Contextualisation in Industrial Energy Symbiosis: design process for a knowledge repository

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Abstract: Industrial Symbiosis (IS) encourages companies to adopt a collaborative approach so that resources can be recovered, reprocessed and reused elsewhere within their industrial network. It entails both environmental and economic benefits mainly due to the reduction of resources consumption and waste generation. However, in spite of potential benefits of IS, there is still a considerable implementation gap, with practitioners failing to fully exploit the possibilities of IS. One of the main barriers for IS implementation, but also one of the main research opportunities, is the high degree of characterization needed for the design of IS in different contexts. Thus, the development of tools and methods to address contextualization challenges is now a priority for researchers. In the present work, a methodology for the creation of an Energy Synergies Database, as well as first findings from the analysis of case studies are presented. The creation of such database allows to provide the practitioner with useful background for IS implementation. In addition, the contextualization of different energy flows given by the classification of flows’ end uses and the proposal of synergy typologies, allows practitioners to extract useful additional information from the knowledge repository, enabling an innovative systemic approach to IS implementation.

Keywords: Industrial Symbiosis; Manufacturing process; Energy efficiency; Energy flows

1. Introduction

Industrial Symbiosis is seen as a positive phenomenon, with benefits to the individual companies concerned and the communities, environments and economies of which they are a part. In an ideal IS application, waste material and energy are shared or exchanged among the actors of the system, thereby reducing the consumption of virgin material and energy inputs, and likewise the generation of waste and emissions (Sokka et al., 2011).

Ehrenfeld and Gertler (1997) consider IS as an initiator of linkages between firms to raise the efficiency, measured at the scale of the system as a whole, of material and energy flows through an entire cluster of processes. Therefore, from an environmental perspective, IS can help improving the overall efficiency of the industrial system (Holgado et al., 2016), while from an economic perspective, it provides new opportunities to increase revenue streams through by-products sales and increase profit by cost savings that would not be achieved by acting alone (Paquin et al., 2015). It additionally enables innovative green growth through network efforts to adopt eco-innovations and long-term culture change (Lombardi and Laybourn, 2012).

IS related exchanges can occur as a one-off material waste exchanges or more continuous flows can be exchanged between different entities with certain geographic proximity (Chertow, 2000). These exchangeable elements can be not only material waste; energy, waste water or by-products are also a target for the symbiotic exchanges.

In particular, energy flows are often discussed separately from the other kinds of flow (Dong et al., 2014, Zabaniotou et al., 2015), as they present some peculiarities from both a managerial and technical perspective, for example the impossibility to effectively store electricity, the presence of relevant transformation losses and the differences among load profiles of different plants. These particular challenges for energy flows could bring additional obstacles to the implementation of symbiotic exchanges in which energy is involved.

In order to help both academics and practitioners in such hard job, a contextualization of IS is needed, since there is no one-size-fits-all when planning and implementing IS, and context specific characteristics will shape the scope and opportunities for IS in each individual case. The high degree of characterization needed for the design of IS in different contexts means practitioners would benefit from support (e.g. tools and methods) developed specifically to address contextualization challenges for IS design and planning (Holgado et al., 2016).
It is with such objective that the work presented in this paper has been conducted. Concretely, it aims at creating a database of flows exchanged in existing IS, thus providing companies willing to approach IS with a solid and helpful background. The creation of such a knowledge repository can also enable the IS contextualization by providing data regarding existing cases and flows to be analysed. Thus, bringing knowledge to understand IS development paths and possible barriers to be overcome.

This paper focuses on the first part of this research work. In the following paragraphs, the methodology used to design the Energy Synergies Database is presented, results from a first data analysis are illustrated and briefly discussed, and further research activities are introduced.

2. Methodology

The process used to create the Energy Synergies Database and to perform preliminary data analysis is represented in the following Figure and described in the followings.

![Figure 1: Representation of database creation and data analysis process.](image)

The knowledge repository is designed on the basis of a preliminary literature review, which has been conducted using academic databases (ScienceDirect and Scopus), scientific search engines (Google Scholar) and general search engines (Google); the use of the latter has allowed to take into account whitepapers and industrial presentations other than scientific papers, thus including into the knowledge repository also simple but effective forms of Industrial Symbiosis that are usually left out of academic research. Keywords used for searching in databases and search engines in the first place are: “Industrial Symbiosis case studies”, “symbiosis case studies”, “symbiosis”, “Industrial Symbiosis”, “Energy Symbiosis”, “Energy Synergies”.

