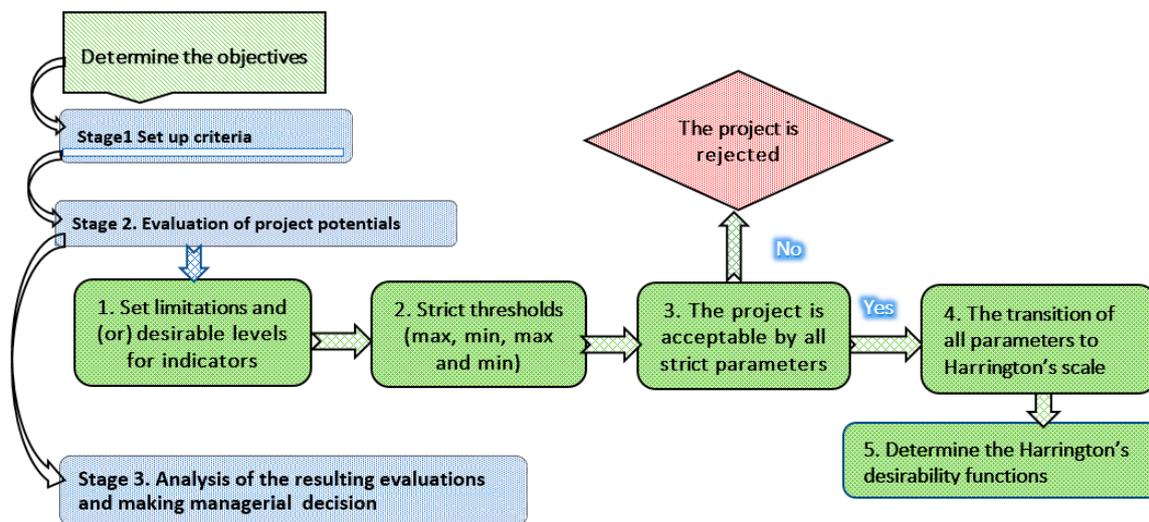


Figure 3. A flowchart for the methodology of evaluating industrial ecosystem projects. Source: own elaboration.

Stage 1. Choosing the criteria for evaluating industrial ecosystem projects

A conceptual prerequisite in the formation of criteria included in the author’s model is an idea of the ecosystem as a set of related projects, evaluated using a set of quantitative and qualitative indicators and determining a list of diagnostic parameters, which ultimately reflects the multidimensional pattern of the “industrial ecosystem” category.

1. An enlarged quantitative parameter for assessing the results of intellectual activity (E_{ia}). This indicator characterizes the intellectual potential of the project (1).

2. An enlarged quantitative parameter for assessing the significance of the project determines the “possibility of rebirth” of the project.
3. An enlarged quantitative parameter for assessing the economic efficiency of projects based on cash flows allows determining the financial potential of the project.

The resulting quantitative indicator of the project assessment (E_p) was recommended to be defined as the geometric mean of three components: the number of generated results of intellectual activity; growth rate of added value; cash flow from intellectual activity. Diagnostic results for three components, as well as a general assessment were determined in points on the scale with boundary marks of 0 and 1.

Harrington’s desirability function was used in transition of quantitative indicators into points. The desirability scale sets a correspondence between a quantitative system of preferences and an empirical system of preferences (desirability).

To diagnose the state of the industrial ecosystem by qualitative parameters, it was necessary to develop evaluation maps combining descriptive characteristics of possible gradations of the estimated enlarged parameters, including reference gradation (Table 1).

Table 1. Evaluation map of the analyzed enlarged parameters of industrial ecosystem state (compiled by the authors).

Indicators of Project Potential	Gradations of Parameters According to the Harrington’s Desirability Scale				
	(1.00)	(0.8)	(0.63)	(0.37)	(0.2)
Creativity	A high level of creative, constructive, innovative activity in the implementation of the project. Creation of qualitatively new products and services characterized by originality and uniqueness.	...	...	...	Utility is the process of creating material and intellectual values and managing already created and used values in accordance with established technologies, accepted by norms or existing principles
Technological potential	High technological potential, which is provided by a set of available, attracted, and mobilized material and technical, organizational, and management resources and possibilities to achieve the objectives of scientific and technological development.	...	...	...	Lack of technological potential.
Idea elaboration	The idea has been developed, various elements have been taken into account, and the components of the problem have been combined in whole.	...	...	...	The idea is not efficient for solving problems.

