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The circular transformation of chemical industrial parks: An integrated evaluation framework and 20 cases in China

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ABSTRACT

It is a challenging task to evaluate the ecological progress of chemical industrial parks (CIPs) due to their complexity and diversity. By combining qualitative and quantitative evaluations, we have constructed an integrated evaluation framework. The qualitative evaluation was based on observations of the coevolution of the parks' three core elements, which are the industrial chain system, the infrastructure system, and the management system. We identified the development stages of the parks by investigating the degree towards attaining ideal conditions and the correlation of the CIPs' three core elements. We based the quantitative evaluation on the ranking of the ecological performance of the CIPs by considering 15 indicators and using principal component analysis. Combining qualitative and quantitative evaluations, we ranked the ecological progress of China's 20 CIPs. Our work can be used to formulate national evaluation standards of CIPs, promote the scientific evaluation and management of CIPs, and advance the progress of the construction of ecological civilization in China.

1. Introduction

Over the past years, China has become known as "factory to the world" through its rapid industrial development. With a massive accumulation of material wealth, however, China also has encountered ever-growing resource and environmental problems. To address these problems, China began to take measures under the umbrella policies of ecological civilization and circular economy, including eco-industrial park (EIP) pilot projects and circular transformation at the industrial park level. A series of pilot, demonstration, and evaluation studies have been carried out since the turn of this century (Bai et al., 2014; Geng et al., 2007; Shi and Yu, 2014; Zhang et al., 2010).

Among these pilot projects, chemical industrial parks (CIPs) are heavily stressed because of their high environmental burdens and risks. As early as 2000, with support from Tsinghua University, a CIP located in Quzhou City in Zhejiang Province carried out the first EIP project. In the following years, more CIPs joined this list, including in the cities of Lubei, Shanghai, Zhangjiagang, and Weifang. This experimentation has significantly improved environmental performance and competitive advantage. Many existing CIPs, however, have not yet gone through EIP upgrading or circular transforming. As a result, in recent years, China's central and regional governments have issued some regulations to speed up the transformations, all of which stressed the importance of establishing evaluation methodology to set standards or guidelines.

There are both qualitative and quantitative ways (Bai et al., 2014) to measure the ecological progress of the CIPs. At present, researchers mainly adopt the quantitative approach because of its convenience and apparent objectivity, and several evaluation index systems and evaluation methods have been developed (Azapagic and Perdan, 2000).

Jung et al. (2013) evaluated the economic, environmental, and social performances of 18 commercialized pilot projects within five EIP regions in South Korea. The discounted cash flow method was used to evaluate economic performance. The multi-attribute global inference of a quality method was used for environmental and social evaluations.

Tian et al. (2014) adopted a quasi-gray-box model to evaluate the economic and environmental performances of 17 accredited

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Abbreviations

AP	Air products
AR grade	Analytical reagent grade
BCDMH	1-Bromo-3-chloro-5,5-dimethylhydantoin
BIIR	Bromobutyl rubber
BR	Butadiene rubber
C4	Carbon 4
CIIR	Chlorinated butyl rubber
CIP	Chemical industrial park
COD	Chemical oxygen demand
CPCIF	China Petroleum and Chemical Industry Federation
EG	Ethylene glycol
EIP	Eco-industrial park
EO	Ethylene oxide
GIOV	Gross industrial output value
HNBR	Hydrogenated nitrile rubber
IAV	Industrial added value
IIR	Butyl rubber
Jiaxing Park	Jiaxing Advanced Chemical Material Park
MEE	Ministry of Ecology and Environment
MEP	Ministry of Environmental Protection
MES	Methyl ester sulfonate
MF	Ministry of Finance
MIIT	Ministry of Industry and Information Technology
MTG	Methanol to gasoline
MTHPA	Methyl tetrahydrophthalic anhydride
MTO	Methanol to olefins
NDRC	National Development and Reform Commission
NG	Natural gas
NOx	Nitrogen oxides
PA	Phthalic anhydride
PBED	Polybutylene ether diol
PC	Polycarbonate
PP	Polypropylene
PTA	Pure terephthalic acid
PX	Para-xylene
SEPA	State Environmental Protection Administration
Shanghai Park	Shanghai Chemical Industrial Park
SLES	Sodium alcohol ether sulphate
SO_2	Sulfur dioxide
TEAL	Triethylaluminum
VOCs	Volatile organic compounds
WWTP	Waste water treatment plant

