

A heuristic approach to cultivate symbiosis in industrial clusters led by process industry

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Abstract. *This paper introduces a heuristic approach for industrial symbiosis (IS) facilitators to investigate and instigate better energy and resource management via synergies across process industries. The proposed method studies the industrial system at three levels; regional, cluster and company. At the company level, in-depth information is collected using a pentagonal LESTS (Legal, Economic, Spatial, Technical, Social) survey, which is formulated after weighing the regional effects on the whole system. At the cluster level, an inventory of technological and organisational opportunities is produced, offering leverage for IS activities. A gap analysis between the IS potential of the cluster and the IS appreciation on the industrial sites is visualised via LESTS pentagons. The coupled investigation at company and cluster level results in a list of realisable IS activities, which is then translated into business strategies for each participating company using a SWOT analysis.*

1. Introduction

Process industry transforms material resources into intermediate or end-products and holds an important place at the core of every value-chain [1]. In Europe alone, the process industry represents about 20% of the manufacturing industry (employment and turnover) [1]. This provides the opportunity to significantly improve resource and energy efficiency and the global environmental footprint of industrial activities. Current systems of resource efficiency and recycling, however, are not enough to replace extraction of virgin materials to keep at par with the increasing needs of the present society. Such improvement can only result in 50% to 75% improvement in environmental performance [2], but in order to bring a substantial reduction in environmental burdens radical innovations are needed.

Global material consumption has doubled between 1950 and 2010 and has even accelerated during the last decade [3]. According to an estimate in 2005, globally recycled material only contributed to 6% of the total processed material, with 13% in Europe [4]. Owing to the rate at which human society is pushing the planetary boundaries [5], businesses require improved management and utilisation of energy and resources, reduction of waste and finally a circular economy. Especially in Europe, current business structures, cultures and practices are evolving, opening windows for new ideas and innovations [6] within and across process sectors.

In the past, collaborations between companies of a sector have grown organically, starting from a wish, a need or a duty to collaborate [7,8]. **Industrial Symbiosis** (IS) examines cooperative management of resource flows [9] between businesses. IS engages traditionally separate entities in a collective approach to competitive advantage [10] involving, on one hand, physical exchange of materials, energy, water, and by-products, and on the other hand social tactics at the firm and multi-organisational level [11]. Based on the principle that businesses working together can strive for a collective economic and ecological benefit that is greater than the sum of individual benefits each company can achieve [10, 4], the European Commission adopted an ambitious package on circular economy in mid-2016. The circular economy package includes roadmaps and action plans towards sustainable economic development including concrete measures to promote reuse of materials and to stimulate IS [14], hence also introducing legislative changes related to waste registration and handling of resources.

Despite the incentives, practical implications to achieve symbiosis activities are complex due to the intra-cooperative level at which the resources are treated and the way regulations are built around this process [15]. Legal inconveniences, economic barriers such as the lack of financial profit, as well as spatial, technological and social boundaries, can all lead to failing cooperation [7]. Hence, there is a need to bridge the gap between bottom-up appreciation of IS by businesses and the top-down policies at national or international level.

In support of tackling these challenges, this paper presents a heuristic approach to cultivate cross-sectorial industrial symbiosis. Building on consolidated studies in the field of business park management [7], a systemic methodology to identify IS opportunities across process industries is developed. The proposed methodology is applied to a selection of three self-organising cross-sectorial industrial clusters in Europe, under the H2020 project 'EPOS' [16]. These clusters involve two or more process industries from five different sectors: steel, chemicals, minerals, cement and engineering. Taking into account the characteristics of the process industries analysed, the industrial clusters are placed in a system's perspective with the aim to investigate, instigate and initiate IS collaborations, and to turn the industrial clusters into eco-clusters.

The paper first introduces the methodology and then defines three systemic levels, each with a unique set of impacts and precursors for IS. An exemplary result is discussed for one EPOS cluster, followed by a conclusion with recommendations for applying the methodology.

2. LESTS methodology

In order to propose an approach based on existing industrial clusters and to deal with the complexity of the industrial clusters, the frame is set in systems perspective and LESTS (Legal, Economic, Spatial, Technical and Social) approach is applied to capture the multidisciplinary aspects that influence industrial symbiosis.

2.1 LESTS approach

The pentagonal approach of LESTS was developed to assess the appreciation of existing resources at a business park and provide a set of guidelines for better park management. The LESTS book series [7] has served as a practical basis for building the LESTS methodology for IS facilitators in industry clusters.