Thus, the assessment of qualitative indicators characterizing the potential of the project could be implemented using a specially developed scale of evaluations, normalized in the range from 0 to 5. To assess the qualitative indicators of potential, the scale shown in Table 2 was recommended. Interconnection of actors’ and ecosystem development strategy was carried out in the process of decomposition of objectives and corresponding key performance indicators (KPI) within the framework of management technologies and balanced scorecard (BSC).

In the absence of reliable information on indicators, the assessment was carried out by a limited range of indicators. A specific assessment tool was selected in each case individually. The list of qualitative indicators characterizing the potential of the project at each stage of the life cycle was determined by evaluation. An example of a scale for assessing qualitative indicators (creativity, idea elaboration, and technological potential) is given in Table 2.

Table 2. Assessment scale of qualitative indicators of the project potential (compiled by the authors on the basis of [19]).

Assessment	Description		
0	Low level of creativity of the project. The processes of creating material and intellectual values and managing already created and used values in accordance with established technologies, accepted norms or existing principles.	The idea has not been developed, as it is not efficient for solving the tasks.	No technological potential.
+1	It is not a high level. New methods of project activity allow being adapted to changing external conditions, but internal reserves are not optimally used.	The idea has not been developed enough; there is no relationship with resulting project indicators.	The productivity of the technological structure of production corresponds to the industry average indicator.
+2	Ability to abandon stereotypical methods of project activity.	The idea has been tested, the results were obtained, but they are lower than planned.	Timely technological modernization of fixed assets aimed at resource saving.
+3	Ability to generate original ideas in terms of resolving or posing new problems.	The ability of an idea to inspire finding new solutions.	The level of asynchronous change of the technological structure.
+4	Creation of qualitatively new products and services characterized by singleness, originality and uniqueness.	The idea gives a new look at the problem, a new way to solve it, and at the same time, it is itself capable to be changed and modified.	The correlation of the level of new and old technologies.
+5	A high level of creative, constructive, innovative activity in the implementation of the project.	The idea has been developed, various elements have been taken into account, and the components of the problem have been combined in whole.	Newly created advanced technologies are applied, technological and product diversity is expanding.

Stage 2. Evaluation of project potentials included into the ecosystem

Stages 1 and 2 were performed according to the same algorithm. Here is the algorithm of Stage I. It provides the sequential implementation of 5 steps [29].

Step 1. We defined a classifier for evaluating the potential of some project as a variety of so-called “gray” Pospelov scale [30] which is a polar (opposition) scale in which the transition from property A+ to property A– occurs smoothly, and the scales satisfy the conditions: (a) mutual compensation between the properties of A+ and A– (the more A+ appears, the less A– appears, and vice versa); (b) the presence of a neutral point A0, interpreted as the point of greatest contradiction, in which both properties are equally present.

Step 2. A number of indicators characterizing the potential of project performance were determined by evaluation. Depending on the reached value of the indicator, the project takes a certain place (rank) by this indicator, which we denoted by the variable X_i ($i = 1, \dots, n$), where n is the number of indicators. We took such an order for ranking indicators that the less the value of the rank of the indicator is, the greater the value of the potential is. If there is an opposite tendency for any indicator, then in the analysis it is replaced by the conjugate one. For example, if an indicator takes the first place in terms of obsolete technologies, then its potential will be lower (with the equality of the ranks of

other indicators) than the potential of a region, for example, having the 10th place in terms of obsolete technologies. So, for this indicator, ranking in the reverse order was necessary.

