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Emergy evaluation of an industrial park in Sichuan Province, China: A modified emergy approach and its application

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ABSTRACT

China's industrial parks have made great contributions to its economic growth with their rapid development. However, the resources and environment related issues have been challenging their sustainability to different degree. There still exist the following challenges in evaluating the sustainability of industrial systems due to the existing researches ignoring one or more related issues, including (1) ignorance of ecosystem's contributions to industrial activities, (2) neglect of quality differences between different resources, energies and labors, (3) involving subjectivity of human, (4) inadequate consideration of emissions' impact, and (5) lacking consideration on recycling and reuse benefit derived from industrial symbiosis. Therefore, they are isolated to some degree and lack completeness and systematization. This study aimed to deal with the five issues by adopting classic EA (emergy analysis) method (Overcoming issues 1–3.), quantifying emissions' impact in terms of emergy with some modified parameters (Addressing issue 4.) and proposing indicators to evaluating recycling and reuse benefit (Focusing on issue 5.). Then one proposed emergy method and the related indicator system for assessing the sustainability of industrial parks were set up. Next, an industrial park in Sichuan, China, as a case, was research using the proposed method and indicator system. The study results show that, according to the classic emergy based indicators, this industrial park has relatively high economic competition ability (EYR = 1.14), relatively low environmental press (ELR = 29.31), and relatively strong sustainability (ESI = 0.0388) compared to other industrial parks in China. However, its low economic efficiency and low wastes recycling/reuse degree still seriously challenge its sustainability with the local mineral resources exhaustion in the future. In terms of modified emergy indicators, emissions' impact further raises its environmental load by 3.42% and reduces its sustainability level by 2.70%. Finally, some corresponding suggestions are put forward.

1. Introduction

Industrial parks integrate traditionally single industrial enterprises into an organic whole through physical exchanges of materials, energy, water and by-products so as to strengthen their comprehensive performance (Martin et al., 1996; Chertow, 2007.). Companies in an industrial park can benefit from economies of scale in terms of construction, land development and common facilities by grouping various types of industrial activities within one designated area (Geng et al., 2014). In recent years, over 6, 000 industrial parks have been operated in China, including high-tech zones, national economic and technological development zones and export processing zones (Song et al., 2014). In addition, more than 1500 industrial parks were approved by national and provincial governments, whose output value accounts for more than 60% of all the gross industrial output value (Wen and Meng, 2015). However, the related environmental problems, such as air pollution, water contamination, solid wastes, and noise have been also increasingly concerned with the rapid development of China's industrial parks (Geng et al., 2014).

Therefore, it is urgent to call for a comprehensive method to measure the sustainability of industrial parks. A lot of works have been carried out to evaluate the comprehensive performance of Chinese industrial parks. Therein, some of them were mainly based on material flow analysis (Geng et al., 2014), including Standard for National Demonstration Eco-industrial Parks (HJ247-2015) by

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Ministry of Environmental Protection of the People's Republic of China (2015), National Circular Economy Industrial Park Indicators by National Development and Reform Commission and National Low-carbon Industrial Park Indicators by Ministry of Industry and Information Technology (Liu et al., 2016b; Geng et al., 2012); others were derived from LCA (life cycle assessment) (Liu et al., 2011a; Tong et al., 2013), economic analysis (Zhang et al., 2009a), and energy analysis (Tian et al., 2012; Yan and Chien, 2013). However, material flow analysis and energy analysis does not recognize the differences between all kinds of energy resources, and flows of different energies, materials and services are usually not comparable due to their different functions (Pan et al., 2016); the results of LCA depend on human preferences to some degree (Pan et al., 2016); economic analysis method relies on artificial markets or shadow pricing, which makes its results inevitably subjective. Furthermore, all those evaluation methods above mentioned ignore ecosystem's contribution to economic activities. Such incomplete assessments may encourage the optimization of one individual resource and mislead the policy makers to pay less attention to appropriate environmental management (Geng et al., 2014). It has been proposed that economic and ecological systems should be linked together so that ecological products and services are accounted for in commercial markets, and then sustainable management becomes a prerequisite for economic sustainability (Barrett and Scott, 2001). Therefore, it is very necessary to develop innovative indicators to evaluate industrial parks from a systematic point.