Main attributes initially associated to each entry are the followings:

- Reference to the document where the symbiosis case is described;
- Country or region where the symbiotic companies are set;
- Name of the companies taking part to the symbiosis (if available), their main business and industry sector (defined according to the European list of NACE codes) and their role in the energy flow exchange (supplier, receiver);
- A synthetic description of each energy flow exchanged and its end use;
- Actors involved in the flow exchange (single enterprises, enterprises within a district or an industrial park, a district of enterprises, urban entities);
- State of completion of the analysed exchange (completed or planned).

Subsequently to the first analysis of the documents, other four attributes have been added to each entry in the database, considering characteristics of flows or of Industrial Symbiosis cases highlighted in literature:

- Whether the symbiosis is dominated by a specific industry, i.e. forming an industrial cluster, or composed by mixed industries (Chertow, 2008);
- Whether it is the result of national and supranational incentives or not (if explicitly indicated, as for example in Mirata and Entairah, 2005);
- Whether it is a spontaneous form of symbiosis or the result of national or regional planning (as for example in Sokka et al., 2011, Li et al., 2015, Notarnicola et al., 2016);
- Whether a payment is expected for the supplied energy flow or not (if explicitly indicated, as for example described in International Synergies, 2015).

After that, documents have been thoroughly analysed in order to classify end uses and energy synergies thus enabling an easier data analysis, and then to input energy flows’ data into the database.

Finally, data have been analysed in a preliminary fashion in order to start extracting information from the knowledge repository and to use them to guide following research on the Energy Symbiosis topic.

3. Results

The total amount of analysed documents is 29, including 22 scientific papers, 2 industrial presentations, 2 scientific conference presentations, 1 whitepaper and 2 international projects’ websites.

Within these documents, 29 Industrial Symbiosis case studies are described. Most of them are set in Europe (17), while others are set in Asia (8), America (3) and Australia (1).

The majority of case studies is referred to districts of enterprises (15), or to districts of enterprises and urban entities (8), while a small amount of them is instead referred to industrial parks (3) or to single enterprises.
engaging together (3). Case studies belonging to this last category are all located in Europe. A mixed industry configuration is definitely the most common one, while 8 cases are dominated by a main industry (usually belonging to either “Manufacture of wood and paper products, and printing” or “Manufacture of basic metals and fabricated metal products, except machinery and equipment” sector).

Only in 3 case studies, all set in Europe, the presence of national or supranational incentives is explicitly declared.

Within the 29 case studies, 113 energy flows have been identified. Of these flows, 87 are already existing and 26 are under feasibility study; 50 flows are the result of a national or regional planning, while 63 are spontaneous (the 90% of which is set in developed countries).

End uses of the abovementioned flows have been classified into 9 different categories (categories’ definitions and percent breakdown are given in Table 1).

Table 1: Energy flows’ end uses.

<table>
<thead>
<tr>
<th>Use</th>
<th>Description</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban energy</td>
<td>The flow is used to power an urban entity.</td>
<td>2%</td>
</tr>
<tr>
<td>Urban heating</td>
<td>The flow is used to heat an urban entity.</td>
<td>12%</td>
</tr>
<tr>
<td>Power supplies</td>
<td>The flow is used as fuel in a power plant.</td>
<td>14%</td>
</tr>
<tr>
<td>Public transport</td>
<td>The flow is used as transport fuel in an urban entity.</td>
<td>2%</td>
</tr>
<tr>
<td>Space heating</td>
<td>The flow is used for space heating in an industrial company.</td>
<td>1%</td>
</tr>
<tr>
<td>Process cooling</td>
<td>The flow is used as coolant in an industrial process.</td>
<td>2%</td>
</tr>
</tbody>
</table>

The analysis of energy synergies led to identification of 6 different synergy typologies, represented in Figure 2, together with their percent breakdown.

Suppliers of energy flows are usually enterprises belonging to either “Electricity, gas, steam and air-conditioning supply” (36%) or “Manufacture of basic metals and fabricated metal products, except machinery and equipment” (13%) sector (Figure 3), while receivers of energy flows are usually enterprises belonging to either “Electricity, gas, steam and air-conditioning supply” (28%) or “Manufacture of chemical and chemical products” (14%) sector or to urban entities (16%), see Figure 4.
Figure 4: Industrial sectors of energy flows receivers.

