Cenological approach in industrial ecosystem research in transition to industry 5.0

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Abstract. The concept of industrial ecosystems and cenological theory are co-evolutionary, since they are based on the similarity of living, non-living and artificial things. At the present time there are no works proving the functioning of industrial ecosystems as cenosis, the hypothetical possibility of applying the cenological approach to the study of industrial ecosystems. This determines the relevance of the research. The purpose of the work is to form a theoretical basis for the use of the cenological approach in the study of industrial ecosystems at the present stage of their development, characterized by the use of digital technologies and the transition to Industry 5.0. The main method of research was a rating analysis based on the initial data of the digitalization index of 20 enterprises - leaders of the industrial ecosystem for the year 2021. It was concluded that the industrial ecosystem of digital leaders has formed as a new type of cenosis - the industrial cenosis. Consideration of the law of rank distribution is a management condition for the functioning of the industrial ecosystem, allows to optimize its composition in order to achieve the ideal set of actors and increase stability.

1 Introduction

The concept of industrial ecosystems has received quite extensive coverage in modern research [1-5]. In previous works of the scientific team, which includes the authors, it is proved that under the conditions of transition to Industry 5.0 ecosystems have the greatest efficiency in comparison with networks and platforms [6, 7]. The unique properties of industrial ecosystems enable us to consider them as promising forms of sustainable industrial transition to Industry 5.0, the formation of technological sovereignty and response to new big challenges.

The idea of the similarity of the biological (living) and physical (non-living), technical (artificial) arose at a time when scientific and technological progress exponentially increased the complexity of systems and made it possible to bring the diversity of manufactured products closer to the natural species diversity, the power of the population. The idea of applying the concepts of biology to describe and predict large technologically

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generated systems is the basis of the cenological theory that considers complex systems as "cenoses" (techno-, business-, socio-, astrocenoses, etc.) [8-11].

Thus, the concept of industrial ecosystems and the technocenological theory are co-evolving. A systematic review of the literature conducted by the author showed a lack of works devoted to industrial cenoses, industrial ecosystems as cenoses, the cenological approach in the study of industrial ecosystems. In these circumstances, the author considers it relevant to prove the possibility of applying the techno-cenological theory to the study of industrial ecosystems.

The purpose of the work is to form a theoretical basis for the use of the cenological approach in the study of industrial ecosystems at the current stage of their development, characterized by the use of digital technologies and digital transformation of all processes based on the transition to Industry 5.0.

The object of the study are industrial ecosystems, functioning in the context of adaptation to the digital environment in the transition to Industry 5.0.

2 Literature review

The evolution of terminology associated with the development of the ecosystem approach, biology, bioeconomics, and cenological theory includes the period from the late 19th century to the second half of the 20th century:

- in 1871 the concept of biocenosis as an organic community in the works of M.N. Bogdanov (Russian Empire) [12], which is finally formed in 1877 by C. Mebius (Germany);
- microcosm as a concept similar in meaning to biocenosis appears in 1887 in the works of S. Forbes (USA);
- in 1903 the term "population" was introduced by W.L. Johansen (Denmark);
- in 1911 the concept of biosphere is introduced for the first time (V.I. Vernadsky [13], Russian Empire);
- in 1927 the term "noosphere" is first used in the works of E. Le Roy (France);
- the concept of biotic potential was introduced in 1928 by R. Chapman (USA);
- 1935 is marked by the appearance of the term "ecosystem" in an article by A. Tansley published in the journal Ecology [14] (England);
- in 1942 the concept of biogeocenosis appears in the works of V.N. Sukachev (Russian Empire);
- in 1956 F. Evans in his article in the journal "Science" [15] extended the boundaries of the use of the concept of ecosystem to refer to any part of life interacting with the environment;
- 1972 saw the pioneering work of V.A. Mezhgerin [16], in which the method of bioeconomic analysis of biological systems is considered within the framework of dialectical-materialistic analysis of the main research methods in biology and medicine;
- in 1974 the first conceptualization of the value theory by B.I. Kudrin [17];
- In 1976 the publication of Soviet scientists M.P. Polyakov and M.P. Shlimovich [18] for the first time used the term "bioeconomics" and proposed bioeconomic programs for the rational use of natural resources;
- In 1978 the theoretical foundations of bioeconomics were conceptualized by Romanian economist N. Georgescu-Regen [19].

