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Industrial symbiosis indicators to manage eco-industrial parks as dynamic systems

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ABSTRACT

The industrial symbiosis in eco-industrial parks requires intense broker involvement to be implemented. However, market changes and technological advancement could undermine the level of symbiosis during operations. In this research, the existing symbiosis indicators were identified and classified using a systematic literature review. The results demonstrated the necessity to achieve indicators sufficiently simple that brokers are enabled in confronting the monitoring and promotion of symbiosis. In this paper, an industrial symbiosis indicator is introduced that detects the variation of symbiosis over time and that provides a dynamic perspective of the eco-industrial parks. This indicator can be used in the underpinning of decisions and the provision of continuous improvement. It was evaluated in several theoretical scenarios created from real data. The three scenarios are: absence of symbiosis, presence of symbiosis, and perfect symbiosis. The results demonstrate consistency between the values of the indicator and changes in the scenarios. The industrial symbiosis indicator proposed was able to detect variations in symbiosis with simple measures, and could support managers in encouraging companies to actively engage in effort for more advanced levels of symbiosis. The concept of "environment impact momentum", proposed and applied in this research, is a theoretical construct that could support a new class of indicators capable of identifying the dynamic behavior of eco-industrial parks.

1. Introduction

The growth of eco-industrial parks (EIPs) represents an important trend in the new industrial reality (Shi et al., 2010). The purpose of EIPs is to achieve environmental benefits and economic growth through collaboration between companies, and as such, they must be able to promote industrial symbiosis (IS). IS is a process that involves the interchange of materials, energy, and water between companies; thereby generating better collective benefits than could have been achieved if all individual benefits were combined (Chertow, 2000).

The success of EIPs depends on broker performance in providing political and managerial support, services, and infrastructure (Gibbs and Deutz, 2007). They are the agents responsible for decisions that may introduce industrial symbiosis and must encourage this practice. For example, brokers are responsible for attracting new companies, and gaining the cooperation of all regulatory agencies. According to Massard and Erkman (2007), it is the duty of the broker to inform economic agents about issues pertaining to resource efficiency and the exchange of waste materials, to promote the sharing of flow management experiences, and to identify, evaluate, and implement IS potential.

A broker needs decision-making tools and processes that support the identification or selection of companies, as well as those that monitor and improve the park's operation (Chiu and Yong, 2004; Sopha et al., 2010; Oh et al., 2005). The most common methods used are those of Life Cycle Assessment (LCA) (Sokka et al., 2011a,b) and Material Flow Analysis (MFA) (Geng et al., 2009, 2012; Sendra et al., 2007). Together with environmental indicators (Zhu et al., 2010; Kurup and Stehlik, 2009; Pakarinen et al., 2010), these tools enable the characterization of an EIP, measurement of the level of waste being reused therein, environmental impacts, and the level of eco-efficiency.

The use of these methods enables brokers to assess the flow of materials and the environmental impact of companies, and can also be used to make decisions about which companies should be

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allowed to participate in the park (Zhu et al., 2010). This allows comparison with other parks, benchmarking (Geng et al., 2009; Jung et al., 2013; Zhang et al., 2009; Shi et al., 2011), and the quantification of the environmental benefits of reusing wastes (Eckelman and Chertow, 2009; Mattila et al., 2010; Sokka et al., 2011a,b). Such methods could be used to plan the location of facilities, to mitigate environmental impacts, to reduce costs, and to increase waste treatment efficiency (Sendra et al., 2007).

The two most widely used methods, LCA and MFA, are considered to be highly suitable for this purpose because they provide absolute numbers that measure the magnitude of impacts and flow, respectively. Despite their accuracy, these measurements represent the situation of an EIP over a short and specific period of time. Continuous assessment is undermined because the evaluation is time-consuming. Therefore, when used as single indicators, they limit the broker by delivering a narrow and static view of the industrial ecosystem.

The brokers need indicators capable of detecting trends and variations among periods. This kind of indicator would support them in evaluation of the impact of the decisions made. Chertow and Ehrenfeld (2012) discussed this need, and they offered examples of parks that disintegrated over time due to changes made throughout the park's lifespan, even when the park was built to provide high levels of symbiosis.

