The role of eco-industrial parks in promoting circular economy technologies in the regions

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Abstract. The authors proposed a method for evaluating the relationship between eco-industrial parks with circular economy technologies. The novelty of the study was the introduction of a new term, the specialization index of circular economy technologies for eco-industrial parks. The authors proposed an algorithm for calculating this index. It is based on four types of technologies: waste treatment, industrial symbiosis, water resource efficiency, and renewable energy. The authors conducted a correlation analysis of 15 regions for 2021. Eco-industrial parks appeared due to the development of circular economy technologies. The balance of demand and supply formed only for waste treatment technologies as of 2021. The industrial symbiosis technology is at an average level in industrial parks. In 2021, markets for water efficiency and renewable energy technologies began to emerge. Eco-industrial parks must implement the full range of circular economy technologies. This will make it possible to achieve the goals of sustainable development.

1 Introduction

The transition of regions to the principles of the circular economy is a topic of discussion in the world. Various countries recognize the need for efficient waste management and extended producer responsibility, reduction of carbon footprint, water efficiency and transition to renewable energy. The pace of development of circular economy technologies varies from country to country. Therefore, we studied the factors influencing the development of circular economy technologies. The impact of eco-industrial parks on the circular economy technologies (namely, collection, sorting and recycling of polymer wastes) was examined.

The purpose of this study is to determine the relationship between eco-industrial parks and circular economy technologies.

The object of research is the activity of the regions in the field of circular economy.

The subject of the study is circular economy technologies used in eco-industrial parks in regions of the world for the year 2021.

The hypothesis of the study is that the circular economy technologies develop under a special condition, i.e. when the region has a balance of supply and demand in the market. In this case, the patent owners of technologies for the collection, sorting and recycling of

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waste are responsible for supply in the regional market. The eco-industrial parks are responsible for the demand in the regional market.

The papers by S. Shehab, M. Farooque, H. Hong and Y. Liu revealed the leading role of eco-industrial parks in the application of circular economy technologies [1-4]. The development of eco-industrial parks in different regions of the world and the use of circular economy technologies in them were discussed in papers by T. Vu (Vietnam), J. Ong (Malaysia), D. Zeng, W. Xun (China), A. Rweyendela (Africa), A. Gourgiotis (Greece), M. Sessa (Italy) [5-11].

One of the types of circular economy technologies is industrial symbiosis. Y. Liu, D. Kröhling, F. Han, I. Saha, S. Barile, S. Foong, G. Das, and S. Nuhu described the use of industrial symbiosis in eco-industrial parks [4, 12-18].

Another type of circular economy technologies is waste recycling. I. Shah and T. Wang described the use of waste recycling technologies in industrial parks [19, 20].

The studies on the introduction of renewable energy in eco-industrial parks were less common. For example, S. Shehab and I. Shah investigated this topic [1, 19].

Several papers consider water efficiency in eco-industrial parks [21].

Many studies consider the methods of evaluating the activity of eco-industrial parks. All these studies are based on the principles of circular economy in certain regions. Here the papers by Y. Liu, D. Zeng, S. Foong, S. Nuhu, D. Van Beers, Y. Fan, B. Qiu can be cited [4, 7, 16, 18, 22-24].

2 Materials and methods

This study consisted of five stages as follows.

At the first stage, we identified types of circular economy technologies in eco-industrial parks. The expert method was used for this purpose. World Bank experts were selected as experts. The experts' opinion was published in the 2021 report “Circular economy in Industrial Parks: Technologies for Competitiveness” [25].

At the secont stage, we proposed a method for the correlation analysis. It is the analysis of the relationship between eco-industrial parks with the technologies of circular economy.

At the third stage, we have chosen the regions for the correlation analysis proposed at the second stage of the study. The data for the analysis of these regions was collected.

At the fourth stage, we introduced a new indicator, the specialization index of circular economy technologies for eco-industrial parks. This indicator was tested on the example of eco-industrial parks as of 2021.

At the fifth stage, we conducted a correlation analysis by the method proposed at the second stage. It analyses the relationship between eco-industrial parks and circular economy technologies. MS Office "Excel" software was used for this purpose.

3 Results

The types of circular economy technologies in eco-industrial parks of various countries are presented in Table 1 [25].