Step 3. Evaluation of the indicator influence on the value of the potential was carried out depending on its rank also using a linguistic variable. We introduced the linguistic variable b_i = the value of the indicator x_i . The universal set for the variable b_i is the segment $[1,m]$, where m is the number of evaluated objects. We accepted that each linguistic variable has a trapezoidal membership function, which can be determined by quadruple of numbers.

$$x = (a_1, a_2, a_3, a_4)$$

Step 4. We defined a term set of 5 elements, i.e., $B = \{B_{i1}, B_{i2}, B_{i3}, B_{i4}, B_{i5}\}$ and used the following values of terms depending on the values of the ranks according to the analyzed indicator (for example, in proportion of 1:2:4:2:1), the levels of indicators in the form of trapezoidal numbers:

B_{i1} is a very low level of indicator x_i ;

B_{i2} is low level of indicator x_i ;

B_{i3} is average level of indicator x_i ;

B_{i4} is high level of indicator x_i ;

B_{i5} is a very high level of indicator x_i .

Step 5. We represented the transition from indicators characterizing the potential $x = \{x_1, x_2, x_3, x_4, x_5, x_6\}$ to the statements on the value of potential $G = \{G_1, G_2, G_3, G_4, G_5, G_6\}$.

To form the transition rule from evaluations of indicators to linguistic variables, it was necessary to determine the weight (importance) of the indicator by the degree of contribution to the potential, i.e., match each indicator x_i with its weight r_i , which determines the contribution of the indicator to the potential. If the weights of the indicators are ordered, i.e., there is information that $r_1 \geq r_2 \geq \dots \geq r_n$ and there is no more information about these values, then the weight is determined according to the Fishburn’s rule:

$$r_i = \frac{2(n - i + 1)}{(n - 1)n} \tag{1}$$

If indicators are equally preferable or there is no preference system, then we accepted that they have equal weight:

$$r_i = \frac{1}{n} \tag{2}$$

With the chosen system of indicator weights, the transition rule from the values of competitiveness indicators to term weights of linguistic variable g has the form:

$$p_k = \sum_{i=1}^n r_i \mu_{ki} \quad k = 1, 2, 3, 4, 5 \tag{3}$$

After calculating the observed weights of each term of linguistic variable G_i , we obtained the values of the variable g by the formula:

$$g = \sum_{k=1}^5 p_k \bar{g}_k \quad k = 1, 2, 3, 4, 5 \tag{4}$$

where \bar{g}_k is the middle of the interval that is the carrier of the term $\bar{g}_k \in (a_{k1}, a_{k4}]$.

Evaluation of the project potential depends on the project customer, which may be another actor or several actors at once.

If it is necessary to rank (to assess) the evaluated projects by a certain significant (critical) group or several significant (critical) groups of parameters for the customer (hereinafter, critical parameters) for making a fundamental decision, it is necessary to identify them first. Then it is necessary to evaluate by them, setting strict limitations, and discard those actors (if there are some), which do not correspond in principle. Evaluation by the remaining parameters is useless for them. For example, we singled out

critical groups for potential project evaluation: technological, entrepreneurial, and intellectual potentials. If the actor’s evaluation did not meet the strict limitation of the customer by any parameter, then such a project potential was evaluated as unacceptable one. The generalized optimization criterion in the form of Harrington’s desirability function takes a value equal to 0, which corresponds to “very bad” on the scale of the desirability function (Table 3). This was a special case in relation to the first version; therefore, it did not have fundamental differences in the evaluation.

Table 3. Harrington’s desirability scale.

Empirical System of Preferences (Desirability)	Quantitative System of Preferences (System of Psychological Parameters)
Very good	1.00–0.80
Good	0.80–0.63
Satisfactory	0.63–0.37
Bad	0.37–0.20
Very bad	0.20–0.00

Let us consider the methodology for assessing the potential of the project.

1. Initially, it was necessary to set limitations and (or) desirable levels for all indicated particular parameters of assessment for each group of indicators. All the assessment parameters indicated in Table 4 have quantitative values with units of measurements or qualitative values in the form of evaluation (points).

2. According to the assessment parameters for which strict limitations were set, i.e., strict thresholds (max, min, max and min), it was necessary to establish acceptability. If the potential of the project was unacceptable by some strict parameter, then such a project was inefficient or unsuitable for this ecosystem. The evaluation of the actor’s potential (if it is the only one) ended thereon.

