Chapter 76
Research on Eco-Industry Symbiosis System Based on Complex Network

Jian Li and Yang Gao

Abstract The construction of Eco-Industrial Park (EIP) is the basis of Eco-Industry System (EIS) and an important guarantee for implementing the scientific outlook on development, which has a great significance for promoting regional sustainable development. Industrial Symbiosis Network (ISN) is the main organization form for cooperating enterprises in Eco-Industrial Park (EIP) and the key content of the construction of EIP. This paper analyzes the drawbacks of traditional linear model of industrial development and explains the importance of the development of Eco-Industry, also system analyzes the circulation development pattern of eco-industrial symbiosis system. Based on Complex Network, this paper puts forward to build the model of eco-industrial symbiosis system from three aspects that include node, degree and weight, and finally verify the feasibility of the model through the analysis of case. The conclusion can offer a certain guidance and practical significance for development of circular economy and construction of Eco-Industrial Park.

Keywords Complex Network • Development model in Circular • Eco-Industrial Symbiosis Network • Eco-Industrial Symbiosis System

Introduction

The traditional industrial development is a linear industrial economic pattern, namely, "to extract resources from earth and to transfer the resources into products and services; and then put the rest of the stuff (garbage) return to the eco-system

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(Li Huibo 2006). Because of the traditional linear mode of production brought about increasing pollution which has aroused the concern of the relevant government departments, a series of laws, regulations and policies having been introduced that require companies have to deal with the production of garbage, and the one that meet the requirements can be authorized to emission, but it's only the end of the treatment approach that can not address the root questions. At this time the development of circular economy and clean production came to be introduced. To establish Eco-Industrial Symbiosis System is an important way to achieve clean production and the development of circular economy. Denmark Kalundborg eco-industrial park is a typical eco-industrial symbiosis. Kalundborg eco-industrial park recycles and reduces the emissions of industrial waste, it's not only can reduce the pollution of the environment, but also make the industrial waste recycled and the efficiency of resource utilization promoted.

Eco-Industrial Symbiosis System and Complex Network

Eco-Industrial Symbiosis System

Eco-industrial symbiotic system is a complex organic system, there are a variety of direct or indirect symbiotic relationship among its internal industry, Eco-industrial symbiotic system is a complex system of enterprises and inter-enterprises relations that formed by the close cooperation of all types of enterprises through the economic, social and environmental aspects, the basic starting point is that there must exist the environmental cooperation between enterprises, the fundamental purpose is to improve resource utilization and ecological efficiency. Eco-industrial symbiosis system emphasizes the coordination and sustainable development among economic, environment and society.

The eco-industrial symbiosis system is to emulate natural ecosystem and to apply ecosystem integrity principle, using the interaction between its physical and chemical composition and putting a variety of raw materials, products, by-products and even waste emissions make up a reciprocal causation symbiotic network with coordinated structure and function. In eco-industrial symbiosis system, the industrial waste generated by a business or department of industrial production is regarded as the by-product, which can be used as the raw material of another enterprise or department, and form a pattern that is "resource-industrial waste-resource", thereby can reduce the emissions of industrial waste and form a symbiosis system that include multilayer utilization of substance and energy and a win-win situation between economic benefits and ecological benefits, and can make the effective circle of economic development (Yin Yanbin and Zhao Tao 2008).

The development of eco-industrial symbiosis system is from the pattern of linear development change to the circular pattern of resources-products-renewable resources (Liu Yifang and Tong Rencheng 2011), in order to change from the

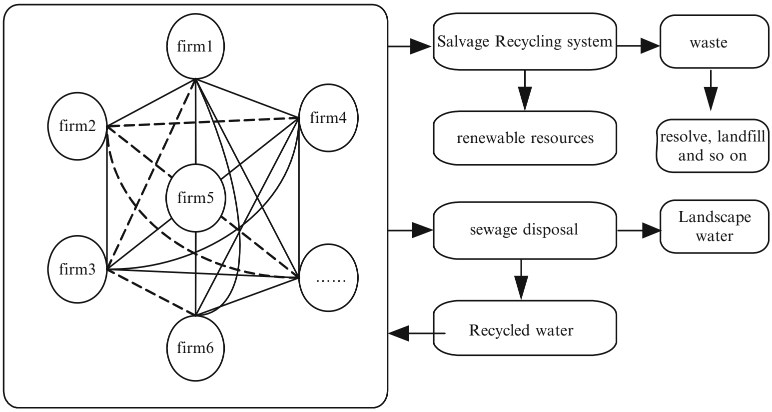

Fig. 76.1 Type of eco-industrial symbiosis network

traditional growth pattern that depend on utilization and exploitation of resources to the pattern that establish the symbiotic relationship between enterprises, make the substances in the enterprises circulate within the system, and put regard production waste as raw materials of another enterprise, which can improve resource utilization, at the same time, to establish an effective system that can achieve clean production is a important method for developing of circular economy (Fig. 76.1).

