Resources, Conservation & Recycling 125 (2017) 293–299

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

A modified ecological footprint method to evaluate environmental impacts of industrial parks

Yupeng Fan[a], Qi Qiao[a,*], Chaofan Xian[b], Yang Xiao[b], Lin Fang[a]

[a] Key Laboratory of Eco-Industry of the Ministry of Environmental Protection, Chinese Research Academy of Environmental Sciences, Beijing, 100012, China
[b] Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, 100085, China

ARTICLE INFO

Keywords:
Industrial park
Ecological footprint
Ecological capacity
Eco-industrial development
Sustainability
Environmental impact

ABSTRACT

Industrial parks have been playing a crucial role on driving regional economic development, but also been exerting significant impacts on natural ecosystems due to intensive resource consumption and waste emission. Ecological footprint method is a tool for analyzing the impact of human activities on environment, which has been applied in many fields. Most of the researches applying ecological footprint are conducted on large-scale objects, such as nation and globe. The ecological footprint analysis on the scale of the industrial park, however, is limited. This paper presents a modified ecological footprint accounting model, and applies it to appraise the environmental impact of an industrial park-Hefei economic and technological development area. Results show that the ecological footprint (8.87E+05 gha (global hectares)) far exceeds the ecological capacity (4.82E+04 gha), meaning that the ecological footprint is 18.4 times of the ecological capacity in the study park. In addition, the ecological footprint reduction caused by eco-industrial development in the study industrial park is quantified by ecological footprint model. The ecological footprint has been reduced by 15.9%, from 1.06E+06 gha to 8.87E+05 gha, which signifies an obvious environmental performance and economic benefits. Based on this study, the utilization of energy and material could be optimized in industrial park to reduce the influence of industrial activities on natural ecosystem. This paper provides a basis for an industrial park's environmental management and decision making.

1. Introduction

Among various human activities promoting economic growth in China, industrial parks are themajor contributor. In the past 30 years, China established more than 2000 industrial parks, which accounted for more than 60% of gross national industrial output value and more than 50% of GDP (Bao, 2013). In 2014, the GDP growth rate of industrial parks, 29.1%, prominently surpassed that of the national average, 7.4% (CADZ, 2014). Industrial parks play an important role in driving the regional economy, but it has a huge impact on natural environment due to intensive industrial activities. It is very important for industrial parks' sustainable development to assess the environmental impact caused by resource consumption and waste emissions.

Market prices or other monetary appraisal methods are untrustworthy ways for indicating the long-term viability of ecosystems that provide goods and services such as topsoil evolution, climate-related security, biodiversity, fuel, and feed. The ecological footprint (EF) measures demands for natural resources and pressures on ecosystems (Wackernagel and Rees, 1998). As an effective assessment tool, ecological footprint can measure human's resources throughput and evaluate the actual depletion of natural resources, and thus appraise the gap between humanity's demand and natural services supply (Van Kooten and Bulte, 2000).

The original EF concept, introduced by Rees (1992), is that every individual, process, activity, and region has an impact on the Earth, via resource usage, waste generation and the use of services provided by nature. These impacts can be converted to biologically productive area which can be quantified. Ecological footprint signifies the land area required to maintain present levels of resource consumption and waste discharge by a given population. It provides an intuitive framework for understanding the ecological bottom-line of sustainability, and then stimulates public debate, builds common understanding, and suggests a scheme for action. Ecological footprint makes the sustainability challenge more transparent—decision makers have a physical criterion for rating policy, project or technological options according to their ecological impacts (Wackernagel and Rees, 1997). Ecological footprint is closely related to the concept of ecological carrying capacity, which is the population of a given species that can be supported in a defined

* Corresponding author.
E-mail addresses: 531631392@qq.com, qiaoqi@craes.org.cn (Q. Qiao).

http://dx.doi.org/10.1016/j.resconrec.2017.07.003
Received 3 February 2017; Received in revised form 30 June 2017; Accepted 1 July 2017
Available online 08 July 2017
0921-3449/

habitat without permanently damaging the ecosystem (Catton, 1986; Arrow et al., 1995). If an EF is larger than the corresponding ecological carrying capacity, 'ecological deficit' occurs (Wackernagel and Rees, 1997), indicating the ecological capacity barely supports sustainable development.

EF analysis has been used to study many systems of different scales, including regions (Wackernagel et al., 2006; Wackernagel and Yount, 1998), nations (Lenzen and Murray,2001; Begum et al., 2009; Wang et al., 2017), and even the whole globe (Galli et al., 2012; Wackernagel et al., 2002), in which the national EF analyses are popular due to data availability. The national scale data needed in EF estimation is easy to get from the international organization such as FAO (Food and Agriculture Organization) or UN (United Nations). Many EF analyses affirmed that most countries with advanced economies were not sustainable (Kitzes et al., 2007; Wackernagel et al., 1999; Wackernagel et al., 2002). Globally speaking, Wackernagel et al. (2002) concluded that the total ecological footprint of human beings in a given time surpassed the regeneration capacity of the Earth's resources. Some EF analysts claimed that if a region's ecological footprint was larger than its ecological carrying capacity, it would impair the regenerative capacity of the local natural assets (Rees and Wackernagel, 2008; Wackernagel et al., 2006). The region therefore must import external resources, and strengthen technological innovation to reduce the consumption of local resources (Opschoor, 2000). In addition, EF is widely applied in various fields. Many scholars studied the aquaculture industry by EF analysis (Gyllenhammar and Håkanson, 2005; Roth et al., 2000; Berg et al., 1996). Gössling et al. (2002) and Castellani and Sala (2012) applied EF analysis to tourism, and both found that ecological footprint was an effective tool in assessing the sustainability of tourism; Wright and Drossman (2002), and Flint (2001) conducted EF analysis on schools respectively, and identified those components which accounted for the large parts of the footprint and thus provided the opportunity for effective management. Through the study of the EF of many products and services consumed in the western economy, Huijbregts et al. (2008) found that the ecological footprint of most of the products was dominated by the non-renewable energy consumption.