According to Chertow and Ehrenfeld (2012), the methods and techniques used in industrial symbiosis need to be remodeled to encompass such a perspective, which they call “dynamic”. They supported their argument using the management approach of complexity and dynamic systems, and they stated that the traditional point-of-view is “static”, when symbiosis is evaluated at any given time.

According to this dynamic outlook, the LCA and MFA tools are limited in their ability to assist in the decision-making processes. Despite the precision and reliability of impact measures, these indicators are not useful as measures of trends, and it is not possible to assess how any decision affects industrial symbiosis.

Jung et al. (2013) added to this point of view by stating that in the composition of the proposed index for the EIP assessment system, there is a lack of indicators available to measure the individual characteristics of companies. Geng et al. (2009) affirmed that eco-efficiency indicators encourage companies to improve their individual processes, but also determined that they are not sufficient to evaluate the park as a complex system. In other words, indicators that both show the result of the EIP (i.e., the network of companies) and relate this performance to the individual contribution of each organization are required, in order to allow for incentive mechanisms.

A systematic literature review (SLR) was conducted to verify the existence of indicators that could contribute to EIP management. The SLR showed a lack of available indicators for symbiosis that support the dynamic view (Section 3). As a result, a new concept is introduced in the paper, named “Environment Impact Momentum”, along with a specific indicator, the Industrial Symbiosis Indicator (ISI). Together, these allow monitoring of the evolution of industrial symbiosis in an EIP, and might act as an essential decision-making tool for brokers (Section 4). The ISI is then evaluated using three different scenarios, which were created using data from actual companies within a park (Section 5). Finally, the important features of the indicator and its limitations are described (Section 6).

2. Research methods

Three distinct methods were used: a systematic literature review, a conceptual proposal that combines the experience of researchers and the theoretical background, and an analysis and evaluation of indicators.

2.1. Systematic literature review

A systematic literature review (SLR) was conducted, considering indicators applied for EIPs as well as for the evaluation of symbiosis. Two objectives were considered as part of the scope of the search: (1) to identify indicators proposed to assess, analyze, and contribute to the management of EIPs, and (2) to identify indicators proposed to assist in the process of industrial symbiosis.

The method described by Biolchini et al. (2005, 2007) was used to verify the existence of indicators that could contribute to the management EIPs, and a systematic literature review protocol was developed (presented in Table 1). All procedures are in accordance with the proposition of Bakker et al. (2005).

The dataset used in this paper was elaborated using the ISI Web of Science database for publications up to March 2014. Every publication that contained the words “eco-industrial park,” or “industrial symbiosis,” and “indicator” in its title, keywords, or abstract, was identified.

Using this methodology, a total of 178 articles were found, and three filters were then applied. The first filter involved reading the title, keywords, and abstract of the article, while applying the criteria for inclusion and exclusion of articles; 39 articles were shortlisted with this filter. The second filter involved partially reading each article, including the introduction, results, and conclusion, and in doing so applying the same criteria for inclusion and exclusion of articles. Finally, the third filter involved reading the complete article, and applying the selection criteria for inclusion and exclusion of the articles. Using this filter, 31 articles were shortlisted.

A database with all the identified papers was created using Microsoft Excel, whereby the names of authors, title, journal name, year of publication, volume number, issue number, pages, the indicators description and main references were recorded. The Appendix contains a synthesis of the papers selected, including the theoretical background classification.

The articles were reviewed and the identified indicators became the focus of the analysis. The indicators were analyzed in order to determine the feasibility of creating time series data about the symbiotic behavior of the ecosystem.

2.2. Conceptual proposal

The identified indicators were grouped by similarity and analyzed. Three distinct groups were identified: eco-efficiency (EE), Life Cycle Assessment (LCA), and Material Flow Analysis (MFA). The characteristics and limitations allowed the researchers to identify demands and deficiencies (Section 3.1).

The researchers started an investigation to formulate theoretically an indicator proposal, by which to settle the limitations identified. In this process three theories were applied:

a) **Material flow analysis** was used to identify, understand, evaluate and implement the process of industrial symbiosis. Such an analysis offers insights into the behavior of waste flows among the companies in an EIP, describes the use of material resources, and provides information about their economic efficiency and environmental effectiveness.
b) **Environmental impact assessment** methods in the context of an EIP (Sokka et al., 2011a,b; Mattila et al., 2012; Liu et al., 2011) highlight important aspects that need to be evaluated during the process of by-product exchange.

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