3. If the project was acceptable by all strict parameters, then it was necessary to proceed with the transition of all the given parameters, various physical entities, both quantitative and qualitative ones, into the Harrington’s desirability scale (Table 4).

Table 4. Assessment groups of project potential at life cycle stages.

Project Potential/Life Cycle Stages	Project Potential				
	P1	P2	P3	P4	P5
Anticipation	novelty	relevance	intellectuality	financial	technological
Birth	creativity	demand	intellectuality	financial	technological
Growing up	organizational	idea elaboration	intellectuality	financial	technological
Adulthood	idea elaboration	managerial	personnel	financial	technological
Transfer of experience	demand	originality	performance	efficiency	management activity
New life	possibility of rebirth	creativity	intellectuality	financial	technological

4. If limitations specified by the assessment parameters (indicators) were presented as a unilateral constraint (either *min*, or *max*), then, to determine the desirability functions (d_{ij}) of these parameters, the following Harrington’s formulas were used:

$$d_{ij} = e^{-e^{-y_{ij}}} \tag{5}$$

$$y'_{ij} = \frac{y_{max} - y_{ij}}{y_{max}} \tag{6}$$

$$y'_{ij} = \frac{y_{ij} - y_{min}}{y_{min}} \tag{7}$$

where d_{ij} is a particular desirability function with a unilateral constraint for i -th parameter of j -th project; y_{max}, y_{min} are upper and lower limits of a unilateral constraint for i -th particular parameter; y'_{ij} is coded (normalized) value of i -th particular parameter of j -th project, transited into the desirability scale.

5. If the limitations specified by the assessment parameters (indicators) were presented as a bilateral constraint, which is possible for some parameters (both min, and max), then, to determine the desirability functions (d_{ij}) of these parameters, the following Harrington’s formulas were used:

$$d_{ij} = e^{-|y'_{ij}|^n} \tag{8}$$

where y'_{ij} is the coded (normalized) value of i -th particular parameter of j -th project, transited into the desirability scale; n is an exponent established having its own significance for each particular parameter with bilateral constraint, depending on the requirements of the customer.

In this case, the coded (normalized) value of i -th particular parameter of j -th project, transited into the desirability scale, was determined by the formula:

$$y' = \frac{(2y - (y_{max} + y_{min}))}{(y_{max} - y_{min})} \tag{9}$$

Table 5 presents data of assessing several projects (A), where n is the number of assessment parameters, and, m is the number of assessed projects.

Table 5. Project assessment form according to Harrington’s model.

Parameters $i = 1, n; A, j = 1, m$	Parameter 1		Parameter 2		Parameter 3		Parameter i		Parameter n						
	y_1	y'_1	d_1	y_2	y'_2	d_2	y_3	y'_3	d_3	y_i	y'_i	d_i	y_n	y'_n	d_n
A_1	d_{11}	...	...	d_{21}	...	...	d_{31}	...	...	d_{i1}	...	...	d_{n1}
A_2	d_{12}	...	...	d_{22}	...	...	d_{32}	...	...	d_{i2}	...	...	d_{n2}
A_3	d_{13}	...	...	d_{23}	...	...	d_{33}	...	...	d_{i3}	...	...	d_{n3}
A_j	d_{1j}	...	...	d_{2j}	...	...	d_{3j}	...	...	d_{ij}	...	...	d_{nj}
A_m	d_{1m}	...	...	d_{2m}	...	...	d_{3m}	...	...	d_{im}	...	...	d_{nm}

6. The generalized Harrington’s desirability function (optimization criterion) of j -th actor was defined as the geometric mean of particular desirability according to the formula:

$$D_j = \sqrt[n]{d_{1j} \times d_{2j} \times d_{3j} \times K \times d_{ij} \times K \times d_{nj}} \tag{10}$$

The geometric mean allowed discarding any participant which will not match at least one parameter by which a strict limitation was set.

We established the best projects with optimal potential by $D_j \rightarrow 1$ criterion. The closer the project potential assessment to the unit was, the better this participant for the ecosystem was in terms of assessment of all the constituent elements of the potential. The resulting assessments of alternative

projects were compared with the preferences of the desirability scale (Table 3), and could be used as alternative options (“satisfactory”, “good”, and “very good” ratings).