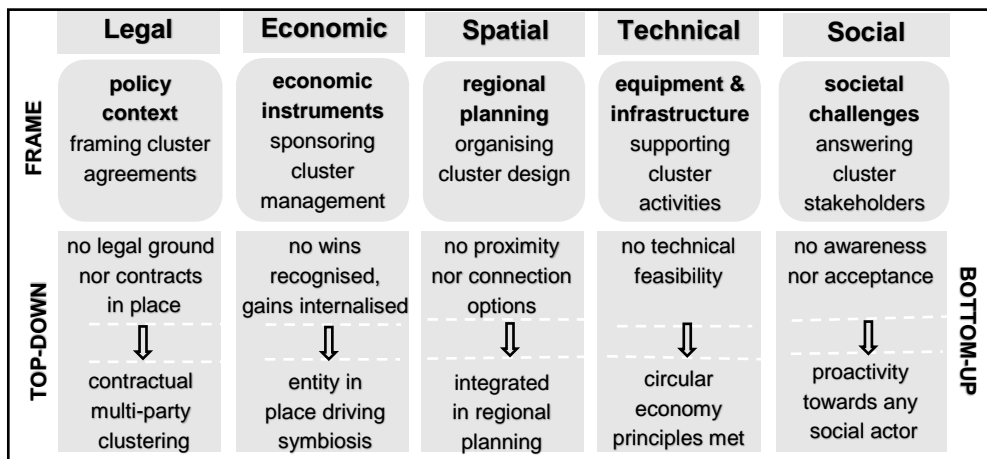


Fig. 1. LESTS framework adapted from [7]

In the adapted LESTS approach, the IS facilitator assumes the role of park or site manager and follows a roadmap to identify IS opportunities for the process industries in a (cross-) sectorial cluster. The proposed methodology incorporates the LESTS considerations into IS identification and initiation process and hence brings a holistic view of the system, by adding both technological and non-technological information under one umbrella as shown in **Fig. 1**. Within each LESTS domain the framework for managing cluster activities is investigated and the level of collaboration is scored from a top-down as well as bottom-up perspective. When the data is collected at the company level, the bottom-up approach is used to investigate the potential to start symbiosis activities (as used in this study). When the information is collected from a park manager or a cluster manager, it follows a top-down approach of implementing symbiosis in the industrial cluster. The arrows suggest the progressive stages of an industrial network (scored 0-5) when symbiotic relationships are formed and mature over time. The intermediate stages of industrial clusters are detailed in **Table 1**.

Aiming for sustainability progress in industrial systems is a challenging task. Interactions across companies or process sectors make up the industrial cluster, which is embedded in a regional system, which in turn is surrounded by the global system. The IS facilitator should understand these hierarchies and envision system trends that promote a more sustainable future.

3. System hierarchies applied to case study

To capture the intrinsic complexity and dynamism of each industrial cluster, the LESTS methodology is applied in the clusters to investigate IS possibilities around the selected process industries. The system effects are studied at three levels; regional, cluster and company in the following manner.

3.1. Regional

At the regional level, two LESTS aspects are most prominent; the policy context and regional planning rules. These two aspects define the envisioned development direction for the region and outline the system drivers or hurdles towards resource and energy efficiency. Since the industrial system exists within a global system, it is effected by contextual elements that are factored through weighing. Examples are bio-based or circular economies, pull & push market forces, availability of utility networks, planning instruments for renewable energies, the geo-political state of affairs affecting the supply chain, etc. This helps to identify the possible constraints and drivers of IS and streamline the focus of the surveys developed for the individual site analysis.

For the EPOS clusters, the evolving European regulation defines the threshold for the impact of all proposed IS projects. The literature review of technological advancements of individual process industry established the drivers and bottlenecks for IS projects that were proposed to individual industry. Theoretically this stage of system study is followed by a cluster level analysis; in this study the company level analysis preceded the cluster level analysis. For practical reasons, the data collected at company level were also used to draw inferences for the characteristics of the clusters.

3.2. Cluster

At this level, the IS facilitator carries out an inventory of the cluster elements. Used and unused; material and energy resources, business and social networking platforms, IS facilitation opportunities, potential IS partners in the vicinity, trust building events between potential partners, information exchange linkages, access to local public or private (financial and non-financial) incentives, common linkages between individual companies, stakeholder knowledge, social networks, and other characteristics intrinsic to the cluster, are taken into account.

Based on this inventory and feedback from the LESTS surveys and in-depth studies at the company level, a gap analysis is carried out to exhibit the unused potential of available resources. For the EPOS industrial clusters, the surveys and interviews carried out at the company level helped to draw inference about the level of interconnectivity of businesses in each cluster.

