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NEW PERFORMANCE INDICATORS FOR INDUSTRIAL SYMBIOSIS: AN ECOSYSTEM APPROACH

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Abstract This paper proposes new performance indicators for industrial symbiosis networks (ISNs) based on the ecosystem approach. ISNs are framed as ecosystems where the firms correspond to the organisms and perform specific functions, i.e., recovering wastes and saving inputs. Two kinds of indicators are designed: 1) indicators assessing the performance of each waste exchange; 2) indicators assessing how each firm is contributing to these exchanges. The designed indicators can be useful in backing up decision-making tools for ISNs.

Keywords: Industrial Symbiosis Networks, Performance Indicators, Input-Output, Ecosystem approach.

1. Introduction

Industrial symbiosis (IS) is recognized a key practice to support the sustainable development since it can generate economic benefits for firms and environmental benefits for the collectivity. Despite policymakers in many countries have introduced IS into their agenda, the IS practice appears to be underdeveloped compared to its theoretical opportunities. Therefore, IS needs decision-making tools suggesting policy makers with strategies to support the evolution of IS networks (ISNs). To do this, it is required to analyze the performance of the ISNs through appropriate performance indicators [1]. The literature proposes performance measurements mainly based on three categories: life-cycle assessment (LCA), eco-efficiency indicators, and material flow analysis (MFA). LCA indicators focus on the environmental impact of products during all their life-cycle, which is a different point of view than the waste exchanges within ISNs. Eco-efficiency indicators are aimed at assessing the individual performance of firms, but without considering how firms are connected among them [2]. MFA focuses on each waste flow separately, hence considering how firms are connected among them. However, since each flow has a different metric and compare indicators concerning different flows is a difficult task, MFA indicators cannot be used to measure the overall contribution of each firm to the ISN [3]. Moreover, all the above-mentioned indicators are unable to highlight the extent to which the current performance of the ISN could be further increased, because they do not provide a reference point. Based on the above, we recognize that there is a lack of indicators able to measure both the performance of each waste exchange within ISNs and the extent to which each firm contributes to these exchanges. This paper is aimed at filling this gap by designing performance indicators for ISNs based on the ecosystem approach.

2. Methods

We frame the ISN as an ecosystem where the firms correspond to the organisms and perform specific functions [4]. Two kinds of functions are performed: recovering the produced wastes and replacing the required inputs. Firms contribute to these functions by producing, requiring, and exchanging wastes. Through these functions, the ISN generates two services: 1) creating economic benefits for firms; and 2) creating environmental benefits for the collectivity. All the waste flows among firms are modeled by adopting the Enterprise Input-Output approach [5]. Two kinds of performance indicators are designed: 1) indicators assessing the performance of each function; 2) indicators assessing the extent to which each firm contributes to the ISN functions.

3. Results

For the generic function f_{w_i} "recovering waste *i*", the following performance indicator is defined:

$$p^W(f_{w_i}) = \frac{w_i^S}{E_i^W} \times \frac{E_i^W}{w_i} \quad (1)$$

where w_i^S is the amount of waste *i* saved, i.e., not disposed of in the landfill thanks to the IS practice, w_i is the amount of waste *i* produced by firms belonging to the ISN, and E_i^W is the highest amount of waste *i* which is possible to save through waste exchanges. $E_i^W = \min\{w_i; \sum_j s_{ij} \times r_j\}$, where *j* is the generic input which can be replaced by waste *i*, s_{ij} is the amount of waste *i* replacing one unit of input *j*, and r_j is the amount of input *j* required by firms belonging to the ISN. Similarly, for the generic function f_{r_j} "saving input *j*", the following performance indicator is defined:

$$p^I\left(f_{r_j}\right) = \frac{r_j^S}{E_j^I} \times \frac{E_j^I}{r_j} \quad (2)$$

where r_j^S is the amount of input *j* saved, i.e., not purchased from conventional suppliers thanks to the IS practice and E_j^I is the highest amount of input *j* which is possible to save through waste exchanges. $E_j^I = \min\left\{r_j; \sum_i \frac{w_i}{s_{ij}}\right\}$, where *i* is the generic waste which can replace input *j*. The first factor in Equation 1 (Equation 2) stands for the amount of waste *i* recovered (input *j* saved) compared to the highest possible quantity, being representative of the operational performance of the function. The second factor stands for an ISN structural factor, being representative of the match between waste demand and supply. $p^W(f_{w_i})$ and $p^I\left(f_{r_j}\right)$ range between 0 and 1. They are equal to one when $w_i^S = E_i^W = w_i$ and $r_j^S = E_j^I = r_j$, respectively, otherwise they are lower than one. For the generic firm *K*, the following performance indicator is defined:

$$p(K) = \frac{1}{f^W}\sum_i \frac{w_{iK}^S}{w_i^S} + \frac{1}{f^I}\sum_j \frac{r_{jK}^S}{r_j^S} \quad (3)$$

where f^W is the number of wastes exchanged within the ISN, f^I is the number of input saved within the ISN, w_{iK}^S is the amount of waste *i* saved by firm *K*, and r_{jK}^S is the amount of input *j* saved by firm *K*. The value of $p(K)$ depends on: 1) how many functions the firm *K* performs within the ISN; 2) the contribution of firm *K* to each function. $p(K)$ ranges between 0 and 1: the higher the value, the higher the contribution of the firm *K* for the ISN. When $p(K) = 1$, the overall ISN will disappear if *K* leaves the network.

4. Discussion and Conclusion

The proposed indicators are able to assess the performance of each ISN function and how each firm is contributing to these functions. We apply them to several ISNs with different topology and test their application and usefulness. Furthermore, we highlight how the proposed indicators can be used to back up decision-making tools for ISNs, since they highlight: 1) which ISN functions are currently underdeveloped respect to their potential; 2) which firms are providing the strongest contribution to the ISN.

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