Stage 3. Analysis of the resulting evaluations and making managerial decision on the possibility of including projects and actors under consideration into other ecosystems.

After resulting evaluations, the coded values of control points (y_{ij}) were determined in points, taking into account the lower and upper limits of the admissibility of the value ($y_{min} = 0, y_{max} = 5$) according to the Harrington’s desirability methodology (Equations (6) and (7)). Then, the coded value of each qualitative parameter was calculated by Equation (8). The potential (P) of qualitative indicators at each stage of the project life cycle was determined as the geometric mean of the coded values (y_{ij}, d_i) where the resulting potential of the project was considered as the arithmetic mean between the potentials of indicators—both qualitative and quantitative ones ($\Sigma P_i/n$).

The closer assessment of the project potential to unit was, the better this participant was for the ecosystem in terms of all the constituent elements of the potential. The value of the indicators of the project potential in the range from 0 to 1 corresponds to the Harrington’s scale level “very bad” (0.2–0); from 1 to 2—“bad” (0.37–0.20); from 2 to 3—“satisfactory” (0.63–0.37); from 3 to 4—“good” (0.80–0.63); from 4 to 5—“very good” (1.00–0.80).

This methodology for assessing the project potential allows making managerial decisions on further actions of ecosystem actors regarding project development.

5. Case Study

We tested the presented methodology on the example of projects implemented by research centers and laboratories of National University of Science and Technology (MISIS).

(a). An ecosystem in the field of “Industrial design and technologies for reindustrialization of the economy” with National University of Science and Technology (MISIS).

Project area of the ecosystem. Digital production technologies for industrial machinery and shipbuilding (United Shipbuilding Corporation and United Engine Corporation):

- (1). Hybrid additive and subtractive systems;
- (2). Formation of complex shape products from metamaterials (products with volume-controlled structural heterogeneity) using digital manufacturing technologies;
- (3). Next generation flexible manufacturing systems.

Actual and potential actors of this ecosystem are:

- LLC NEW DIAMOND TECHNOLOGY;
- PJSC ALROSA;
- JSC RUSNANO Fund for Infrastructure and Educational Programs for JSC New Diamond Technologies;
- Production laboratories at educational institutions;
- OJSC Kristal;
- JSC Almazinstrument;
- JSC VNIIALMAZ;
- CJSC Terekalmaz;
- LLC Technical Ceramics Plant;
- FSBI TISNCM; JSC VNIINSTRUMENT;
- Ustav geoniky AV CR (Czech Republic);
- JSC Sukhoi Company (Sukhoi SuperJet-100);
- RSC Energia (manned space vehicle);
- RD & PE Zvezda JSC (Kamov-62, Kamov-226T);
- JSC KAMAZ;
- Rostselmash;

- Soyuz Agro, LLC;
- JSC A.A. Bochvar High-Technology Research Institute for Inorganic Materials;
- JSC RPA CNIITMASH.

Projects implemented by this ecosystem can be related to the following stages of the life cycle:

1. “Creation of a multi-laser automated complex for the layer-by-layer synthesis of polymetallic products with cellular elements” is at the Adulthood Stage, as it has been implemented for specific customers, but has not been replicated to other groups of consumers.

2. “Creation of an engineering center for high complexity prototyping” is related to the Adulthood Stage. The center has been created, but this project cannot yet be related to fully complete one.

3. “Development of digital manufacturing technologies for industrial machinery and shipbuilding” is at the New Life Stage.

The ecosystem “Industrial Design and Technologies for the Reindustrialization of the Economy” is at the Operation and Maintenance Stage, searching for the optimal system configuration for adaptation to external and internal challenges by self-organizing processes.

(b). An ecosystem in the field of “Materials and technologies to improve expectancy and quality of life” with National University of Science and Technology (MISIS) as an integrator.

Project area of the ecosystem. Development and creation of medical implants including those with bioactive coatings for reconstructive surgery and regenerative therapy. National University of Science and Technology (MISIS) creates new types of bioresorbable materials and bioactive coatings with antibacterial effect. Creation of shape memory alloys (SMA) with super elasticity allows to achieve the functionality of medical and other purpose devices, unachievable using traditional materials and technologies, which allows implementing fundamentally new technologies for surgical interventions.

