The development of a diagnosis and risk assessment model for the industrial chain of industrial park and its verification through case study

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Abstract: Supplement chain diagnosis is the premise for the transformation of industrial park into more sustainable and circular-economy system. This paper proposed diagnosis model for the supplement chain which can help to identify the risk factors and calculate the risk coefficient. The Kalundborg industrial park and its experience, as well as the changes, in the times span from 1975 to 2000 were taken as a case study to verify the proposed model, which showed that the risk coefficients calculated by this model can reflect the risk changes along with the formation of the industrial symbiotic network and provide some insights for the decision-making in the course of circular transformation.

1. Introduction

Since the reform and opening up of China, the economic and technological development parks, high-tech industrial parks as well as other types of industrial parks have developed vigorously in terms of both the number and scale. At present, industrial parks have become an important driven force for regional economic growth in China. In 2016, the total economic value of various types of industrial parks at all levels combined accounted for more than 60% of the national GDP [1]. However, at the same time, industrial parks also became the regional biggest consumer of resources and energy as well as the producer of pollution. With the ever-expanding demands and corresponding growth of the production, a large amount of resources are consumed. The outdated production mode and layout in industrial parks result in even bigger requirements for resource and energy. Due to the lack of foresight in the early planning, the wastes of resources in the processes of production and transportation are generated in considerable amount. There is still a big gap between cascade utilization and recycling of resources. Energy utilization efficiency also needs to be improved. Increasing output and recycling rate of resources and energy have become the biggest demand for establishing a well-functioned circular system in all kinds of industrial parks in China.

The core concept for circular transformation of industrial parks is to establish a circular economy system inside an industrial park, through which the energy consumption and pollutants emission can be reduced, and resources and energy efficiencies are improved. To form a circular economy system, the construction of industrial chains, the sharing of infrastructures, the improvement of the production
process and the improvement of management mechanism are four cornerstones. The first step of the circular transformation of industrial parks is the identification of the industrial chain supplement projects, which is similar to the food chain in nature. Then various means can be taken to extend the industrial chain and upgrade the value chain. Through the diagnosis and evaluation of the industrial chain of existing parks, key units, the missing part of chain and weak link can be located, and longitudinal extension and lateral coupling of chain can be further realized. That is of great significance to realize the circulation of the supplement chain, through which the resources and energy consumption and environmental pollution emission can be reduced, and resource output rate and recycling rate can be improved.

In regard of industrial park diagnosis, Yang L.H. analyzed the institutional structure and network system of the Kalundborg eco-industrial Park in Denmark and the Guangxi Guigang eco-industrial Park by using the social network analysis method, which presented the stability difference of the industrial symbiotic network in different developing states [2]. Fraccasicia L. proposed the concept of industrial symbiosis resilience, and verified the reliability of the proposed elastic indicator based on a real case [3]. Mannino I. discussed the internal and external factors affecting the industrial symbiotic stability base on the failure of the industrial symbiotic network of Italy Porto Marghera eco-industrial Park [4]. Han F. analyzed the characteristics of the symbiotic network of the Xinfa eco-industrial Park using the social network analysis method, with identified the high dependence on water and energy resources. The concept of symbiotic circle, indicative of the clique and symbiotic circle in the symbiotic network was put forward [5]. Wen Z.G. constructed the analysis framework of circular transformation of industrial parks, and identified the key factors of circular transformation for enterprises, industrial chain and industrial park. The key path for the improvement of industrial chain, as well as the infrastructures in circular economy system, was also proposed [6]. The existing literatures mainly focus on the structure and stability of the industrial symbiotic network, and the qualitative identification of the missing parts in the industrial parks. However, the identification of the risk factors and their quantitative assessment were rarely discussed.

2. Diagnosis and risk identification model of industrial chain in industrial parks
This paper constructed a diagnosis and risk identification model of industrial symbiosis network in industrial parks. The following functions can be achieved by the proposed model.