A holistic perspective is applied for identifying the system trends that support IS by using the LESTS framework. The ranking provided in **Table 1** helps to visualise the results of the gap analysis by plotting the existing potential of IS against the realised IS activities. For each of the five aspects, a different set of leverages is presented, which could be exploited by the actors within the industrial cluster. Each aspect was translated into a survey question for the companies. The survey answers and interview responses were coupled with the literature review to infer the connectivity level of industries within their respective clusters. These inferences were plotted on a pentagon, showing the level that can be achieved by the cluster and the level that was actually in place at the time of data gathering.

Table 1. Ranking system for visualisation of LESTS pentagon

	Legal	Economic	Spatial	Technical	Social
0	no legal ground nor contracts in place	no wins recognised, gains internalised	no proximity nor connection options	not technically feasible	no awareness nor acceptance
1	unilateral contracts in place for diverse activities	incentives for collective wins but not in place	local potential but not in place	similar needs* but organised separately	no joint action towards common stakeholders
2	unilateral contracts in place for similar activities	simple win-win clustering in place	local/individual connections* in place	local needs* jointly answered	joint actions* focused on own employees
3	bilateral contracts in place, between parties/ providers	generic win-win collaborations managed	site design supportive of clustering*	basic opportunities* shared via clustering	cluster-integrated actions* & platforms
4	multi-lateral agreements in place	entity in place that offers basic & optional wins	district approach to clustering	opportunities* jointly optimised	active stakeholder networks (cluster, district)
5	contractual multi-party clustering	entity in place that drives IS (3 rd party beneficiary)	integrated in regional planning	principles of circular economy met	proactivity towards any social actor

*All options in the ranking assume interactions & exchanges between parties in clusters, focused on materials, infrastructure and services.

3.3 Industrial site/ company

Company or an individual industrial site, is the key level for IS activities. The actors at the company level have much more knowledge of the technological and organisational drivers and barriers of IS and hence an in-depth analysis is possible. Quantitative methods for material consumption, such as Material Flow Analysis of the industrial site, Life-cycle Analysis can be applied to gather information about the hotspots for IS. In this study, qualitative data collection via an LESTS survey and semi-structured interviews was carried out, regarding all activities on an industrial site that may support or hinder IS with other partners.

The framework of LESTS survey was built around three major activities on an industrial site, which includes; 1) production of by-products, waste and emissions; 2) utilisation of energy, water, equipment and infrastructure; and 3) requirement of packaging, logistics and storage. Related to each factor, information was collected on existing collaborations with neighbouring companies; nature and length (time) of these collaborations and finally; a possibility to extend these collaborations to other industry partners. The LESTS survey was supplemented with semi-structured interviews with key company representatives (often, site manager, energy/environmental manager) to collect information about the interaction and consultation between stakeholders at the cluster level. The interview focused on gaining insight into the decision making power of the site, stakeholder engagement at the cluster level, communication with neighbouring communities. These interviews helped to gain an overview of stakeholder perception about possibilities of IS activities.

In essence, LESTS surveys lead to a longlist of potential exchanges and interactions between the companies - and even municipal communities - in the region. Via consecutive SWOT analyses, indicating strengths and weaknesses (internal factors) that induce opportunities or point to threats (external factors) viable symbiosis opportunities are put forth, consequently, building a framework to identify and formulate business strategies. The potential IS opportunities are further developed into IS business cases and calculated for their sustainability improvements, considering the three pillars of sustainability (Van Eetvelde et al., 2005). To identify the opportunities of IS that are sustainable in nature, leverage is created when the principles of cleaner production are in place, a commitment to CSR has been incorporated into company policy, company is inclined to minimising its footprint or when good management practices are already in place.

4. Results

The described LESTS methodology resulted in identifying a number of IS activities within each cluster. To provide an exemplary result on the applicability of this methodology, IS opportunities from one cluster are presented in **Fig. 3**. The identified opportunities have been communicated to the respective industries and are currently under study for techno-economic feasibility.