Table 1. Circular economy technologies used in eco-industrial parks, as of 2021

Region	Types of technologies, units			
	Waste treatment	**Industial symbiosis**	**Water efficency**	**Renewable energy**
China	1	1	1	1
USA	1	-	1	1
EU	1	1	-	1
Russian Federation	1	-	-	-
Australia	1	1	-	-
Canada	1	1	-	-
Republic of Korea	1	1	-	1
India	1	1	1	1
Malaysia	1	-	1	-
Japan	1	1	-	-
Great Britain	1	1	-	1
Mexico	1	-	1	1
Israel	1	-	1	1
Saudi Arabia	1	-	1	-
South Africa	1	-	1	-

The data was obtained from the World Bank's 2021 report. By the number of eco-industrial parks that have applied technologies in the field of circular economy:

- 1st place was occupied by waste treatment technologies (248 eco-industrial parks);
- 2nd place was occupied by renewable energy technologies (227 eco-industrial parks);
- 3rd place was occupied by water efficiency technologies;
- 4th place was occupied by the industrial symbiosis [25].

Further we proposed a method to analyse the relationship between eco-industrial parks with technologies of circular economy. We chose the first indicator of analysis, the specialization index of circular economy technologies for eco-industrial parks. This factor provides a qualitative assessment. It shows the contribution of eco-industrial parks to the development of market demand for circular economy technologies.

The factorial feature is the number of active eco-industrial parks in the regions as of 2021. It quantifies the contribution of eco-industrial parks to the demand for circular economy technologies.

The second indicator was the specialization index of technologies for the collection, sorting and recycling of polymer waste for patent holders in the regions for 2021. This factor provides a qualitative assessment. It shows the contribution of patent developers to the development of market supply for circular economy technologies.

The next factor is the number of active eco-industrial parks in the regions for 2021.

At the third stage of the study, we selected the regions for correlation analysis, their parameters are presented in Table 2. The specialization index of technologies for the collection, sorting and recycling of polymer waste was calculated in the previous study [26].

Table 2. Data for correlation analysis for 2021.

Region	Number of eco-industrial parks, units	Specialization index of technologies for the collection, sorting and recycling of polymer waste, rel. units
China	107	0.77
USA	35	0.77
EU	126	0.54
Russian Federation	12	0.38
Australia	3	0.27
Canada	4	0.23
Republic of Korea	52	0.15
India	9	0.15
Malaysia	1	0.15
Japan	26	0.12
Great Britain	9	0.08
Mexico	1	0.08
Israel	1	0.04
Saudi Arabia	1	0.04
South Africa	4	0.04

At the fourth stage of the study, we developed an algorithm for calculating the specialization index of the technologies in the circular economy. For this purpose, we defined the term "specialization" as a set of types of technologies for the circular economy. These technologies were developed by the eco-industrial parks in the regions. The calculation algorithm includes the ratio of the number of technology types in an eco-industrial park of a region to the total number of technologies types in the world.

The calculated of specialization indexes of technologies for circular economy are shown in Table 3.

Table 3. Specialization indexes of technologies for circular economy in eco-industrial parks for 2021

Region	Specialization index of technologies for circular economy in eco-industrial parks, rel. units
China	1
USA	0.75
EU	0.75
Russian Federation	0.25
Australia	0.5
Canada	0.5
Republic of Korea	0.75
India	1
Malaysia	0.5
Japan	0.5
Great Britain	0.75
Mexico	0.75
Israel	0.75
Saudi Arabia	0.5
South Africa	0.5

Further we performed the correlation analysis according to the method presented in the second stage. This analysis reveals the relationship between eco-industrial parks and circular economy technologies, Table 4.

Table 4. Correlation analysis of the impact of eco-industrial parks on circular economy technology for 2021.

Factor	Correlation coefficients, rel. units				
	Total specialization index of circular economy technologies	**Specialization index of waste treatment**	**Specialization index of industrial symbiosis**	**Specialization index of water efficency**	**Specialization index of renewable energy**
Number of eco-industrial parks in the regions	0.45	1	0.52	-0.09	0.39

The condition in the first correlation model was determined. The construction of each eco-industrial park provided a small increase in the range of circular economy technologies in the region.

The increase in the number of eco-industrial parks depended directly on the introduction of waste treatment technologies.

The expansion of eco-industrial parks depended on the introduction of industrial symbiosis technologies. We believe that this indicator has potential for further growth.

The increase in the number of eco-industrial parks did not have an impact on the introduction of renewable energy technologies.