Complex Network

Complex Network mainly refers to a complex topology and dynamic behavior of large-scale networks, it is diagrams that constituted by the large number of nodes interconnected by edge (Bai Tingting and Zheng Xinqi 2011). Large number of complex systems which exist in the real world can be described through network. Such as the Internet network, transport network, human social relations network, neural networks and so on. Network research mainly includes three aspects. The first one is to define a variety of quantities of network characteristic and to characterize the macroscopic properties of real complex systems. The second one is to establish a network model to help people understand the macroscopic properties of real systems in a variety of micro-generation mechanism. The third one is do research on the characteristics of the dynamic process in the network with a different structure.

In recent years, the research on Complex Network is becoming a hot issue focus of various fields (Albert and Barabás 2002; Dorogovtsey and FMendes 2002; Strogatz 2001). Complex Network is a research methods of complex systems with multi-disciplinary, especially in mathematics, statistical physics, computer and information sciences (Xiao Zhongdong et al. 2010). The following figure shows the main contents and methods of complex network theory (Fig. 76.2).

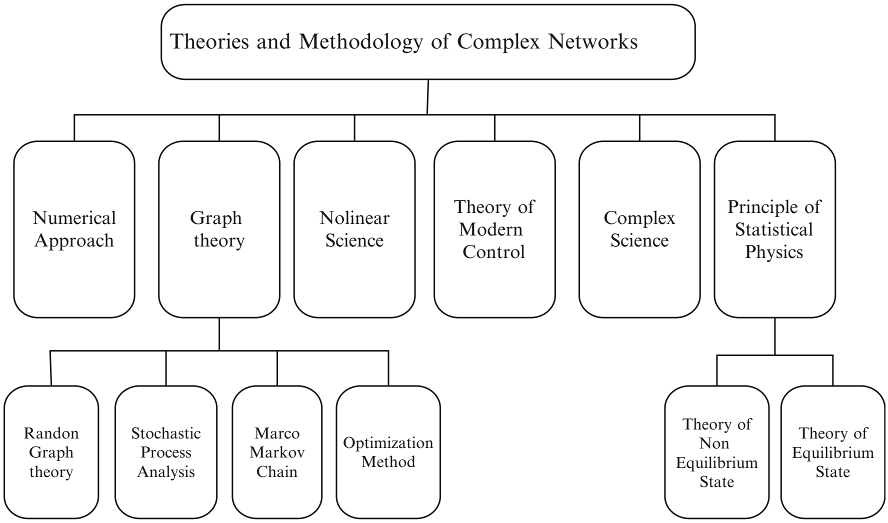

Fig. 76.2 Theories and methodology of complex network

The Model of Eco-Industrial Symbiosis System

Traditional economic mode of production is a predatory type of resource consumption patterns, the industry is too simplex and large-scale, the situation of duplication investment is rather serious, we adopt the end of treatment to protect environment, which have to take high cost, but get low return, the overall efficiency is rather low, so it's form the vicious cycle pattern of "production – consumption – pollution". The traditional pattern has not a mechanism of recycling of resources, the eco-industrial symbiosis system is a new production pattern that for the recycling of resources. Eco-industrial symbiosis system is not simply start under control of pollution, but starting from the change of production mode, by changing the mode of economic and social development to achieve the purpose of environmental protection and economic development. Eco-industrial symbiosis system requirements economic construction to improve efficiency of resource productivity, reduce energy consumption of resources, improve the economic quality and reduce the economic substance and energy density, promote the greening industry, get regard the implementation of the "3R" principle (Reduce, Reuse, Recycle) (Wang Zhaohua 2002) as the main principles for clean production, we must develop eco-industry and circular economy and promote technological innovation, and promote mutually benefit of economic and environmental.

Based on complex network to analyze the eco-industrial symbiosis network mainly consider the following three aspects:

Node

In the model of eco-industrial symbiosis system, the node refers to the enterprises in the symbiotic system. This node as well as can supply production of raw materials to meet other nodes, the raw materials which may be the production enterprises produced or the waste enterprises discharged, at the same time, this node could be accept raw materials or waste that come from other node as its raw materials for production. It may also be the garbage generated in their production, while the node to receive the product or waste from other nodes as the raw materials needed.