- Computer modeling, virtual development, and functional testing of fracturing behavior (biocompatibility and mechanical properties) of biocompatible metal nanomaterials.
- Creation of implantable three-dimensional biostructures from titanium alloys with considerable relief of surface and bioactive nanostructured coating with antibacterial effect.

Projects implemented by this ecosystem can be related to the following phases of the life cycle:

1. Development of multicomponent bioactive nanostructured coatings, including those with antibacterial effect can be related to the Adulthood Stage. The developments have been completed, a patent has been obtained, and the results are implemented at industrial enterprises.

2. Creation of multicomponent nanostructured shape memory alloys (SMA), which combine biomechanical and biochemical compatibility are related to the Transfer of Knowledge and Experience Stage. The alloys have been developed, patented abroad, and medical devices operating on the basis of shape memory effects and super elasticity are commercialized.

3. Obtaining of highly porous composite and bioresorbable materials for reconstructive surgery is at the Birth Stage. A full range of structural, mechanical, and tribological testing, having confirmed competitive characteristics of the materials, as well as biomedical testing of the material and products made thereof was carried out.

The ecosystem “Materials and technologies to improve expectancy and quality of life” is at the Building stage, as it is poorly studied, but is a strategically important direction in Russia.

Then, we assess the potential of two industrial ecosystem projects.

Project 1. Development of digital production technologies for industrial machinery and shipbuilding.

Project 2. Development of materials and technologies to improve expectancy and quality of life.

To assess the potential of each project, the quantitative indicators (P_1 , P_3 , P_4) listed in Table 6, and the qualitative ones (P_2 , P_5) given in Table 2 are used. It was established by evaluation that Project 1 is at the New Life phase. Qualitative indicators of this life cycle stage are creativity (P_2) and technological potential (P_5). Project 2 is at the Growing up phase of the life cycle; accordingly, elaboration of the idea (P_2) and technological potential (P_5) are related to the qualitative indicators of this stage.

Quantitative potential indicators for the two projects are the same: intellectuality (P_4), idea elaboration (P_1), financial potential (P_3). The calculation results of quantitative indicators for the project potential are presented in Tables 7–9. Qualitative indicators are calculated according to Equations (6)–(8); the results are presented in Tables 10 and 11.

Table 6. Assessment of the project for the development of digital production technologies for industrial machinery and shipbuilding.

Indicators	Stages of the Project Life Cycle					
	Anticipation	Birth	Growing up	Adulthood	Transfer of Experience	New Life
Results of intellectual activity, units	2	4	7	8	9	8
Growth rate of value added, %	4	11	12	14	18	17
Intellectual activity cash flow, million rubles	−148	164	215	254	271	265

The Harrington’s desirability function (Equation (4)) is applied for the transition of quantitative results of intellectual activity into points using a dimensionless ordinal scale that is common to all parameters of the assessment model. Further, the assessment was carried out according to the algorithm described above. For this, two control points were set at each stage of the Project 1 life cycle. As the lower limit of the admissibility of the value, the number of results of intellectual activity is taken as a unity (unilateral constraint). In this case, this limit corresponds to $d = 0.37$ on the desirability scale. Further, the value of the results of intellectual activity, equal to 10, is “very good,” that is, it corresponds to 0.8 ($d = 0.8$) on the desirability scale. The coded values of these control points (y_{ij}) and the coded value of the desired parameter were calculated.

$$y'(1) = -\ln\ln\left(\frac{1}{0.37}\right) = -0.00576 \tag{11}$$

$$y'(10) = -\ln\ln\left(\frac{1}{0.8}\right) = 1.4999 \tag{12}$$

The equation $y' = a \times y + b$ acts as a mechanism for transition of y into y' . The values of a and b can be found using the system of equations.

$$0.00576 = a \times 1 + b \tag{13}$$

$$1.4999 = a \times 10 + b \tag{14}$$

Thus, $a = 0.16576$ and $b = -0.16025$.

The final equation takes the form of $y' = 0.16576y - 0.16025$.

