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Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy

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A B S T R A C T

Last years have seen a surge of Industrial Symbiosis (IS) development in association with ad-hoc widespread policies to encourage more circular and sustainable practices in the manufacturing sector. Developments in Europe, despite having attracted less attention in the literature, have been significant, driven both by public and private initiative. This paper provides an updated overview of IS activity in Europe, with a mapping of key networks, and a study of prevailing typologies of networks, size, geographical distribution and main streams/ resources traded. The analysis is based on a combination of desk research, gathering of primary data from case studies, a survey to IS network facilitators (n = 22) and in-depth interviews and focus groups (3) with IS practitioners, policy officers and industry representatives (n = 25). The analysis identified pockets of IS activity across all Europe, although varying in nature, resources exchanged and scale and scope of the initiatives. The average size of the mapped networks is approx. 473 members, but the median is approx. 100 members, which indicates high variability of sizes. The geographical scope of the synergies also seems to be dependent upon the following factors: 1) the type of waste stream/by-product; 2) transport costs and 3) market value of secondary materials. Types of waste streams exchanged common to most networks, are chemicals (e.g. chemical base products), biomass and agriculture by-products, wood and wood pellets, plastics, reusable construction materials, equipment, inert waste and water (different qualities including industrial water), residual heat and steam. The paper also discusses key obstacles facing IS development in Europe highlighting: 1) weakness of economic incentives given the low margin of IS projects associated to undeveloped secondary markets; 2) geographical variation of incentives and drivers, given differences in policy frameworks and support mechanisms (e.g. landfill tax levels) and 3) legislative issues that make transport over geographic boundaries extremely complex and administratively burdensome. Finally, the paper concludes with a general discussion of the potential of IS to contribute to the transition to the circular economy (CE) in Europe and identifies some key areas of future research.

1. Introduction

1.1. Industrial symbiosis and the Circular Economy

Industrial symbiosis (IS) is a system approach to a more sustainable and integrated industrial system (Chertow and Ehrenfeld, 2012), which identifies business opportunities that leverage underutilised resources (such as materials, energy, water, capacity, expertise, assets etc.) (Lombardi and Laybourn, 2012). IS involves organisations operating in different sectors of activity that engage in mutually beneficial transactions to reuse waste and by-products, finding innovative ways to source inputs and optimising the value of the residues of their processes. IS has also been seen as a practical approach to "*enhance resource efficiency, reduce waste generation and GHG emissions* via *material, energy, by-products exchange between different processes and industries*" (Sun et al., 2017), and thus has been included at the core of strategies to promote the transition towards the Circular Economy (CE), through promoting flows of resources through multiple cycles across different sectors of activities and supply chains.

The concept of the CE has recently attracted increasing policy and

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business attention. It proposes an alternative to the predominant 'take-make-consume-dispose' linear model of production and consumption, which is '*restorative and regenerative by design*' and where resources are maintained at the '*highest utility and value*' for longer (EMF, 2013). The concept of the CE is intuitively easy to understand, however, realising it in the practice is a complex issue. Industrial symbiosis has been identified as a practical approach to close the loop of manufacturing processes by transforming waste of different processes and industries in feedstock to other industries and, therefore, enabling the transition from wasteful to closed loop systems (Wen and Meng, 2015), where materials are kept in productive cycles for longer reducing the pressure on primary raw materials and impacts linked to waste generation and GHG emissions. IS is considered a solution to enhance environmental sustainability while achieving economic benefits simultaneously and one of the practical routes to embed CE in manufacturing activities (Lieder and Rashid, 2016). Policy developments in both China and Europe have attempted to accelerate the transition towards the CE (McDowall et al., 2017).

In China, the CE law (2008) has been supported by specific targets and programmes included in the 12th and 13th five-year plants (Matthews and Tan, 2011). Eco-Industrial Parks and Economic Zones have been the target of many of these initiatives to use waste as a resource (see, for example, Wen and Meng, 2015; Yuan and Shi, 2009). From the EU side, building on the Europe 2020 strategy, the European Commission (EC) launched a revised CE package in 2015 'closing the loop_ An action Plan for the Circular Economy (EC, 2015), which includes measures covering the whole cycle of materials: from production and consumption to waste management and concrete measures to stimulate the market for secondary raw materials. The programme specifically refers to the role of IS as an innovative approach to transform '*waste or by-products of one industry to become inputs for another*' and proposes that the revision of the waste directives contributes to clarify rules on by-products to create a level-playing field for IS in Europe.