Eco-industrial symbiosis system is consisted of nodes. Node is at the core of the eco-industrial symbiosis system. Numerous nodes (Enterprise) that have mutually beneficial symbiotic relationship form an industrial symbiosis system.

Some enterprises have a symbiotic relationship with numerous other enterprises in the eco-industrial symbiosis system, some enterprises have symbiotic relationship with just a few enterprises. The enterprises have most symbiotic relationship with other enterprises and these enterprises are the core enterprises in the eco-industrial symbiosis system.

Wang Xiaofan, Li Xiang and Chen Guangrong pointed out in "theory of complex network and application" that 20% of the nodes determine the nature of 80% of the eco-industrial symbiosis system. There are studies have shown that if remove and load of the largest single node on the network can cause the loss of 25% or more efficiency.

It must be noted that the production advance of eco-industrial symbiosis system is manifested by the symbiotic relationship between the node and the node's own mode of production.

Degree

Degree refers to the number of connections between nodes with other nodes in the eco-industrial symbiosis system (He Yu and Zhao Hongli 2011), the degree i is indicated by k_i. What the degree shows is the materials exchange between the nodes (enterprises), which show symbiotic relationship between enterprises (node) in the eco-industrial symbiosis system. What degree reflects is the existence of material exchange between the two nodes. Degree includes out-degree and in-degree. The out-degree is the number of edges from the node to point to other nodes, the out-degree of node i is indicated by k_{i-out}, which is equal to $k_{i-out} = \sum_{j=1}^{n} k_{ij}$, k_{ij} is the connected edges that from node i direct to node j. The in-degree of node i is indicated by k_{i-in}, which is equal to $k_{i-out} = \sum_{j=1}^{n} k_{ji}$, k_{ji} is the connected edges that from other node direct to node i (Wang Xiaofan et al. 2006). The economic significance of in-degree represents is that the raw materials needed by node (enterprise) are supplied by other nodes, namely, the node (enterprise) accepts the other products or waste from node (enterprise) in the industrial symbiosis system as its own raw materials needed.

As for the degree of the node i:

$$k_i = k_{i-out} + k_{i-in} = \sum_{j=1}^{n} k_{ij} + \sum_{j=1}^{n} k_{ji} = \sum_{j=1}^{n} \left(k_{ij} + k_{ji}\right) \tag{76.1}$$

Degree is the main manifestations of the nature of nodes in eco-industrial symbiosis system. The greater the degree of a node, the more important the node relative to the whole, if the degree of a node larger than that of other nodes, we define the node as the core node in eco-industrial symbiosis system, which indicated by the following formula:

$$\max(i) = Max(k_1, k_2, \ldots, k_n) \tag{76.2}$$

The core node can be defined by the following way to confirm in eco-industrial symbiosis system:

$$\max(i) = Max(k_i), i = 1, 2, \ldots, n \tag{76.3}$$

$$\max(i) > Max\left(k_j\right), j = 1, 2, \ldots, n \text{ and } j \neq i \tag{76.4}$$

If the node i can meet the formula (76.3) and (76.4), so the node i is the core node in eco-industrial symbiosis system. The core node determined the structure of eco-industrial symbiosis system to a great extent, namely, which determined the nature of eco-industrial symbiosis system to a great extent.

Weight

What the degree shows is a relationship that materials exchange between the nodes (enterprises) in the eco-industrial symbiosis system. What the weight shows is the specific amount of this relationship of material supply. The weight is indicated by w_i. The weight is the edge weight (Xing Lizhi 2012). A supply relationship that one enterprise correspond to other enterprises may consist of two parts in eco-industrial symbiosis system, namely, there may be a supply relationship between the two enterprises or not in the eco-industrial symbiosis system, By setting a variable node x_{ij} to show the relationship that node i input its products to node j, in which the x_{ij} is defined as 0 or 1. When the variable x is 0, indicating that the node i will not input the products to node j. When the variable x is 1, indicating that the node i will input the products to node j. Similarly, by setting a variable node y_{ij} to show the relationship that node i input its waste to node j, in which y_{ij} is defined as 0 or 1.

