Agent-based models of industrial symbiosis networks

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Introduction

Industrial symbiosis has been proposed as an approach to operationalise the circular economy in terms of a by-products integration for industrial systems (Chertow, 2000). Flows of waste and energy become resources for other industries, achieving in theory a certain level of circularity, beyond the unsustainable current linear model of producing. Industrial parks are an example of how to put this concept into practice, but their implementation remains challenging. How to build resilient networks of exchanges between companies is an open question, for which the behavior of actors and their economic geography are expected to be crucial factors (Desrochers, 2001). We propose in this contribution a bottom-up modeling approach to the issue of understanding, managing and optimising industrial symbiosis networks, extending some previous work (Raimbault et al., 2020).

Methodology

We introduced in (Raimbault et al., 2020) a generic agent-based model to grow and optimise industrial symbiosis networks. The model builds on the concept of Probabilistic Niche Modeling which has been introduced in ecology to model complex food webs (Williams et al., 2010). Companies are described by statistical distributions of their inputs and outputs in some product space. The probability to build an exchange relationship will depend on the distribution overlap between outputs (waste) of one company and inputs (resources) of one other. The model furthermore takes into account the spatial aspect of such networks, by integrating spatial interaction models to simulate potential interactions and transport costs. A network of exchanges is thus iteratively grown between industrial actors. The model can be applied at several scales, from the mesoscopic scale of an urban area to the macroscopic scale of a region or country. The network built is quantified by the total remaining waste and cost of exchanges, which are two contradictory objectives.

Results

The agent-based model was previously explored and partly validated. Our main results included (i) a systematic exploration of the model parameter space, unveiling some non-linear patterns such as congestion effects; (ii) an application on synthetic urban systems and real systems at different scales, with significant differences depending on the geographical context and scale; (iii) the existence of Pareto fronts of compromise between waste and cost objectives, suggesting policy implementations depending on transportation cost and industrial structure; (iv) a

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limited influence of controlling spatial correlations to ensure circularity, which may be linked to the difficulty to build efficient eco-industrial parks; and (v) a proof-of-concept of model calibration using the European Pollutant Release and Transfer database.

In this contribution, we extend our model in several directions. First, it has been suggested that several mechanisms are simultaneously driving industrial symbiosis networks (Boons et al., 2017). These can range from self-organisation to third-party mechanisms or somme central control. We implement these processes in our model in a multi-modeling approach, and compare their respective role in terms of optimising final networks and which are the most plausible given a multi-model calibration. First results suggest that a full central control is not optimal, nor is a full self-organisation of actors, since hybrid configurations seem to perform better. The impact of policies at different levels also seems to strongly depend on the geographical context and scale.

Second, we explore with a new insight a data-driven implementation of the model. Using the FAME database at the UK level and the AMADEUS database at the European level (databases of ownership links between companies, provided by Bureau Van Dijk), we simulate product space distributions based on industrial classification similarities, and strengthen the probability to cooperate between companies with some ownership proximities.

Finally, we discuss the integration of our model into broader multi-scale geographical models. In particular, industrial symbiosis exchanges between companies are embedded into systems of cities which also interact. The link between the macroscopic structure of systems of cities and the microscopic level of companies remains to be explored, with potential reciprocal influences on their respective sustainability.

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Keywords

Industrial Symbiosis; Circular Economy; Agent-based Modeling