Some researchers have applied EF method to the analysis of industrial parks (Liu et al., 2015a; Chen et al., 2013). These researches are however limited and not comprehensive in EF accounting. Compared to other sustainability assessment methods such as LCA or emergy method (Guinée,2002; Liu et al., 2014; Odum, 1996), ecological footprint method is more intuitive and more transparent. Since EF uses a land area (global hectares) to reflect the human impact, people will understand this concept more easily. LCA can analyze the environmental impact but it cannot conduct comparison with the carrying capacity (Guinée, 2002). Emergy method could quantify the resources consumption by a unified physical unit, but it is not directly comparable with local environmental capacity (Chen et al., 2017; Liu et al., 2014). EF method can measure ecological footprint and ecological carrying capacity, and conduct comparison between them.

Promoting eco-industrial development (EID) by the principles of industrial ecology (IE) provides a way to approach sustainable development in industrial park. Industrial ecology is a concept for studying the sustainable development of environmental and economic systems (Chertow, 2000; Chertow, 2007). According to the United Nations Environment Programme (UNEP, 2004), IE is "the systems-oriented study of the physical, chemical, and biological interactions and interrelationships both within industrial systems and between industrial and natural ecological systems." Eco-industrial park (EIP) is one of the important practical forms of IE. Industrial symbiosis (IS), in the form of eco-industrial parks, provides a method to combine local economic development with advantageous environmental outcomes (Chertow and Ehrenfeld, 2012). Gathered according to principles of industrial ecology, the functions of industries in an EIP complemented each other by improving outputs, saving resources and energy, and abating environmental impacts (Yu et al., 2014). The eco-industrial development practices involved physically exchanges between one another of raw material and wastes/by-products and sharing/consolidating/coordinating the management of utilities and infrastructures such as water supply, energy utilization, pollutant emissions, and distributions (Gibbs and Deutz, 2007; Yang and Feng, 2008). Since the success of the Kalundborg industrial symbiosis in Denmark (Jacobsen, 2006), EIPs have emerged around the world (Farel et al., 2016), including Europe (Gibbs and Deutz, 2007), the United States (Gibbs and Deutz, 2005), Australia (Roberts, 2004), Korea (Behera et al., 2012), and China (Zhang et al., 2010; Yu et al., 2015). Chinese EIPs incorporate the principles of industrial symbiosis, such as infrastructure sharing and wastes/byproducts exchange. Also, they adopt varied environmental management tools, including cleaner production and energy audit, to promote eco-industrial development and improve environmental performance (Shi et al., 2012a,b; Tian et al., 2014; Yune et al., 2016; Liu et al., 2015b). In industrial ecology, the industries in a park formed a community and each industry occupied a niche. If the community is symbiotic, the energy and resources they used, products they produced, and the wastes they generated would form an ecological echelon and the resources and energy flowed through from bottom up. The functionalities, benefits, and impacts of the industrial park community therefore should be characterized in terms of flows and balances of energies and resources that were present in different forms and were expressed in different units.

In this study, from an ecosystem perspective, a modified EF accounting method was proposed, as an unbiased and comprehensive tool, to evaluate the sustainability of one industrial park and the performance of eco-industrial development.

Complete EF accounts of an industrial park measure the biologically productive space occupied exclusively to provide all the resources which the industrial park consumes and to assimilate all the wastes the park generates. This study aims to explore the natural impact of the industrial activities at an industrial park based on modified EF analysis. In the following, Section 2 introduces an innovative component EF method which can investigate the whole impact of industrial park. Section 3 describes a case study of a typical industrial park in Hefei. Section 4 calculates the ecological footprint, ecological capacity and ecological deficit of the study park, and discusses EF reduction due to the implementation of eco-industrial development.

2. Method

2.1. Ecological footprint estimation

The original methodology for calculating ecological footprint, developed at the University of British Columbia, is outlined in earlier publications (see for example Rees (1992) and Wackernagel and Rees (1998)). Ecological footprint accounts express the use of built-up areas, and the consumption of energy and renewable resources—crops, animal products, timber, and fish—in standardized units of biologically productive area, termed global hectares (gha). One global hectare is equal to 1 ha with the average productivity of the 11.4 billion bioproductive ha. Two conversion factors—equivalence factor (see Table 1) and yield factor—convert each of the biologically productive areas from hectares into global hectares. Equivalence factor represents the relative productivity of a particular type of land to the world average productivity of all land. Yield factor accounts for differences between countries in productivity of a given type of land. For this study, the equivalence factors are cited from the work presented by Wackernagel et al. (2004a). The global average productivity is applied in this study so the yield factor is not needed for this ecological footprint calculation.

The conventional EF analysis does not take into account the non-renewable resources and water resources (Wackernagel et al., 2004b). The non-renewable and water resources, however, are important powers to drive industrial production in the industrial park (Yune et al.,