The coded parameter value for the results of intellectual activity at the Anticipation Stage of the life cycle for $y = 2$ is $y_{ij} = 0.171$. As a result, desirability of $d = 0.43$ was obtained by Equation (4). The results of calculations for the remaining stages of Project 1 life cycle are given in Table 7.

In a similar way, the growth rate of the value-added parameter was estimated. As the lower limit of admissibility of the parameter value, 2% was adopted (unilateral constraint). In this case, this limit corresponds to $d = 0.37$ on the desirability scale. Further, the results of value-added growth rate, being 20%, is “very good”, that is, it corresponds to 0.8 ($d = 0.8$) on the desirability scale. The final equation takes the following form: $y' = 8.3y - 0.16024$.

For the parameter of cash flow from intellectual activity, a minimum value of 0, and a maximum value of 300 million rubles were set. The final equation will take the form: $y' = 0.005y + 0.00576$.

The final average rating for the three parameters is calculated using Equation (10).

Table 7. An example of standard mark interpretation on the Harrington’s scale for Project 1 in accordance with the life cycle phase.

Phase of Project Life Cycle	Intellectual Activity Results		Value Added Growth Rate		Intellectual Activity Cash Flow		Generalized Harrington’s Desirability Function (D)
	y_{ij}	d_1	y_{ij}	d_2	y_{ij}	d_3	
New life	1.486	0.797	1.251	0.751	1.331	0.768	0.77

Using the proposed methodology, at this stage we evaluate Project 2’s “Development of materials and technologies to improve expectancy and quality of life” (Tables 8, 9 and 11).

Table 8. Assessment of the project for the development of materials and technologies to improve expectancy and quality of life.

Indicators	Phase of the Project Life Cycle					
	Anticipation	Birth	Growing up	Adulthood	Transfer of Experience	New Life
Results of intellectual activity, units	15	27	39	41	43	45
Growth rate of value added, %	6	12	14	15	17	19
Intellectual activity cash flow, million rubles	279	349	372	393	416	442

Table 9. An example of standard mark interpretation on the Harrington’s scale for Project 2 in accordance with the life cycle stage.

Stages of Project Life Cycle	Intellectual Activity Results		Value Added Growth Rate		Intellectual Activity Cash Flow		Generalized Harrington’s Desirability Function (D)
	y_{ij}	d_1	y_{ij}	d_2	y_{ij}	d_3	
Growing up	1.135	0.725	0.864	0.656	1.378	0.78	0.718

Table 10. Determination of Project 1 potential at the life cycle stage.

The Potential of Project 1 at the New Life Stage of the Life Cycle	Type of Indicators	y_{ij}	d_1	The Value of the Project Potential Parameters
P_1	quantitative	1.251	0.751	0.94
P_2	qualitative	1.120	0.527	0.59
P_3	quantitative	1.486	0.797	1.18
P_4	quantitative	1.331	0.768	1.02
P_5	qualitative	1.223	0.662	0.81

Table 11. Determination of Project 2 potential at the life cycle stage.

The Potential of Project 2 at Growing Up Stage of the Life Cycle	Type of Indicators	y_{ij}	d_1	The Value of the Project Potential Parameters
P_1	quantitative	0.864	0.656	0.57
P_2	qualitative	0.745	0.617	0.46
P_3	quantitative	1.135	0.725	0.82
P_4	quantitative	1.378	0.78	1.08
P_5	qualitative	0.948	0.749	0.71

The resulting potential for Project 1 was $P_{p1} = 0.91$; and it was $P_{p2} = 0.73$ for Project 2.

The assessment of the two projects’ potential was carried out on the basis of the analysis of the results of the potentials of qualitative and quantitative indicators (Tables 5, 7 and 9). Thus, the resulting potential for Project 1 “Development of digital production technologies for industrial machinery and shipbuilding”, which is at the New Life Stage, was $P_{p1} = 0.91$. According to the Harrington’s scale,

the project relates to the category “very good”, therefore, it does not require to take corrective actions by the actor.

The resulting potential for Project 2 “Development of materials and technologies to improve expectancy and quality of life”, which is at the Growing up Stage, was $P_{p2} = 0.73$. According to the Harrington’s scale, the project relates to the category “good”. The actor is recommended to control the progress of the project implementation for timely adoption of corrective actions.