The pioneering work of R. Frosch and N. Gallopoulos [20] of 1989 presented industrial ecosystems from the position of industrial symbiosis in the context of industrial ecology. This approach was further developed at the beginning of the 21st century by J. Korhonen. He identified three types of industrial ecosystems (young, combined, mature) [21], as well as four principles of industrial ecosystems (circulation, diversity, locality and gradual
change) [22]. In addition, J. Korhonen postulated the similarity of industrial ecosystems with biological ecosystems, drawing parallels between the flow of materials and energy in the cycle "bacteria - plants - animals" with the cycle of raw materials, fuel and further waste and emissions into the environment. The main difference between industrial ecosystems and biological ecosystems according to J. Korhonen is the lack of complete sustainability of the former compared to the latter.

The modern representation of industrial ecosystems is based on the platform approach [23], within which the organizational forms of industrial ecosystems are networks of industrial symbiosis, as well as eco-industrial parks, and the main components are eco-clusters (structural components), eco-platforms (infrastructure components), eco-industrial networks (business-process components), eco-technoparks and eco-incubators (innovative components), etc.

3 Materials and methods

In order to determine the possibility of applying the cenological approach to industrial ecosystems, and to consider industrial ecosystems as cenoses, we will use the method of rank analysis according to the classical procedure (Figure 1).

![Fig. 1. Procedure for checking industrial ecosystems for "value" based on rank analysis. Source: compiled by the author from [24, 25].](image)

Industrial ecosystem will be a cenosis if the rank distribution of its actors occurs according to a hyperbolic function. The coefficient of the distribution curve, which characterizes its shape, in values from 0.5 to 1.5 indicates the stability of cenosis, some ideal distribution of actors of industrial ecosystem.

As part of this study, we will check for "cenosis" for the industrial ecosystem of twenty actors - industrial digital leaders at the end of 2021. Such an industrial ecosystem functions in the context of adaptation to the digital environment, ensuring the transition to Industry 5.0.

The ranking parameter is the digitalization index, whose data for 2021 are taken from the Digital Passport of Industrial Enterprises of the GISP of the Ministry of Industry and Trade of the Russian Federation. The tabulated rank distribution, including the 20 actors of the industrial ecosystem ranked in descending order of the digitalization index, as well as the values of their logarithms, is presented in Table 1.
Table 1. Tabulated ranking of leaders in the digitalization of the industrial ecosystem of the transition to Industry 5.0. Source: compiled and calculated by the author according to the Digital Passport of Industrial Enterprises of State Industry Information System SIIS.

<table>
<thead>
<tr>
<th>Element name</th>
<th>r (rank)</th>
<th>W (parameter)</th>
<th>Ln r</th>
<th>Ln W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond Fertilizer</td>
<td>1</td>
<td>73.43</td>
<td>0.00</td>
<td>4.30</td>
</tr>
<tr>
<td>Vyksa Metallurgical Plant</td>
<td>2</td>
<td>73.4</td>
<td>0.69</td>
<td>4.30</td>
</tr>
<tr>
<td>Tactical Missile Weapons Corporation</td>
<td>3</td>
<td>71.19</td>
<td>1.10</td>
<td>4.27</td>
</tr>
<tr>
<td>Nizhneamsk Thermal Power Plant</td>
<td>4</td>
<td>71.04</td>
<td>1.39</td>
<td>4.26</td>
</tr>
<tr>
<td>Cheboksary Enterprise Sespel</td>
<td>5</td>
<td>70.88</td>
<td>1.61</td>
<td>4.26</td>
</tr>
<tr>
<td>UEC-Saturn</td>
<td>6</td>
<td>70.81</td>
<td>1.79</td>
<td>4.26</td>
</tr>
<tr>
<td>Tonar Machine Building Plant</td>
<td>7</td>
<td>70.05</td>
<td>1.95</td>
<td>4.25</td>
</tr>
<tr>
<td>Cable factory &quot;Expert Cable&quot;</td>
<td>8</td>
<td>69.79</td>
<td>2.08</td>
<td>4.25</td>
</tr>
<tr>
<td>United Engine Corporation</td>
<td>9</td>
<td>69.72</td>
<td>2.20</td>
<td>4.24</td>
</tr>
<tr>
<td>Kemerovo AZOT JSC</td>
<td>10</td>
<td>69.43</td>
<td>2.30</td>
<td>4.24</td>
</tr>
<tr>
<td>Polys Krasnoyarsk</td>
<td>11</td>
<td>68.86</td>
<td>2.40</td>
<td>4.23</td>
</tr>
<tr>
<td>Perm Machine-Building Plant</td>
<td>12</td>
<td>68.58</td>
<td>2.48</td>
<td>4.23</td>
</tr>
<tr>
<td>Design Bureau of Special Machine Engineering</td>
<td>13</td>
<td>68</td>
<td>2.56</td>
<td>4.22</td>
</tr>
<tr>
<td>Irkut Scientific and Production Corporation</td>
<td>14</td>
<td>67.87</td>
<td>2.64</td>
<td>4.22</td>
</tr>
<tr>
<td>Russian Helicopters</td>
<td>15</td>
<td>67.74</td>
<td>2.71</td>
<td>4.22</td>
</tr>
<tr>
<td>Trading and Manufacturing Company &quot;Varton&quot;</td>
<td>16</td>
<td>67.34</td>
<td>2.77</td>
<td>4.21</td>
</tr>
<tr>
<td>Concern for Radio Engineering Vega</td>
<td>17</td>
<td>67.13</td>
<td>2.83</td>
<td>4.21</td>
</tr>
<tr>
<td>Research and Production Enterprise &quot;Torii&quot;</td>
<td>18</td>
<td>66.6</td>
<td>2.89</td>
<td>4.20</td>
</tr>
<tr>
<td>Chelyabinsk Tractor Plant-Uraltrak</td>
<td>19</td>
<td>66.46</td>
<td>2.94</td>
<td>4.20</td>
</tr>
<tr>
<td>Ulan-Ude Instrument Manufacturing Association</td>
<td>20</td>
<td>66.3</td>
<td>3.00</td>
<td>4.19</td>
</tr>
</tbody>
</table>

