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The index system for project selection in ecological industrial park: A China study

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ABSTRACT

It is critical to extend and broaden the eco-industrial chain (*EIC*) by introducing new projects so that the stability of *EIC* network can be enhanced. At present, there is lack of effective control for project selection to eco-industrial park (*EIPs*) in China. This has led to low compatibility level of enterprises with the overall *EIC* network. By introducing the admission composite index, a framework is proposed in this study to assist the project selection in *EIPs*. It consists of three layers, i.e. target, criterion and variable. The preliminary index database is synthesized and simplified with Fuzzy Clustering Analysis (*FCA*). Fuzzy Analytic Hierarchy Process (*FAHP*) was employed to determine the weighting of each indicator. On the basis of the evaluation criteria, the evaluation method of the index system under two different conditions were established. This enriches the theory and methodology of ecological industry development in China. Meanwhile, the index system is effectively verified via an empirical case study. Results show that the index system is feasible, and quantitative results are consistent with the practice. These findings provide a good practical reference for the decision making of project selection in *EIPs*.

1. Introduction

The concept of *EIPs* was introduced by Lowe of Indigo Development Institute of the United States in 1992. Since then, *EIPs* development has achieved rapid development. Kalunborg is the first ecological industrial park over the world. Similarly, *EIPs* gained rapid growth in China. To date, 51 state-level *EIPs* have been built in China, and 82 state-level EIPs are under construction (Ministry of Environmental Protection of China, 2015). *EIPs* have become an effective way for China to transform the economic development mode and adjust the industrial structure towards sustainable development (Ministry of Environmental Protection of China, 2016). However, compared with developed countries, there is lack of corresponding theories to support the development of *EIPs* in China (Wang et al., 2016b). As a result, various issues exist due to the lack of overall planning for the development of industrial parks as well as the low symbiotic efficiency between enterprises. In addition, pollution control still remains at the corporate level (Wang and Wang 2010; Yu et al., 2014; Yuan et al., 2015). In particular, there is lack of effective control of the project selection for *EIPs*. As a result, existing enterprises do not match with newly-introduced enterprises very well from the industry chain perspective. Meanwhile, some projects even failed to meet the consistency requirement of function division in the ecological park. This is mainly because much attention was paid to economic indicators and environmental requirements for those newly-introduced enterprises whereas the long-term planning for the acceptance of park is largely overlooked (Zhu et al., 2010). This calls for a timely study to develop framework and methodology for project selection in *EIPs*. This helps to guide the sustainable innovation and development of *EIPs*.

With the development of *EIPs*, some studies have been carried out in this field. Robert and Nicholas (1989) discussed the characteristics of industrial ecosystem from different aspects such as energy efficiency and waste management, which laid the foundation for the development of *EIPs* index evaluation. David and Pauline (2005) argued that *EIPs* indicators include networking, resource recycling, clean production, industrial agglomeration,

Abbreviations: *EIC*, eco-industrial chain; *FCA*, Fuzzy Clustering Analysis; *EIP*, eco-industrial park; *FAHP*, Fuzzy Analytic Hierarchy Process.