The weights includes out-weight and in-weight. Out-weight refers to the sum of products and by-products (waste and garbage generated in the production of products) of the node want to output to all other nodes, the out-weight indicated by w_{i-out}, In-weight refers to the sum of the node receives products and by-products from all other nodes, which indicated by w_{i-in}. Obviously, the out-weight and the in-weight both include products and by-products.

As for the node i, the products of node i are defined as p_i and the by-products are defined as sp_i. Then the output that the from node i to node j could be defined as $x_{ij}p_{ij} + y_{ij}sp_{ij}$. So sum of output is the following formula:

$$OUT_i = y_{ij}sp_i + x_{ij}p_i = \sum_{j=1}^{n} \left(y_{ij}sp_{ij} + x_{ij}p_{ij} \right) \tag{76.5}$$

Similarly, the sum of input that from node i to node j could be defined as:

$$IN_i = \sum_{j=1}^{n} \left(y_{ji}sp_{ji} + x_{ji}p_{ji} \right) \tag{76.6}$$

There will get the following balance relationship under the condition that takes no account of product time of node produces products:

$$OUT_I = IN_I \tag{76.7}$$

Namely, it's equal that:

$$\begin{aligned} y_{ij}sp_i + x_{ij}p_i &= \sum_{j=1}^{n} \left(y_{ij}sp_{ij} + x_{ij}p_{ij} \right) \\ &= \sum_{j=1}^{n} y_{ji}sp_{ji} + \sum_{j=1}^{n} x_{ji}p_{ji} = \sum_{j=1}^{n} \left(y_{ji}sp_{ji} + x_{ji}p_{ji} \right) \end{aligned} \tag{76.8}$$

It can assume that all nodes (enterprises) will not produce by-products in the production course (Zhang Jianyi 2011), and then the balance relationship of the node i could be change to:

$$OUT_i = \sum_{j=1}^{n} x_{ij}p_{ij} = \sum_{j=1}^{n} x_{ji}p_{ji} = IN_i \tag{76.9}$$

Based on the mentioned three aspects and we can get the model of eco-industrial symbiosis system, as the following Fig. 76.3:

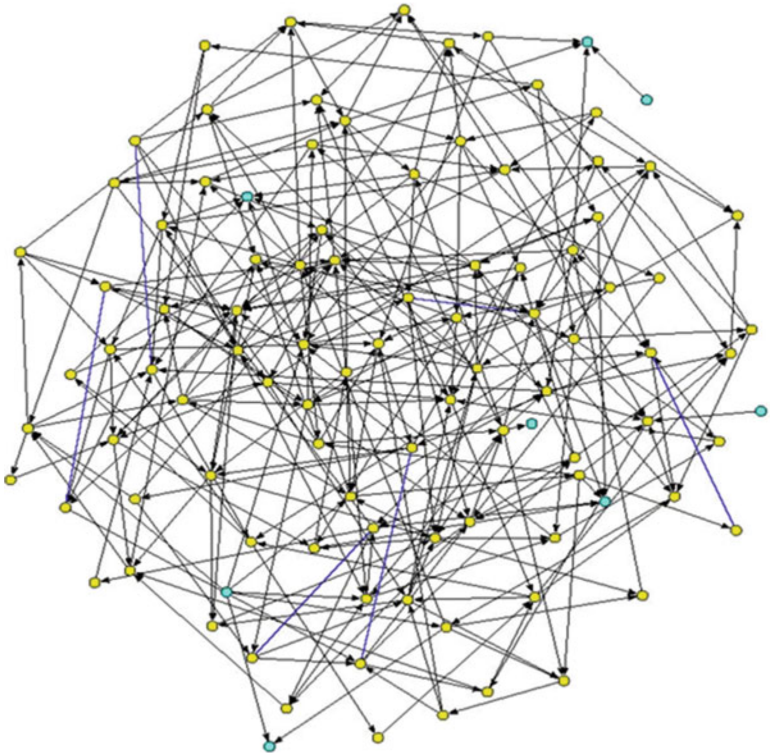

Fig. 76.3 Model of eco-industrial symbiosis network

Example Analysis

Modeling

Because the model is a theoretical model (Liu Guangwei and Zhao Tao 2011; Wu Di and Wu Chunyou 2011), at present, it is hard to find a good case in the existing eco-industrial symbiosis system. In order to illustrate the application of eco-industrial symbiosis network model, where assume there are five nodes in the eco-industrial symbiosis system and give the following assumptions:

1. There are not external factors to affect eco-industrial symbiosis system.
2. Self-sufficient mode of production. The system does not accept the production of raw materials from outside the system, while the products are not input to the external system.
3. The structure of the system is stable and the changes of the structure system under no consideration, namely, the product type and quantity of production is not changed.
4. Take into no account of changing in technology.
5. The products of the production is united, there is no need to convert the unit.