The empirical rank curve and the trend line as an approximating function are graphically shown in Figure 2.

![Graphical rank distribution and approximating function](https://example.com/graph.png)

**Fig. 2.** Graphical rank distribution and approximating function. Source: compiled by the author.

High value of the regression coefficient square $R^2 = 0.93$ indicates the presence of a sustainable community-cenosis of the industrial ecosystem of digital leaders in the...
transition to Industry 5.0. The low value of the rank coefficient $\beta = 0.036$ indicates the weak stability of the industrial ecosystem as an ideal set of elements in the cenosis.

The plot of the rank distribution in the logarithmic scale and the approximating linear function are shown in Figure 3.

![Graphical rank distribution and approximating function on a logarithmic scale. Source: compiled by the author.](image)

The graphs show that the curves are approximated with great accuracy by a hyperbola: $R^2$ has a high value of 0.93 in both cases. The empirical points are almost all within the confidence interval. The above allows us to conclude that the industrial ecosystem of digital leaders has formed as a new type of cenosis - industrial cenosis.

4 Discussion

To form the theoretical basis of the cenological approach in the study of industrial ecosystems, the author systematized similar and distinctive features of industrial ecosystems and cenoses (Figure 4, Figure 5, respectively).

![Similarities between industrial ecosystems and cenoses. Source: compiled by the author according to [24-27].](image)
Thus, industrial ecosystems and cenoses have both similar and different characteristic properties. The main similar characteristics of industrial ecosystems and cenoses (ecocenoses, technocenoses) are the following: consistency, complexity, sustainability, self-organization, territorial localization, common purpose, longevity of creation, etc.

The main difference between an industrial ecosystem and a technocenosis is the decentralization of management. A number of authors [26, 28] believe that it is more logical to use the term "orchestration" rather than "management" in relation to industrial ecosystems, which emphasizes the need to replace the vertical power with peer-to-peer relations between actors in the industrial ecosystem.

Another important difference between an industrial ecosystem and cenosis is the nature of competition: competition for resources is a prerequisite of "cenosis," but not of ecosystems. Both competitive forms of interaction and pre-competitive joint partnership are possible in an industrial ecosystem.

Fractality, large size, and the strength of connectivity between objects can vary from one industrial ecosystem to another. Thus, an industrial ecosystem can be both fractal and non-self-similar; an industrial ecosystem often includes multiple actors, but even three objects are sufficient for its existence; an industrial ecosystem strives for coherence and sustainability, but is not always coherent and sustainable.

5 Conclusion

This study proves that industrial ecosystems functioning as digital leaders in the context of the transition to Industry 5.0 represent a new type of cenosis - industrial cenosis. As a theoretical basis of the cenological approach in the study of industrial ecosystems in the transition to Industry 5.0, similarities and differences between industrial ecosystems and cenoses are identified.

The hyperbolic law of rank distribution is a mathematical expression and reflects the level of digitalization of industrial enterprises, digital leaders included in the ecosystem in the transition to Industry 5.0.
Consideration of the law of rank distribution is a management condition of industrial ecosystem functioning, allows to carry out optimization of its composition in order to achieve an ideal set of actors and increase stability.

Acknowledgements

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