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Evaluating the comprehensive benefit of eco-industrial parks by employing multi-criteria decision making approach for circular economy

Haoran Zhao, Huiru Zhao, Sen Guo*

School of Economics and Management, North China Electric Power University, Beijing 102206, China

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ABSTRACT

With the increasing conflicts among economic growth, environmental deterioration, and resource shortage, as an effective way to achieve the sustainable development and circular economy, the eco-industrial park gradually becomes a critical research issue in the field of recycling economy. In this paper, a hybrid framework for evaluating the comprehensive benefit of eco-industrial parks from the perspective of circular economy was proposed. Firstly, the evaluation index system for eco-industrial parks was constructed by employing the grey-Delphi method according to the opinions provided by experts from relevant fields, which includes economic benefit criteria, social benefit criteria, environmental benefit criteria, ecology industry construction criteria, and management level criteria, consisting of seventeen quantitative sub-criteria and nine qualitative sub-criteria. Secondly, in order to solve complicated, uncertain and ambiguous problems under the fuzzy background, a hybrid multi-criteria decision making (MCDM) approach was put forward on the basis of superiority linguistic ratings and entropy weight method for weight determination as well as fuzzy-VIKOR for ranking alternatives. Finally, the effectiveness and practicality of the proposed hybrid MCDM approach was demonstrated through a case analysis of six representative eco-industrial parks in China, and the comprehensive benefits of six eco-industrial parks were prioritized effectively. The hybrid MCDM approach in this paper presents a great potential in evaluating and ranking the comprehensive benefits of eco-industrial parks through solving complex and ambiguous problems in a fuzzy environment and varying MCDM tools. The evaluation findings by employing the proposed MCDM approach can provide references for the construction and management of eco-industrial parks and relevant policy formulation.

1. Introduction

Since the first industrial revolution in the middle of the 18th century, the industrial activities promoted the development of productivity to a great degree and created a huge amount of material wealth for human beings. However, excessive industrial production also brought a series of environmental ecological problems, such as the depletion of water and soil resources, greenhouse effect, sharp reduction of biodiversities, as well as fog and haze weather. With the extensive recognition of sustainable development proposed in the International Union for Conservation of Nature (IUCN), a new form of industrial organization on the basis of circular economy, namely eco-industrial parks, emerged as times required and soon received wide attentions throughout the world.

Eco-industrial park is one of the main research fields in industrial ecology, which concentrates on the production processes of goods and services from the perspectives of nature and making every effort to imitate a natural system through conserving and recycling resources (Chertow, 2000; Valenzuela-Venegas et al., 2016). It also researches on the interaction of industrial development with environmental and social systems with various scales and aims at improving business success, protecting environment and considering the life of local community. Eco-industrial parks achieve the overall coordinated and sustainable development in economic benefit, social benefit and environmental benefit through the exchange of by-product and waste, recycling utilization of

* Corresponding author.
E-mail addresses: guosen324@163.com, guosen@ncepu.edu.cn (S. Guo).

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energy and waste water, and infrastructure sharing among the members in the eco-industrial park (Chertow, 2007; Sun et al., 2016). The pioneer of eco-industrial parks is the regional industrial symbiosis in Kalundborg of Denmark where the participants shared fresh water, waste disposal facilities, fuel, by-products and waste products which can be the raw material in other processes (Chertow, 2008). The superiorities of the symbiosis for Kalundborg eco-industrial parks and local community are:

- The dramatic decrease in energy consumption, such as coal, fuel, and water demand.
- The significant reduction in sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions.
- The transformation of conventional waste products including sulfur and fly ash into raw feedstock for other processes.

Some countries have analyzed the development characteristics of eco-industrial parks, such as the United States (Gibbs and Deutz, 2005), Netherlands (Heeres et al., 2004), UK (Mirata, 2004), Japan (Van Berkel et al., 2009), Korea (Park et al., 2008; Behera et al., 2012), Brazil (Veiga and Magrini, 2009) and Egypt (Sakr et al., 2011). Boons et al. (2011). summarized the studies on eco-industrial parks from eight aspects, containing conceptual framework, methodologies, models, quantitative evaluation, etc. Sakr et al. (2011). analyzed the development of eco-industrial parks and obtained key success and limiting factors of eco-industrial parks, such as information sharing and awareness, symbiotic relationship establishment, organization structure, as well as legal and supervision framework.