Table 76.1 Relevance of amount of substance among the enterprise in eco-industrial symbiosis network S

	Raw material		Production			
Enterprise	Type	Supply	Type	Output	"By-Production"	
A	B1	20	A1	25	a1	10
	b1	10				
	C1	10	A2	15		
	E1	10				
B	D1	20	B1	30	b1	10
	c1	20				
C	A1	25	C1	10	c1	20
	E3	5				
D	a1	10	D1	20	d1	15
	E2	25				
E	A2	15	E1	10	0	
	B1	10	E2	25		
	d1	15	E3	5		

Five nodes, it assumes that there are five nodes represent respectively enterprise A, B, C, D, E. A produces two kinds of products A_1 and A_2, the by-products is a_1; B produces two kinds of products B_1 and B_2, the by-products is b_1; C produces two kinds of products C_1 and C_2, the by-products is c_1; D produces two kinds of products D_1 and D_2, the by-products is d_1; E produces two kinds of products E_1 and E_2, the by-products is e_1. The number of products and material supply relationships are showed in the Table 76.1.

According to the number of products and material supply relationships in the production of all enterprises in the eco-industrial symbiosis system S is given in Table 76.1, the eco-industrial symbiosis model can be got as shown in Fig. 76.4.

Model Analysis

Based on the formula (76.1) we can get the degree of the nodes in eco-industrial symbiosis system S, namely, each node A, B, and C and D and E can degrees respectively, which are 6, 4, 5, 5, 6. According to the formula (76.2), (76.3), and (76.4) we can get the core nodes are node A and node E in the eco-industrial symbiosis system S. If we remove the node A or node E, the eco-industrial symbiosis system will undergo large changes. However, the eco-industrial symbiosis system itself has little nodes and every degree of node has little difference, therefore, the role of the core nodes in the system are not obvious enough, and the core node is the same with the other nodes that remove any node will have big impact the whole system.

Based on the formula (76.5) to solve the total output of the node A is 50; based on the formula (76.6) to obtain the total input of the A is 50. Taking the total input and total output of node A into the formula (76.7) and (76.8), the equation is set up.

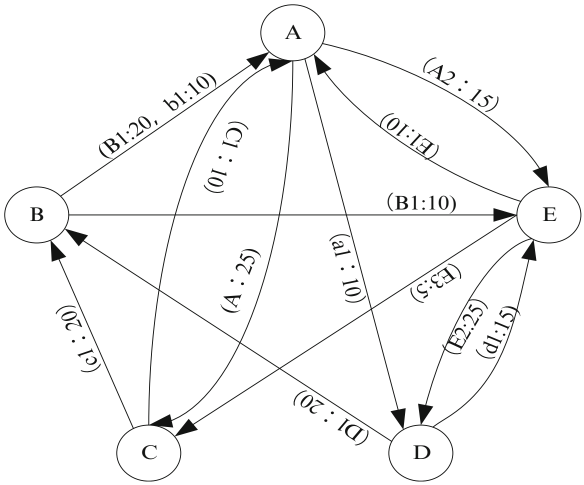

Fig. 76.4 Model of eco-industrial symbiosis network S

Similarly, taking the total input and total output of node B, C and D into the Eqs. (76.7) and (76.8), equations are set up. The node E also satisfy the formula (76.7) and (76.8), but what the E outputs are all the manufactured products without by-product, which is equivalent to the role of waste recycling and processing enterprises in the real eco-industrial symbiosis the system. But the waste recycling enterprises could generate the ultimate waste, in this paper it will not be considered in this system.

Conclusion

This paper gives an introduction to the problems brought up by in the tradition of industrial production and leads to the great significance to build eco-industrial symbiosis system and does an analysis of development pattern of eco-industrial symbiosis system (Fig. 76.1); and gives an introduction of complex network and analyzes its theoretical content and methods (Fig. 76.2); and node do an analysis and construction of eco-industrial symbiosis system from three aspects that are node, degree and weight (Fig. 76.3) and focus on the degree and weight. This paper focus on the balance relationship between input and output among enterprises, and constructs a virtual eco-industrial symbiosis system in order to does an empirical analysis of the contents of this study and to prove the feasibility of this study, the conclusion has a guiding significance for eco-industrial symbiosis system.

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