6. Discussion: Industrial Innovation Ecosystems and Open Innovation Dynamics

A new paradigm for designing and modeling of industrial innovation ecosystems enables fast development of internationally competitive and innovative products. These innovations are relying more and more on collaboration through flexible, dynamic, and open platforms [31].

The proposed approach in this article based on the life cycle concept greatly contributes to the understanding of the sustainability perspective of open innovations. It is important because in practice open innovations increase the complexity of different processes within an industrial ecosystem. Open innovation combines internal and external resources to generate new technologies. An innovation ecosystem focuses on knowledge diffusion through diverse collaboration. Considering the open innovation paradigm, it is obvious that, at the micro level, open innovation is an advantage for any company, regardless of size and industry, and a driver in the context of globalized economic activity [9]. From a macroeconomic point of view, open innovation brings new issues to the concept of industrial ecosystems in terms of sustainable development, formation of the trust between all stakeholders, matching social requirements, culture creation, policy support, responsibility, etc.

In this article, we demonstrated that, using the proposed methodological approach, it is possible to integrate the approaches of open innovation and sustainable development within the industrial innovation ecosystem concept.

The ecosystem model allows forming a special friendly environment from enterprises through a voluntary partnership for the generation and implementation of innovative projects in various fields [9]. Definitely, the innovation ecosystem concept and its contribution to the scientific literature on innovation and industrial processes cannot be fully understood without taking into account life cycle aspects. The development of each of the components of the ecosystem makes companies competitive, which raises labor productivity. It reduces the time for the product launching into the markets, the cost of production, and increases the speed of managerial decisions and the quality of products and services [9,32–35].

The authors presented an innovation ecosystem as an open coevolving system of innovative projects that emerges in this system and then successively goes through all life cycle phases. The formation of the ecosystem’s project portfolio involved an assessment of their potential and must be inseparably linked with the goals, life cycle stages, and characteristics of the ecosystem as a whole. In this article the authors presented a methodology for forming an innovative project portfolio based on the assessment of their potential taking into consideration the life cycle phases of different projects.

Meanwhile, the proposed approach has some shortcomings and limitations caused by them. The following main limitations should be mentioned: high volatility of estimates and problems of specification selection when choosing data sources.

The authors plan to further develop the theory of innovation ecosystems in terms of studying the impact of individual actors, the relationship between them, and the external environment on the sustainability of the ecosystem as a whole. Future works on innovation ecosystems would focus on ecosystem platforms’ development issue, which will make the process of forming innovation portfolio in industrial ecosystems more open, objective, and transparent. It will enhance a culture of open innovation and collaboration and create trust [36], because the actors have to conquer cultural barriers in addition to legal and institutional barriers [31]. Improving the innovative projects’ selection process in industrial ecosystems will allow actors to work effectively within the ecosystem and more

actively collaborate with external stakeholders in order to provide positive synergistic effects from stakeholder interaction.

Our approach may thus serve as a starting point for future empirical studies focusing on ecosystems and provide the basis for a further understanding of the interrelatedness between, and coexistence of, innovative projects.

7. Conclusions

This article presented a new approach to the forming of innovation portfolios in industrial ecosystems with a focus on the life cycle concept. This methodological framework makes it possible to take into consideration the features of the life cycle phases of individual innovative projects and the ecosystem as a whole.

The theoretical and practical significance of the methodology lies in the development of a systematic approach to forming a portfolio of industrial ecosystem's projects, taking into consideration the stages of the life cycle of projects, actors, and the ecosystem as a whole. This approach makes it possible to increase the efficiency of innovation processes in the industrial ecosystem by optimizing the innovation portfolio. The methodology allows making decisions that will ensure the stability and sustainable development of the industrial ecosystem.

The research results are useful for academic researchers and policymakers in emerging economies to adopt and consider so to improve the contribution of innovation ecosystems to the country's economic development. The propositions arising from this analysis provide information to help academics, policymakers, government, and individual enterprises with a more adequate understanding of the practical mechanisms and tools to manage innovation ecosystems effectively.

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