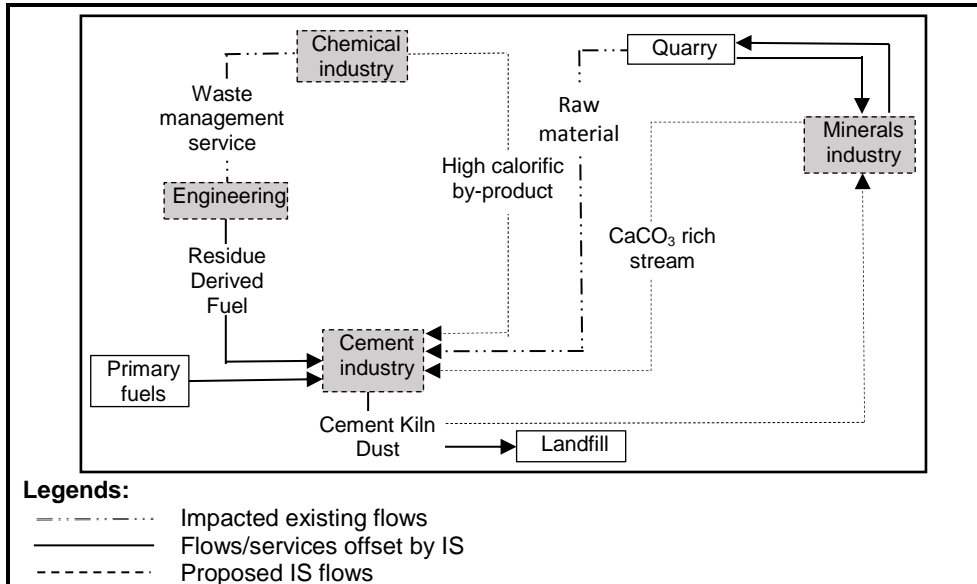


Fig. 3. Identified IS opportunities in the UK cluster of EPOS

The application of the heuristic method presented in this paper provided two sets of results. One for the cluster level and one for the companies within the cluster, willing to involve in an industrial symbiosis. The results for the cluster level visualise the gap between possibilities to engage in IS and the realisation of these possibilities by actors in the cluster as shown in **Fig. 4**. The outer pentagon indicates the leverage provided by the unique properties of the cluster, which arise due to the presence of diverse actors and the linkages formed between them. The inner pentagon exhibits the level to which these opportunities are availed by the actors in the cluster to form symbiosis activities.

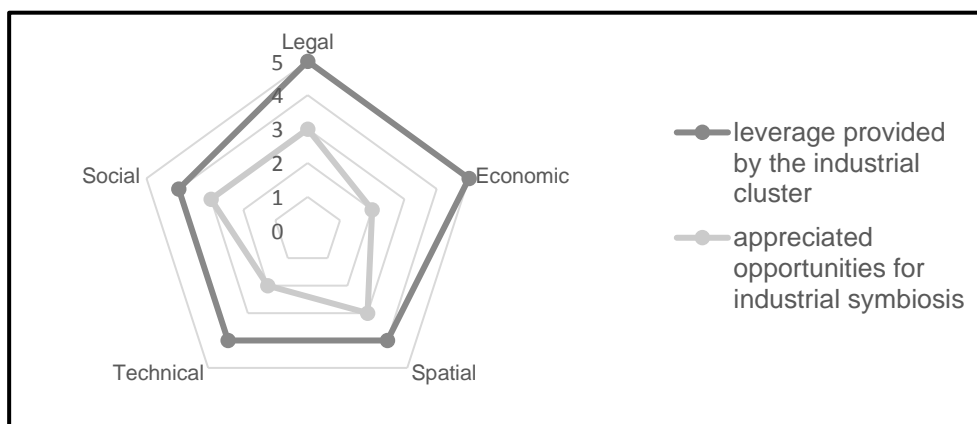


Fig. 4. The gap analysis visualised in an LESTS pentagon

The second set of results for the individual companies is provided in a list of IS possibilities and SWOT strategies to realise the presented IS opportunities. The SWOT analysis of individual companies are communicated individually to each company and are handled under confidentiality agreement between the IS facilitator and the company.

5. Conclusion

The proposed methodology for facilitating industrial symbiosis answers to the needs of process industries active in (cross-)sectorial clusters and willing to improve their energy and resource profile through collaboration. The approach takes a system perspective: it provides flexibility, desired by industrial actors and leads to stability, required by the global society. The LESTS surveys, coupled with semi-structured interviews, proved adequate to identify IS options in cross-sectorial clusters. Still cluster level analysis is perceived as a daunting task and requires many resources (time and costs). Likewise, the identification of key site actors for interviews is a crucial element for the success of the survey and the consecutive implementation of symbiosis activities. With an IS facilitator appointed and key contacts per industrial site identified, a good understanding of the industrial cluster, its actors and potential can be reached through regular exchange of information. Even so, socio-economic benefits are essential to attract and hold a company's interest in symbiosis activities.

Due to the EPOS project boundaries and consortium agreements, only the project partners in each industrial cluster were approached for interviews and surveys. To fully assess an industrial cluster however, it is recommended to include a maximum number of cluster actors in the analysis. The methodology provides enough flexibility to be coupled with different analyses at the company level (product life cycle), as well as, at the cluster level (material flow, environmentally extended Input Output, Social Network).

By applying the methodology at each industrial site in the EPOS project, a longlist of IS activities was identified. In a next step, techno-economic feasibility studies will be performed and the expected environmental improvement will be calculated per industrial site as well as for each cluster as a whole. Current research explores the possibility to model the complex adaptive systems of industrial clusters and predict/ascertain the behaviour of the individual actors with agent based modelling.

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