2.1. Identifying analysis subject
It is clear whether the analysis subject belongs to the symbiotic network of industrial parks, and then determines their relationship. Taking industrial parks as the object, symbiotic network nodes are enterprises or key processes. The relationship is the exchange of the byproducts, waste recycling and energy sharing. The relationship elements are materials and energy. Through analyzing ecological correlation degree between enterprises, the overall network structure and the key nodes in the symbiotic network can be identified.

2.2. Determining the scale of analysis
Determining the analytical scale for subjects, including both time and space. The scale of the study is defined as all the nodes of the industrial symbiotic network in the industrial park. There is no widely accepted standard for defining the time scale of each industrial park, so the latest state can be selected.

2.3. Establishing network database
For highly complex networks, databases need to be established firstly. When building a database, we should define the scale of network, decide the data collection way based on network scale and data availability, and then collect data through questionnaire survey and literature research. Finally, according to the unified format, the data can be used for network complexity analysis and recorded in the database. For smaller networks, the construction of database is relatively simple, and the main
method is literature review. Excel table can be used to store the two value matrix for all nodes and their corresponding relationships.

2.4. Calculating network structure
The computation of network structure mainly refers to the computation of the characteristic parameters and the distribution of symbiotic network. This paper uses the UCINET software to calculate characteristic parameters of the two value matrix in the database. The calculation and analysis of network density, characteristic path length and network centrality were carried out [7].

2.5. Risk assessment model of industrial chain
By calculating the key index of symbiotic network, risk coefficient of each node can be obtained. The risk coefficient is proportional to the degree. Because the higher the degree of the node is, the higher the risk is. The risk coefficient is inversely proportional to the network density. The larger network density indicates that the inter-dependence of the individual module in network is low. The smaller network density means that the higher inter-dependence of the individual modules is, and the higher the risk is. The risk coefficient is inversely proportional to the characteristic path. The shorter path indicates that the better the network connectivity is, and the lower the risk is. The risk coefficient is proportional to the centrality. The higher centrality is indicative of higher significance of the node and the higher risk. This paper measured the centrality with the average of three characteristic values. In this paper, the risk coefficient is expressed as R, k represents the node degree, d represents the network density, a represents the characteristic path, c1 is degree centrality, c2 is betweenness centrality, and c3 is closeness centrality. So the risk coefficient model is showed by formula 1.

$$R_i = \frac{k_i}{d \times a \left( \frac{c_{1i} + c_{2i} + c_{3i}}{3} \right)}$$ (1)

2.6. Identification of supplement chain projects
Using the characteristic indicators of industrial symbiotic network and node risk coefficient, the diagnosis and evaluation of the symbiotic network of industrial park include defining scale and type of waste production and utilization, determining the type and scale of the enterprises which will be introduced, and identifying the missing parts of the supplement chain projects. The key enterprises with higher influence over the marginal enterprises need to be identified, which provide subjects for the optimization of industrial symbiotic network.

3. Empirical research
Taking the industry symbiosis network of the Danish Kalundborg as an example [8], this paper applies the industrial chain diagnosis and risk identification model to calculate the risk coefficient of the symbiotic network nodes in the Kalundborg Park. The Danish Kalundborg Industrial Symbiotic Network was built by a number of enterprises located in the 3km radius of the city, which facilitate them for the exchanges of steam, heat, fly ash, sulfur and some other resources. The network was made up of 6 processing enterprises, 1 waste disposal enterprise and the municipal departments of the city. By signing a mutually beneficial contract, one enterprise provided its by-products, waste or waste heat for another enterprise, which produced raw material or power for another unit. An energy cascade utilization and material recycling system was realized in the Kalundborg Park.

The UCINET software is used to calculate the industrial symbiotic network structure indicators of 1975 and 2000 of Kalundborg, including node degree, network density, characteristic path, and centrality. By formula (1), the risk coefficient of each node can be obtained. Table 1 shows the risk coefficient of each node.