While numerous case studies analyses assess the structure, conditions and performance of IS initiatives in Europe (Domenech, 2010), a comprehensive vision of IS activity in Europe is still missing. This paper undertakes a rigorous assessment of current initiatives in Europe, based on a thorough mapping exercise and provides insights of the nature of IS activity in Europe. Section 2 includes an overview of the state of IS literature in Europe. Section 3 presents the methodological approach for the study; Section 4 provides a mapping of IS initiatives in Europe and discusses its main characteristics; Section 5 discusses barriers, drivers and challenges for IS in Europe, while Section 6 highlights potential areas of contribution of IS to CE strategies in the manufacturing sector. Finally, Section 6 draws conclusions and outlines areas for future research.

2. IS activity in Europe: findings from the literature

A literature review of IS in Europe reveals three main streams of contributions around IS: 1) the first stream of contributions relate to the reporting and review of case studies of IS in Europe; 2) the second main stream relates to contributions to the development of assessment frameworks for IS activity; 3) the third key area of research addresses main drivers and policy interventions for IS, including comparative analyses.

Departing from the Kalundborg case study, often referred to as model of IS networks (Jacobsen, 2006), recent years have seen the 'unveiling' (Chertow, 2007) and reporting of IS case studies as examples of strategies for increasing resource efficiency and resource recovery. Industrial symbiosis activity in the Nordic region was mapped in the 2015 report '*the potential of industrial symbiosis as key driver of green growth in Nordic regions*'. This report includes references to institutional arrangements, policies and economic structure conditions driving adoption of IS solutions. The report points at different types of strategic patterns ranging from top-down pro-active policies in Denmark and Finland to more bottom-up business driven approaches in Iceland, Norway and Sweden. EC's funded research projects have also reported progress of IS implementation in Europe. Evans et al. (2016) gathered a database of industrial symbiosis case studies and linked exchanges as part of the EC H2020 funded project MAESTRI '*Energy and resource management systems for improved efficiency in the process industries*'. The database registers 46 case studies reported in the literature, 35 of which correspond to analysis of EU based networks in 6 EU countries, Italy, Sweden, UK, Germany, Denmark and Portugal. UK and Italy register most of the cases as examples of facilitated synergies by NISP and NI IS in the UK and ENEA in Italy. Another EU funded project on eco-innovation included a survey on eco-innovation initiatives in Europe and internationally (Sofies, 2014). The survey registers 116 initiatives in Europe though the scope is wider than IS network and eco-industrial parks to also encompass other green initiatives both at urban and industrial parks (e.g. technology parks, green businesses, etc.). A number of other contributions have reported incipient IS activity in specific regions and industrial areas or have attempted to identify unrealised potential for IS. Taddeo et al. (2012) analyse a chemical cluster in the Abruzzo region, in Italy, to understand existing and potential IS opportunities. The study unveils some IS kernels through exchanges of unreacted silica sand and recovery of spent sulphuric acid and cascading of steam and mineralised water but also points at other areas and opportunities where IS projects could generate economic and environmental benefits. Similarly, Simboli et al. (2014) explore the potential for IS in a motorcycle cluster in Italy. The study unveils inefficiencies in the current waste management of main waste streams and proposes collective management of metal scraps and the creation of a disassembly and recovery local network as potential solutions.

Linked to the above, another key stream of literature has focused on the development of frameworks to IS activity, both conceptually and assessment-based. Boons et al. (2011) proposed a conceptual framework for IS activity. Their conceptual framework contributes to shed insights on the dynamics of IS. The authors distinguish three main interacting dimensions which encompass: 1) the antecedents of the networks, from industrial structure to types of business organisation, 2) the mechanisms for promotion and adoption of IS and, finally, 3) the assessment of societal, environmental and economic outcomes. The authors conclude with a research agenda for a better understanding of the role of institutional conditions and trigger mechanisms for IS. Taddeo et al. (2017) present a framework to understand the evolution of IS in traditional industrial clusters and the technical and non-technical factors that play a role in the promotion of IS solutions. The proposed framework takes into consideration: 1) the geographic and technical specificities of the cluster; 2) level of heterogeneity of the network; 3) degree of participation of stakeholders; and 4) the regulatory system and combines it with a dynamic understanding of the development stages of the industrial cluster. Attempts to provide quantified assessment frameworks for IS have also been undertaken. Martin et al. (2014) proposes the use of a life cycle approach for the quantification of IS benefits. The method is tested in the area of biofuel production, showing potential of IS to reduce the environmental burden and costs associated to biofuel production.