sector-integrated national demonstration EIPs. The indexes included industrial added value (IAV), ratio of the secondary development and tertiary industry, IAV per capita, IAV per area of industrial land, energy consumption per IAV, fresh water consumption per IAV, industrial wastewater generation per IAV, solid waste generation per IAV, chemical oxygen demand (COD) emissions per IAV, and sulfur dioxide (SO_2) emissions per IAV. They further pointed out that cleaner production, infrastructure sharing, and energy-saving practices at firm level and industrial symbiosis are key measures supporting performance improvements of EIPs.

Valenzuela-Venegas et al. (2016) reviewed the indicators used to measure the sustainable development levels of EIPs. They conducted a literature search in ISI Web of Science's database to explore feasible indicators and 249 indicators were provided. These indicators were classified into social, economic, and environmental dimensions. At the same time, to deal with the difficulty in selecting a proper subset, they proposed four criteria: understanding, pragmatism, relevance, and partial representation of sustainability.

In addition to the quasi-gray-box and the multi-attribute global inference of quality methods, commonly used evaluation methods include analytic hierarchy process (Saaty, 1988; Vaidya and Kumar, 2006), gray clustering method (Chang and Yeh, 2005), fuzzy comprehensive evaluation method (Zhang and Li, 2002), emergy evaluation (Liu et al., 2016; Wang et al., 2006), and principal component analysis (Ho and Wu, 2009; Wang and Du, 2000).

These practices, however, show that index systems are not always open to interpretation as they also can provide values that differ according to experts' opinions and countries' policies (Jung et al., 2013). Moreover, the existing evaluation index systems and methodologies have several limitations, such as being overly rigid, placing too much emphasis on ecological performance evaluation while ignoring core elements and not sufficiently tracking the ecological progress of the parks. In terms of pollution control indicators, only four conventional pollutants, namely, COD, ammonia nitrogen, SO_2, and nitrogen oxides (NOx), are adopted whereas the characteristic pollutants of CIPs, such as volatile organic compounds (VOCs) are excluded. In addition, taking a “one-size-fits-all” approach is common in practice even though this ignores the diversity and complexity of the CIPs (Geng et al., 2008). This has led to dissatisfaction of many related institutions and chemical enterprises. To achieve good rankings and to obtain titles and grants, some parks work hard on individual indicators. Therefore, excessive emphasis on quantitative evaluation may essentially hinder the ecological process of the parks (Geng et al., 2009).

To overcome these disadvantages, we have established an evaluation framework that combines qualitative and quantitative evaluations and have taken 20 CIPs in China as an example.

The rest of this paper is organized as follows. Section 2 outlines the development and environmental regulation of the chemical industry and CIPs in China. Section 3 illustrates our evaluation methodology of CIPs' ecological progress. Section 4 takes the China Jiaxing Advanced Chemical Material Park (Jiaxing Park) as an example to illustrate that the development of CIPs are strictly timed sequentially and can be divided into several stages. Section 5 discusses the evaluation results of the 20 CIPs in China. Section 6 presents the conclusions and policy implications.

2. An overview of the chemical industry and chemical industrial parks in China

2.1. The development of the chemical industry

After decades of rapid development, China has established the world's largest chemical industrial system. As shown in Fig. 1, the gross industrial output value (GIOV) of China's chemical industry began to exceed that of the United States in 2010 (Statista, 2017; Yearbook, 2006–2016). In 2015, the industrial output of the chemical industry of China reached US$1780.9 billion, which was almost twice that of the United States and ranked first in China's 36 industrial sectors.

2.2. Chemical industrial parks in China

In 2015, according to a national survey conducted by China Petroleum and Chemical Industry Federation (CPCIF), China had total 502 CIPs. At three administrative levels, the number of CIPs was state, 47; provincial, 262; and municipal, 193. The geographical