The increase in the number of eco-industrial parks has not led to an increase in the introduction of water efficiency technologies. Few eco-industrial parks have introduced water efficiency technologies.

The correlation analysis is presented in table 5. It considers the impact of technologies for the collection, sorting and recycling of polymer waste on the development of eco-industrial parks for 2021.

Table 5. The correlation analysis of the impact of technologies for the collection, sorting and recycling of polymer waste on the development of eco-industrial parks for 2021.

Factor	Correlation coefficient for specialization index of technologies for the collection, sorting and recycling of polymer waste among patent owners, rel.units
Number of eco-industrial parks in the regions	0.70

Patent owners for technologies of the collection, sorting and recycling of polymer waste had a positive impact on the increase of eco-industrial parks in the region.

4 Discussion

The proposed hypothesis was confirmed. The technologies of the circular economy were developed under a certain condition. The region had to have a balance of supply and demand in the market. Eco-industrial parks were responsible for demand. Patent owners were responsible for the supply on the market. As of 2021, the balance of demand and supply has formed only

for waste treatment technologies. For other technologies of the circular economy, supply and demand did not reach equilibrium in 2021.

Among the 15 regions studied, China stands out. The data shows that China has the maximum number of eco-industrial parks. It is slightly inferior to the EU in this indicator (Table 2). China's specialization index of technologies for collection, sorting and recycling of polymer waste was the highest in the world. The USA had the similar result (Table 2). The specialization index of circular economy technologies of eco-industrial parks in China reached a maximum of 1 rel. unit (Tables 1 and 3). So, China is an example of the confirmation of our hypothesis. Studies by D. Zeng, W. Xun confirmed this fact [7, 8].

According to the World Bank report, the Republic of Korea shows an increase in the quality of eco-industrial parks. This is due to the introduction of smart manufacturing [26]. However, the number of eco-industrial parks in the Republic of Korea was not the highest in the world. The Republic of Korea's specialization index of technologies for the collection, sorting and recycling of polymer waste was lower than the global average. We calculated this index among patent owners. The specialization index of circular economy technologies (0.75 rel. units for the eco-industrial parks) was not the highest in the Republic of Korea.

The practical significance of the study is to find out the impact of eco-industrial parks on the development of circular economy technologies in the region. We considered the evaluations of technologies for circular economy in eco-industrial parks. The number of studies on this topic is not considerable. The developed method will make it possible to conduct a foresight for a region. It will consist of the annual study of supply and demand on the market of circular economy technologies. This foresight will include the opportunities and the threats for technologies.

We believe that it is necessary to conduct an additional correlation analysis for the development of the industrial symbiosis, the water efficiency and the renewable energy in eco-industrial parks.

We plan to perform this analysis using the example of the method proposed in Table 5. For this purpose, it will be necessary to calculate the specialization indexes for the industrial symbiosis, the water efficiency and the renewable energy. It is difficult to calculate the specialization index for the industrial symbiosis since this technology is not patentable. Regions do not keep statistics on the number of developments of this technology.

The proposed method is specified for the regional market. It does not take the factor of external trade in the global market. We did not take into account the possibility of exporting and importing technologies of the circular economy in the regions. This method does not consider the influence of foreign technologies in the eco-industrial parks of the regions. In the future, we plan to develop the method with these factors in mind.

The article considers eco-industrial park activities in the field of circular economy for 15 regions of the world, which exceeds the number of regions discussed in the literature review [5-11].

In our opinion, it is necessary to develop not only one type of circular economy technologies (waste treatment) in eco-industrial parks. We propose to introduce all technologies of circular economy in eco-industrial parks. This is necessary to achieve the UN Sustainable Development Goals. These technologies should also include water conservation, renewable energy sources. These technologies should also include water conservation, renewable energy sources. The results of this study and other articles by S. Shehab, Y. Shah, and H. Gia confirm this [1, 19, 21].

5 Conclusion

Thus, we concluded that eco-industrial parks are interconnected with circular economy technologies. The balance of demand and supply was formed only for waste treatment

technologies in 2021. Eco-industrial parks were responsible for the demand. Patent owners were responsible for the supply on the market.

The market for the industrial symbiosis, water efficiency and renewable energy is beginning to form in 2021. We suggest that regions modify previously established eco-industrial parks and/or create new ones with these recommendations in mind.

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