Journal of Cleaner Production 141 (2017) 791–798

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Emergy analysis on industrial symbiosis of an industrial park – A case study of Hefei economic and technological development area

Yupeng Fan, Qi Qiao*, Lin Fang, Yang Yao

Key Laboratory of Eco-Industry of the Ministry of Environmental Protection, Chinese Research Academy of Environmental Sciences, Beijing, 100012, China

ARTICLE INFO

Article history:
Received 28 October 2015
Received in revised form
18 September 2016
Accepted 20 September 2016
Available online 20 September 2016

Keywords:
Emergy analysis
Hefei
Industrial symbiosis
Eco-industrial park construction
Sustainability

ABSTRACT

Nowadays industrial parks have played a massive role in promoting regional economic development. However, due to intensive industrial activities and enormous energy consumption, industrial parks have become the main areas for pollution emissions. China has carried out the National Demonstration Eco-industrial Parks program to solve such challenges. Industrial symbiosis is the kernel of industrial ecological construction. It aims at promoting several companies to gather in a same geographical site to share services, utility, and by-products in order to decrease environmental impacts of their industrial activities. However how to quantify the impact of industrial symbiosis on improving the sustainability of an industrial park is rarely studied. This study proposed an emergy analysis to conduct an assessment on Hefei economic and technological development area to quantify the performance of industrial symbiosis. Comparing with conventional evaluation methods, emergy analysis can reflect the real contribution of local ecosystem by focusing on nature's free investment, not only the economic value or the resources supplied to the industrial system. Research results show that industrial symbiosis operations improve the study area's sustainable development ability by 33%. Specifically, non-renewable inputs, imported resource inputs, and associated services could be saved by 99.71%, 25.64%, and 9.82%, and the ratio of the money saving to the total gross domestic product of the industrial park would be 29.71%. By examining industrial symbiosis practices in detail within the system, this paper can describe the process of the industrial symbiosis and how these industrial symbiosis practices influence the overall performance of the industrial park. This study indicates that industrial symbiosis could effectively reduce raw materials and energy consumption and improve the overall sustainability, which can help policy-makers make decisions.

1. Introduction

The Shekou Industrial Zone, established in 1979, was the first contemporary industrial park in China. It marked the advent of the nation's industrial modernization. In the pursuing 30 plus years, the industrial parks exceeded 2000 (Bao, 2013). Their outputs accounted for >60% of the gross national industrial products and >50% of the gross domestic products (GDP) (Bao, 2013). In 2014, the GDP growth rate of industrial parks, 29.1%, significantly outpaced that of the national average, 7.4% (CADZ, 2014). While industrial parks have been engines driving the economy, they were immense consumers of energy and resources and vast emitters of pollutants. It was problematic to keep productions sustainable over the long run. The National Demonstration Eco-industrial Parks (EIPs) showed the strategies of conserving energy and resources and minimizing pollutant emissions by encouraging industries in industrial parks to optimize their production processes through sharing/exchanging of energy and resources and collectively planning for emission controls (Geng et al., 2007).

The goal of EIP was to attain industrial symbiosis, IS (Gibbs and Deutz, 2007). Gathered according to principles of industrial ecology, the functions of industries in an EIP complimented one another in terms of optimizing outputs, conserving energy and resources, and reducing environmental impacts (Yu et al., 2014). The practices involved physically trading 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). To be successful, participating industries took advantages of their geographical

* Corresponding author.
E-mail address: qiaoqi@craes.org.cn (Q. Qiao).

http://dx.doi.org/10.1016/j.jclepro.2016.09.159

proximity seeking synergies and opportunities of collaboration in their production operations (Chertow, 2007). The earliest example of industrial ecology was the symbiosis of industries at Kalundborg, Denmark (Chertow, 2007). Since then, the industrial symbiosis had successfully transformed existing industrial parks (Tudor et al., 2007; Veiga and Magrini, 2009) such as the National Industrial Symbiosis Program (NISP) in the UK, the regional synergies in the Australian mineral industries, and the Circular Economy program in Chinese industrial parks (Jensen et al., 2011; Van Beers and Biswas, 2008; Fang et al., 2007). Other notable examples included the symbiotic alliance of Kymi pulp and paper mill and its allied industries in Kouvola, Finland (Lehtoranta et al., 2011), the waste management companies of Chamusca, Portugal (Costa and Ferrão, 2010), and the Tianjin Economic Technological Development Area (TEDA) in China (Shi et al., 2010).