On the purpose of solving the increasingly serious environment concerns owing to the industrial growth, the Chinese government launched a national representative eco-industrial parks program in 2001 (Shi et al., 2010, 2012; Zhang et al., 2010). After the 12th Five-Year Plan period (2011–2015), nearly 50 national representative eco-industrial parks will be established (Tian et al., 2014). Thus, there exist a large amount of cases for questing eco-industrial parks development in the past ten years (Shi et al., 2012). The studies on Chinese eco-industrial parks development can be classified into three types. The first type described the components of Chinese eco-industrial parks development, including history and administration (Geng et al., 2008; Zhu et al., 2010). The second type primarily contains case studies such as Dalian economic-technological development area, Tianjin economic and technological demonstration area, and Suzhou industrial park (Geng et al., 2008; Zhu et al., 2007; Zhang et al., 2009). The third type focused on the optimization of resource and waste management, such as energy saving (Tian et al., 2012a), material management (Tian et al., 2012b, 2012c), solid waste management (Tiejun, 2010), and eco-efficiency analysis (Yuan et al., 2010; Wang et al., 2006). However, the researches related to the comprehensive benefit of Chinese national representative eco-industrial parks are still relatively insufficient. It is necessary to establish an evaluation system to measure the performance of eco-industrial parks reasonably and effectively, which can provide references for the construction and management of eco-industrial parks and relevant policy formulation. Therefore, this paper assesses the comprehensive benefit of six selected eco-industrial parks in China by employing hybrid multi-criteria decision making (MCDM) approach.

For comprehensive evaluation, three most significant sections are the construction of index system, weighting determination, and evaluation model selection. Lin (Lin and Chen, 2004) took both subjective indicators and objective indicators into account. Yuan (2003) decomposed the evaluation index system into four criteria which contained economy, ecological surroundings, management index and ecological network. Huang (Huang et al., 2005) established the index system including economy criterion, environment criterion, ecology criterion and management criterion, consisting of eighteen sub-criteria. Li (Li et al., 2006) proposed the first-class criteria from four perspectives, which are sustainable development, management criterion, economical attribute and ecological environment criterion. However, the current existing literatures could not reflect the operating law and development situation of eco-industrial parks, and the index systems built in those literatures cannot scientifically mirror the comprehensive benefit of eco-industrial parks. According to the indicators proposed in the document of 'Planning guide for eco-industrial parks', the initial index system was established in this paper. In order to ensure the rationality of index system and the validity of evaluation, the grey-Delphi method was employed to select key and critical indicators on the basis of experts' opinions.

For the evaluation method, Zhang (Hui, 2011) assessed the performance of eco-industrial parks through employing AHP to determine the index weight and fuzzy comprehensive assessment model for ranking, which could overcome the shortage of present researches on the basis of qualitative description. Lei (Ming, 2010) evaluated the comprehensive benefit of nine representative eco-industrial parks in China employing AHP, fuzzy math approach, and modern comprehensive evaluation method. From present literatures, it can be known that some common comprehensive evaluation methods, such as TOPSIS, ELECTRE, and grey relational analysis which are widely used in supplier selection (Shemshadi et al., 2011), renewable energy external benefit evaluation (Zhao and Guo, 2015), and the evaluation of thermal power enterprises performance (Zhao and Li, 2015), have rarely been used in the evaluation of eco-industrial parks. Meanwhile, some new MCDM methods have also been employed in comprehensive assessment issues nowadays. Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method, proposed by Opricovic S (Opricovic, 1998) in 1998 at the aim of optimizing multi-criteria of complex systems, takes the balance between the whole and individual satisfaction into account, and introduces decision strategy variables to make the decision more reasonable (Opricovic and Tzeng, 2002). Considering the complexity of eco-industrial parks and the diversity of evaluation indicators including subjective and objective indicators, a hybrid MCDM approach was proposed in this paper which uses the superiority linguistic ratings and entropy weighting method for index weight determination and fuzzy-VIKOR evaluation model for ranking all alternatives.

The primary contribution of this paper is the establishment of a framework for assessing the comprehensive benefit of eco-industrial parks from the perspective of circular economy. In order to promote the development of circular economy, the index system is determined according to the grey-Delphi method which not only considers the regular factors but also takes the opinions of experts into account. On this basis, the evaluation model is derived based on superiority linguistic ratings and entropy weighting method as well as fuzzy-VIKOR method which can solve complicated, uncertain and ambiguous problems in real world.

The remainder of this paper is organized as follows. The comprehensive benefit evaluation index system is established in Section 2. Section 3 introduces the basic theory of the hybrid MCDM approach. The conceptual framework of the proposed model is given in Section 4. An empirical analysis is illustrated in Section 5 through performing the evaluation on six representative eco-industrial parks in China. Result discussion and policy implication are given in Section 6. Section 7 draws the conclusions.

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