The other main key stream of work focuses on policies and approaches to promote or favour the emergence and development of IS solutions. Despite paradigmatic cases such as Kalundborg, a key question that remains unanswered is why advances in IS implementation in Europe are proven timid and slow. IS literature has tried to answer that question by looking at drivers and barriers to promote IS. Based on analysis of European based case studies, Taddeo et al. (2012) provides a summary of main barriers to IS concluding that IS activity is constrained by regulatory and legislative barriers, but also financial obstacles and lack of 'on the ground support' to IS projects. Zander et al. (2016) study the emergence of cooperation in the wood industry in Germany. While the focus is wider than IS cooperation, encompassing any cooperation for sustainability, the contextual factors contributing to network governance are not dissimilar to others discussed in IS

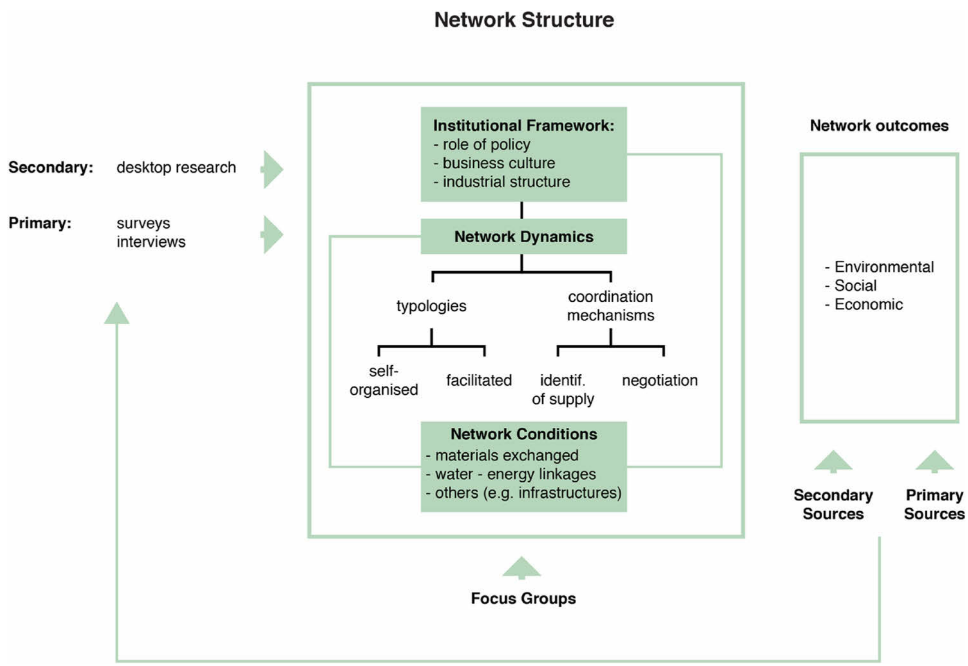

Fig. 1. Research design and data sources.
Source: authors' elaborated.

literature such as trust, exchange of knowledge and information and geographical proximity. Costa et al. (2010) discuss key factors in the development of industrial symbiosis highlighting the role of enabling policy frameworks and of adequate waste policies which incentivise efficient use of underutilised resources. Costa and Ferrao (2010) highlight the role of the policy framework to enable a process of interaction between stakeholders and aligning strategy and policy action, combining top-down and bottom-up initiatives, to support the emergence and development of IS. Similarly, Paquin and Howard-Grenville (2011) differentiate between serendipitous and goal-directed network processes in IS development. Serendipitous processes can generally be observed in the initial stages of self-organised networks. In these cases, network benefits and economic drivers are strong and firms have easy access to one another and cooperate to create value. The pace of development though may be slow and, generally geographically constrained; On the other hand, Goal-directed network processes may accelerate the expansion of the network through alignment of strategies. Both processes may play different roles at different stages in the evolution of networks.

The literature review reveals that while numerous case studies analysis which assess the structure, conditions and performance of IS initiatives in Europe exist, an overall updated overview of IS activity in Europe is still missing. This paper aims to contribute to this by providing a descriptive mapping of IS in Europe and identifying key characteristics of IS networks in Europe. The paper also points to key drivers and obstacles of IS activity in Europe. Section 2 presents the methodological approach for the study; Section 3 provides a mapping of IS initiatives in Europe and discusses its main characteristics; Section 4 discusses drivers and challenges for IS in Europe, while Section 5 provides highlight potential areas of contribution of IS to CE strategies in the manufacturing sectors and points to elements that still need addressing to maximize its contribution. Finally, Section 6 draws some conclusions and suggests areas for future research.