Ashton (2008) demonstrated the social impacts of industrial symbiosis through linkages industries in the Barceloneta region of Puerto Rico. Boons et al. (2011) formulated a conceptual framework that demonstrating the dynamics of industrial symbiosis. Pearce (2008) utilized the industrial symbiosis approach to gain economics of scale and increase efficiencies for manufacturing photovoltaic cells and demonstrated that a symbiotic industrial system was able to increase the manufacturing efficiency while reducing environmental impacts of industrial activities. Zhu et al. (2007) analyzed industrial symbiosis practices in the Guitang Group in China and found that the practices generated additional profits and reduced wastes emissions and disposal costs, while improving the quality of products. The assessments mostly were qualitative and descriptive in nature. How did one quantify the benefits and impacts of industrial symbiosis and compare pros and cons across the industrial parks that took different forms and shapes?

Several approaches had been employed to quantify advantages of industrial symbiosis (Yang and Feng, 2008; Yu et al., 2015; Liu et al., 2011; Li, 2011; Dai, 2010; Soratana and Landis, 2011). Sopha et al. (2010) modeled industrial symbiosis based on the systems engineering framework. Mattila et al. (2010) compared process, hybrid, and input-output life cycle assessment (LCA) approaches in quantifying the environmental impacts of a forest industrial symbiosis in Kymenlaakso, Finland. The methods however did not cover entirely the impacts of industrial symbiosis in industrial parks as resource inputs from both natural and anthropogenic activities needed to be included.

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. From an ecosystem perspective, a comprehensive emergy analysis was adopted, as an unbiased and comprehensive tool, to evaluate the impacts of industrial symbiosis on the sustainable development of industrial parks.

2. Methodology

2.1. Emergy analysis diagram

The emergy assessment (Odum, 1996), applying to the industrial ecology, considered the performance of an industrial system (i.e. industrial park) as if it was a biosphere. In addition to the traditional raw material and energy resources, it took into account naturally occurring inputs such as sunlight, wind, rain, and geothermal heats. It also included the indirect support embodied in human productive activities that were not counted in the conventional methods (Oliver and Jackson, 2001; Franzese et al., 2009). In emergy method, the efforts toward manufacturing a product, providing services, or supporting a flow of material were accounted for in terms of solar emergy, the total amount of solar available equivalent energy measured in units of solar emjoules (sej) (Odum, 1996). To evaluate the industrial symbiosis, the boundary and material flows of the system needed first to be clearly delineated along with system components, interactions among components, final products, and wastes. Then all existing and potential scenarios of industrial symbiosis should be marked on the diagram so that the roles of industrial symbiosis and sustainability of system might be better recognized. Through this diagram, the by-product exchanges among different operations could be visualized and matched to save on virgin raw material and to reduce waste emissions. An emergy evaluation table might then be developed to quantify the energy or mass of each identified symbiotic flows. The energy and mass can then be converted through their solar transformity or specific emergy factors to obtain its emergy in solar emjoules.

2.2. Emergy accounting indicators

For emergy analysis, the resources and energy flowed through the system were grouped into seven categories namely renewable resources (R), local non-renewable resources (N), imported resources (I), labor (L), services (S), waste disposal (W) and the total emergy (U). The renewable resources (R) included the emergy from sunlight, precipitation, wind, and geothermal heats. No tidal energy was considered as the case study presented below was located inland. The non-renewable resources (N) included the emergy from fossil energy, chemical products, mineral resources, and other resources that were not renewable within the system, such as topsoil and clay in the local nature. The imported resources (I) were the resources and energy that were acquired from outside. The total emergy (U) is the sum of R, N, and F where F represented purchased resources (I + L + S + W). In addition, the amount and scale of material/water circulation and energy cascade were considered.

The total global empower (emergy throughput) in 2000 was assumed to be 15.83E+24 sej/yr (Brown and Bardi, 2001). In this study, the solar transformity factors were based on the emergy flow of 15.83E+24 sej/yr.

A symbiotic industrial park should be appraised in terms of its emergy yield ratio (EYR) and emergy loading ratio (ELR) that:

$$EYR = \frac{R + N + F}{F} \quad (1)$$

$$ELR = \frac{N + F}{R} \quad (2)$$

where EYR expressed production capability of the system and ELR reflected the pressure of the economic activity on local eco-environment.

The emergy sustainability index (ESI) was defined as:

$$ESI = \frac{EYR}{ELR} \quad (3)$$

where ESI, considering both the emergy yield and the environment impact, measured the contribution of a resource or process to the system per unit of environmental loading. The higher the ESI was, the more sustainable the system would be. This index reflected the