In this regard, EA (emergy analysis) method, a systematic analysis method found by Odum (1988, 1996), incorporates environmental services into an integrated system analysis and makes quality differences between diverse resources (Zhang et al., 2014a,b), and emergy is a universal measure of real wealth of the work of nature and society based on a common unit (solar energy joule), which can avoids subjectivity theoretically. Especially this approach can evaluate the externalities of industrial activities (e.g., natural inputs, environmental impacts), which may be neglected in traditional economic analysis (Taskhiri et al., 2011). Calculations of emergy production and storage provide a basis for the general public policy-making related to environment and economy so as to maximize real wealth, production and use (maximum empower) (Odum, 2000). In addition, EA can act as one complementary method to other methods due to providing additional information that others cannot address (Geng et al., 2014). Due to these advantages over other related assessment methods, EA has been applied to exploration of the sustainability of different types of industrial parks (Wang et al., 2006a; Geng et al., 2010; Taskhiri et al., 2011; Liu et al., 2014a; Geng et al., 2014; He et al., 2015). Due to differences of industrial parks' categories and focus of attention, the specific emergy indicator systems and descriptive tools alter from one case study to another, but generally they all adhere to the classic EA approach framework and procedure. And these works show the vitality of EA in evaluation of industrial parks' sustainability. However, these researches have not quantified emissions' impact on environment, economy and human health, which is an integral feature of many industrial systems (Bakshi, 2002.); meanwhile, the purchased inputs should be also further divided into renewable and nonrenewable types so as to appropriately address the sustainability of industrial parks. And this shows the limitation of classic EA due to ignorance of waste management and characteristics of purchased inputs. As pointed out by Ulgiati et al. (1995), emissions' impact should not be ignored in emergy evaluation of ecological economic systems because the impact of emissions from human-dominated systems requires environmental services to mitigate or eliminate the damage so as to keep systems' sustainability. In this circumstance, some scholars have attempted to quantify emissions' impacts in terms of emergy when implementing emergy evaluation of industrial production systems. Therein, Ulgiati and Brown (2002) calculated the additional emergy of the environmental services for diluting emissions, but emissions' impacts on economy and human health have been ignored. Bakshi (2002) pointed out eco-indicator 99 approach can assesses the impact of emissions on human beings and ecosystems, but he did not integrated it into EA yet. Yang et al. (2003) considered the impact of wastes and proposed improved EA for evaluating industrial systems; however, ecological services and economic loss caused by discharged wastes have not been addressed. Ukidwe and Bakshi (2007) employed DALYs (disability adjusted life years) approach to quantify emissions' impacts on human health; however, they didn't consider the ecosystem services needed for diluting emissions. Janga (2007) presented an emergy based method to correlate environmental pollution and land use activities with birth defects, and DALYs per Kilogram of emission is used in the chemical emergy calculation, besides unavailable DALY factors were computed by using the Human Toxicity Potential (HTP) values; however, the related ecological services required to eliminate emissions' impact have not been considered. Zhelev (2007) pointed out the combined emergy pinch analysis can quantify the environmental role in disposing pollution, with a specific emphasis on the environmental impact evaluation of process integration activities; however, they did not put forward the specific method for quantifying the environmental role. Mu et al. (2011) improved emergy indices for the evaluation of industrial systems through incorporating waste management and they proposed a simple impact amplification factor for inclusion in the improved emergy indicators; however, the amplification parameter λ they used did not quantify emissions' impacts precisely. Several scholars (Zhang et al., 2009b, 2010, 2011, 2012, 2014a,b; Hu et al., 2014; Liu et al., 2014b) proposed improved emergy-based indicators by integrating dilution method, disability adjusted life years (DALY) method and ecological cumulative exergy consumption (ECEC) method into emergy analysis; however, ECEC method's parameters still need the related revision when being applied in specific countries or districts (Pan et al., 2016). Campbell et al. (2014) estimated the emergy carried by the flows of biologically active elements (BAE) and compounds, and they thought that their work is needed to accurately evaluate the near and far-field effects of anthropogenic wastes. However, the carried emergy is the total energy cost of these outputs spent on biologically active elements (BAE) and compounds. And it still needs to clarify the interrelationships between the carried emergy and effects of anthropogenic wastes.

In a word, there still exist the following challenges in evaluating the sustainability of industrial systems, including (1) ignorance of ecosystem's contributions to industrial activities, (2) neglect of quality differences between different resources, energies and labors, (3) involving subjectivity of human, (4) inadequate consideration of emissions' impact, and (5) lacking consideration on recycling and reuse benefit derived from industrial symbiosis. These existing researches have addressed these issues partly, but they are incomplete to some degree and lack systematization. This study aimed to deal with the five issues by adopting classic EA method (Overcoming issues (1)–(3).), quantifying emissions' impact in terms of emergy with some modified parameters (Addressing issue (4).) and proposing indicators to evaluating recycling and reuse benefit (Focusing on issue (5).). Then one proposed emergy method and the related indicator system for assessing the sustainability of industrial parks were set up. An industrial park in a city of Sichuan Province, China, as a case, was studied using the proposed method and indicators, so as to provide some beneficial suggestions for the decision-makers. And the other