Enterprises belonging to the “Electricity, gas, steam and air-conditioning supply” sector are obviously the only suppliers of “Energy” synergies, while in “Heat” synergies suppliers can also belong to “Mining and quarrying" and “Water supply, sewerage, waste management and remediation” sectors.

“Electricity, gas, steam and air-conditioning supply” sector’s enterprises are the main receivers in “Waste to energy” synergies (71%).

Heavy industries are the main suppliers in “Wasted heat recovered” synergies (48% of flows comes from “Electricity, gas, steam and air-conditioning supply” and “Manufacture of basic metals and fabricated metal products, except machinery and equipment” sectors), while main receivers are light industries (28% of flows goes to “Administrative and support service activities”, Agriculture, forestry and fishing”, “Manufacture of food products, beverages and tobacco products” and “Manufacture of wood and paper products, and printing”) and urban entities (40%).

4. Discussion and future research

This work advances the understanding of contextualisation in Energy Symbiosis cases. It’s built upon existing published cases and therefore aims at creating a unique knowledge repository for Industrial Symbiosis cases. End uses of energy flows and synergy typologies have been classified so as to simplify and enhance further researches on the topic. 29 case studies from different geographical areas have been considered. Most of the identified cases are set in Europe, where symbiosis cases seem to be less pushed by national and regional plans and agreements and more due to spontaneous arrangements between autonomous enterprises than in the rest of the world.

A vast majority of industrial districts and parks described in the analysed document include an energy and heat production plant, which is why “Electricity, gas, steam and air-conditioning supply” industry sector is massively involved in energy flows exchanges.

Energy recovery is not a very common practice, probably due to technical barriers such as the impossibility to effectively store electricity and thus the need of having compatible load profiles to realize the flow exchange (Benedetti et al., 2015). Innovative demand side management techniques and consumption control tools (Benedetti et al., 2016) might enable a wider diffusion of this practice.

Material wastes (mostly from agricultural and urban areas) are largely used to generate electricity, but are usually not directly treated by production companies. Most of them are in fact sent to power plants and the electricity produced is then delivered to final users through the grid. Some improvements might be obtained in this field by enhancing the diffusion of energy onsite production equipment and the creation of logistic platforms, also allowing to reduce energy losses and increase efficiency.

Wasted heat recovery synergies usually involve a heavy industry as a provider and a light industry as a receiver, so this kind of exchanges might be enhanced by promoting networks amongst companies of these two typologies.

The results of the first data analyses suggest the possibility to define an innovative systemic approach to IS implementation, using existing cases to define schemes and standardize patterns to be applied serially. Further research activities are under development to update the knowledge repository with additional case studies (using new keywords identified, reported in Appendix B), to complete data analyses and extract more information from the database, and to extend the presented methodology to non-energy flows.

Acknowledgments

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References


Appendix A: References of documents used for the creation of the Energy Synergies Database

| Scientific papers                     | Bain et al., 2010; Chertow et al., 2008; Chertow, 2007; Costa and Ferrão, 2010; Dong et al., 2013; Dong et al., 2014; Dong et al., 2016; Earley, 2015; Golev et al., 2014; Li et al., 2015; Martin, 2015; Mirata and Emtairah, 2005; Notarnicola et al., 2016; Pakarinen et al., 2010; Park et al., 2008; Pearce, 2008; Sokka et al., 2011; van Beers et al., 2007; Velenturf, 2016; Yang and Feng, 2008; Yu et al., 2015; Zabaniotou et al., 2015. |
|                                     | http://www.ucer.camcom.it/comunicazione/notizie/pdf-2014/All2_Risultati_prog.GREEN.pdf [last accessed 23rd June 2016] |
|                                     | http://www.enea.it/it/pubblicazioni/pdf-volumi/ExperiencesofIndustrialSymbiosisinItaly_Proceedings.pdf [last accessed 23rd June 2016] |

Appendix B: New keywords that will be used to update the Energy Synergies Database

<table>
<thead>
<tr>
<th>New keywords</th>
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<tbody>
<tr>
<td>“Industrial Ecology”; “Eco-town”; “Industrial park”; “Eco-industrial park”;</td>
</tr>
<tr>
<td>“Waste products”; “Reuse”; “Recover”; “Synergy development”; “Resource</td>
</tr>
<tr>
<td>efficiency”; “Utility synergies”; “Ecologically equipped industrial areas”.</td>
</tr>
</tbody>
</table>