As presented in table 1, it can be seen that the risk coefficient of the core enterprise power plant was higher when the surrounding enterprises were increasing, which was due to the inclusion of more
related enterprises. Once the core nodes were missing, the whole symbiotic network would be affected. The risk coefficient of the other less significant enterprises, such as the refinery and the fertilizer plant, became smaller. This is due to the increase of enterprise number and the complexity of the network. The network connectivity also became better. The entire symbiotic network became less dependent on a single node, so the risk coefficient was lowered.

Table 1. The risk coefficient of each node in 1975 and 2000

| Node                              | Risk coefficient | 1975 | 2000 |
|-----------------------------------|------------------|------|------|
| Power plant                       |                  | 0.40 | 0.79 |
| Refinery                          |                  | 0.61 | 0.46 |
| Lake                              |                  | 0.21 | 0.20 |
| Enzyme and insulin plant          |                  | -    | 0.20 |
| Farm                             |                  | -    | 0.13 |
| Seawater                          |                  | 0.21 | 0.07 |
| Coal                              |                  | -    | 0.07 |
| Crude oil                         |                  | 0.10 | 0.07 |
| Plaster                           |                  | -    | 0.07 |
| Concrete road building plant      |                  | -    | 0.07 |
| Material plant                    |                  | -    | 0.13 |
| Warm shed                         |                  | -    | 0.13 |
| Urban district heating            |                  | 0.10 | 0.07 |
| Plaster plant                     |                  | 0.10 | 0.79 |
| Sulphuric acid plant              |                  | 0.40 | 0.79 |
| Fertilizer plant                  |                  | 0.61 | 0.47 |

4. Conclusion

Based on the demand for supplement and reinforcement chain in circular transformation of industrial parks, this paper proposes a diagnosis and identification model for the industrial chain of industrial parks, and calculates the risk coefficient of Kalundborg in 1975 and 2000 as a case study. It is found that increasing the related peripheral enterprises can reduce the risk coefficient of the enterprise, but increases the risk of the core enterprise. Therefore, the decision makers of the industrial park must increase the surrounding enterprises with precaution to the core enterprises. In the process of choosing enterprise, it is recommended to choose the enterprise with high relevance. At the same time, the core enterprise requires extra attention during the optimization of the industrial park, especially for the core enterprise with strong correlations with others. Once the core enterprise is moved or bankrupt, the whole industrial park will be affected even cause a system failure in some extreme scenarios.

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References

[1] Ministry of Ecology and Environment of China. Routine press conference in April 2018, http://www.zhb.gov.cn.
[2] Yang L.H., Tong L.J. Research of typical EIPs based on the social network analysis [J]. Acta Ecologica Sinica, 2012, 32 (13) :4236-4245.
[3] Fraccascia, L., Giannoccaro, I., Albino, V. Rethingking Resilience in Industrial
Sysbiosis: Conceptualization and Measurements [J]. Ecological Economics, 2017, 137: 148-162.

[4] Mannino, I., Ninka, E., Turvani, M., etc. The decline of eco-industrial development in Porto Marghera, Italy [J]. Journal of Cleaner Production, 2015, 100: 286-296.

[5] Han F. Industrial metabolism and structural analysis of industrial symbiosis network in eco-industrial parks [D]. Shandong University Dissertation for Doctoral degree, 2017.

[6] Wen Z.G., Hu Y., Luo E.H. Empirical Analysis of the Industrial Park Circulating Transformation [J]. Environmental Protection, 2017, 44(17): 13-17.

[7] Luo J.D., Social network analysis [M]. Social Sciences Academic Press, 2004.

[8] Dunne J. A., Williams R. J., Martinez N. D. Network structure and biodiversity loss in food webs: robustness increases with connectance. Ecology Letters, 2002, 5(4): 558-567.