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green design, core tenant, etc. Lowe and Evans (1995) argued that the evaluation index of *EIPs* can be divided into economic benefits, environmental benefits and social benefits, etc. Zhao et al. (2016) applied the MCDM approach to evaluate the comprehensive benefit of *EIPs* from the perspective of circular economy. Azapagic and Perdan (2000) suggested that there were four main aspects for the evaluating the sustainable development of *EIPs*: economy, society, ecology and technology. Valenzuela-Venegas et al. (2016) reviewed more than 200 sustainable indicators to evaluate the *EIPs*. Some scholars proposed the evaluation index system of *EIPs* which covers the park location, degree of resource recycling, public participation degree (Audra and Potts, 1998; Roberts, 2004; Oh et al., 2005). These index systems mainly focused on the sustainable development capacity, ecological efficiency and comprehensive development level evaluation of *EIPs*. There are few researches on the enterprise selection index. For example, Chertow (2003) proposed the evaluation criteria of *EIPs* project, i.e. the effective sharing of resources, improving the economic efficiency and environmental quality, and strengthening the management of human resources in business community and local community. Li and Xiao (2017) believed the important degree of node considering ecological factor is a more crucial index measuring the importance of a particular node in the network. There are also some studies in the Chinese context (Zhang et al., 2004; Ma, 2005; Cao et al., 2006; Wang and Li, 2007). Common methods used to develop the evaluation index system include the Comprehensive Evaluation Index method (Department of Economic, 2001; Huang, 2015), Delphi method (Anna and Francesc, 2014), Analytic Hierarchy Process method (Azarnivand and Chitsaz, 2015), Fuzzy Comprehensive Evaluation method (Cao et al., 2006), Principal Component Analysis method (Wang et al., 2013), Entropy Weight Coefficient method (Wang et al., 2012; Wang et al., 2015), etc. The above mentioned methodology laid a good foundation for this study. The importance of project access control for *EIPs* development has gained growing level of awareness. However, much attention is paid to the constraints of economic and environmental conditions. By contrast, there is lack of studies on the compatibility between industrial chains and the introduced enterprises. This study contributes to the existing body of knowledge by proposing a methodology to assist the project selection in *EIP*s. This methodology is based on *FCA* and *FAHP*. Such methodology helps to minimize the uncertainties during the process of index selection and weight determination. This study provides useful references for the decision making process of future *EIPs* developments.

2. Developing the index system

2.1. Framework of the index system

The framework of index system is a structural framework, which is based on the complex logic relation between the different indicators. There are mainly two components: the design of the framework and determining the number of layers. The purpose of developing project selection index system is to ensure the sustainable development of *EIPs*. Therefore, the evaluation index systems of the five representative sustainable development models (Research Group on sustainable development strategy of Chinese Academy of Sciences, 2014; Valenzuela-Venegas et al., 2016) were adapted with a consideration of specific assessment indicators of national *EIPs* (Ministry of Environmental Protection of China, 2016). Three layers are defined in this framework, i.e. target layer, criterion layer and variable layer. The third layer index is variable indicators, i.e. disaggregating the indicators of the criterion layer (see Fig. 1).

The second layer indicators in the framework are divided into two categories: one for the park, and the other for enterprises. The former category mainly emphasizes the matching of the project to the industrial chain, the park's carrying capacity, and the ecological planning and design of park. The second category mainly emphasizes on the requirements of environmental protection, economic benefit, resource utilization, and scientific and technological innovation. The concept of "admission control comprehensive index" is introduced. It represents the evaluation outcome of the candidate project. The value of this index is closely related to the impacts of this candidate project on the park.

2.2. Index system screening

2.2.1. Preliminary screening of indicators

The preliminary screening of indicators is based on the goal and framework structure of the index system. It is necessary to select and design all the indicators that can affect the goal, and to set up a preliminary index database. It is mainly composed of circular economy, ecological system, sustainable development and investment in *EIPs.* The following three methods are adopted for the selection of indicators. Firstly, frequency statistics is used to identify the high frequency indicators used in previous studies. Secondly, the specific indicators that have clear contents are selected with the Delphi method. Thirdly, the related environmental protection standards were critically reviewed.

2.2.2. Finalizing the index system

FCA is a kind of analysis method, which is based on fuzzy similarity relation to objective things (Leekwijck and Kerre, 1999). Fuzzy mathematics method is adopted in this study to carry out the quantification analysis of the fuzzy relation between samples, in order to achieve the objective and accurate clustering. At present, *FCA* method has been successfully applied in the field of society, and it is well recognized as one of effective methods to refine indicators (Khoshnevisan et al., 2015; Yazdi, 2015; Bai et al., 2016; Zhu and Pan, 2016). According to screening results, numerous indicators are identified which formed the preliminary index database. Therefore, the fuzziness of index system is relatively stronger. *FCA* method is employed to synthesize and simplify this index system.

The process of *FCA* is as follows:

(1) The m cluster object is evaluated by n index, and a m × n matrix is formed.

$$x = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (1)$$

Among them, x_{mn} represents the original data of the n index of the m object clustered.

(2) All the original data were standardized with the transformation of translation standard deviation. And then the new matrix is achieved, as shown in Eq.(2).