3. Methodological notes

The paper reports the findings from a EC funded project "Cooperation fostering industrial symbiosis: market potential, good practice and policy actions" (act No 409/PP/2014/FC Lot 3), which main focus is to provide an overview and assessment of IS activity in Europe. Data was gathered through a combination of secondary and primary data sources. Primary sources included: a) an online survey to existing IS facilitated networks in Europe (n = 22), which was addressed at a strategic sample of network coordinators and IS practitioners who act as facilitators including both private and public organisations and PPPs_previously contacted by phone, b) in-depth interviews (n = 25) with key stakeholders, including IS network facilitators and coordinators as well as policy makers and civil servants working in the area of IS and related policies and c) finally, three focus groups were conducted in London, Brussels and Rotterdam with representatives from industry, IS network coordinators and policy-makers. All primary data, including the survey, interviews and focus groups, was collected between March to September 2018. The design of the survey covered the following topics: 1) characterization of the network, including structure, funding and activities offered; 2) network participants and sectors of activity represented; 3) Types of resources exchanges; 4) impact of the network (e.g. landfill diversion, CO2 savings, etc.); 5) drivers and obstacles for IS; 6) the role of facilitation and 7) enabling policy frameworks for IS. Similarly, in-depth interviews revolved around a similar set of topics, but provided further flexibility to elaborate on the key drivers and obstacles faced by IS networks and the discussion in some depth of policy approaches to promote IS in Europe. All interviewees had practical experience in the field of IS either from the facilitation or policy-making side. Interviews were conducted face-to-face or by-phone (conference call). Finally, the focus groups, organized in the three cities discussed main obstacles to upscale IS initiatives and different policy mixes and areas where EU coordinated action could add value to promote IS. Additionally, a review of case studies based on the combination of both desk research and primary information gathered through the survey and interviews, was undertaken to identify main characteristics defining the dynamics of IS, typologies of network, content of the transactions and scale of influence of IS networks in Europe. Fig. 1 summarizes key aspects of the methodological framework. Main sources of primary data relied mainly on facilitated initiatives, where there was a third party coordinator. There are some limitations to the methodological design adopted. Findings from the survey thus mainly reflect drivers and obstacles to IS from the coordinator/ facilitator point of view which may differ from the drivers and obstacles perceived and experienced by firms and other types of IS networks (e.g. self-organised networks). The focus groups partly addressed this issue, by including participants from the private sector among other stakeholders as well as representatives from self-organized activity.

4. Findings: overview of IS developments in Europe

4.1. Mapping IS developments in Europe

The mapping exercise suggests a number of differentiated patterns of IS networks in Europe. Fig. 2 summarises key characteristics of established networks in Europe. Table A1 in the appendix I, provides further detail of the mapped networks.

The mapping suggest that IS activity in Europe is very diverse in terms of its nature, emergence, development patterns and content of the transactions. Geographical scope and coordination mechanisms vary across initiatives. The sections below discuss key characteristics of IS in Europe. The mapping exercise has mainly relied on information from 'formalised' networks, those networks that report activity in the area of IS, whether it is self-organised, planned or facilitated. However, as acknowledged previously, it is likely that pockets of IS activity are happening in other manufacturing and industrial clusters throughout Europe. The mapping, where possible, also considers IS activity 'unveiled' in the literature which is undertaken spontaneously by manufacturing activities. See, Wolf et al. (2007) for the wood-paper industry in Nordic countries or Domenech and Davies (2010) for steel and construction material cluster in Sagunto (Spain). However, **further research is needed to map other IS activity in manufacturing clusters in Europe**.

4.2. Typologies of networks

The literature, generally, classifies IS activity into two main groups: **1) self-organised activity**, emerging as the result of direct interaction among industrial actors; **2) facilitated networks**, those that have a third party intermediary who coordinates the activity (Baas, 2011) and **3) planned networks**, which result from a central plan or vision, generally for a specific industrial area, which includes shared infrastructures and services and coordination/ promotion of IS exchanges.

The mapping exercise undertaken in this research identified examples of IS activity following the three typologies mentioned above. Most of the examples of self-organised networks come from Northern countries and date back to the 1960s or earlier. Among, self-organised networks, the case of Kalundborg is generally refer to as a model for IS. IS activity was initially motivated by scarcity of freshwater for the manufacturing sector in the area and driven by economic gains and cost-saving opportunities, generally linked to common development of infrastructure. Reuse of waste heat, steam and energy created additional opportunities for companies to deepen collaboration. It is also important to note that most companies in the initial Kalundborg network were and still are sustainability leaders in their sectors and there was an open dialogue between CEOs on business sustainability issues coordinated through an informal social network (Domenech and Davies, 2011).

Building on the experience of Kalundborg and widespread adoption of district heating networks, a number of eco-industrial park initiatives and IS networks have been established in Scandinavia and neighbouring countries. They tend to have a strong focus on reutilisation of waste energy and heat through combined heat and power (CHP) systems, district heating networks and other opportunities to reutilise waste heat. Specific instruments have been put in place to favour these types of synergies. In Sweden, for example, the local investment plans (LIP) and the Climate Investment Programme (KLIM) have funded IS projects. The programmes' aims include promoting ecologically efficient systems, increasing the reuse of energy and material resources and improving circularity of nutrients. Local authorities are invited to develop local strategies in collaboration with local stakeholders in projects that generally have a 3–4 year span. LIP and KLIM generally provide 30% of funding for physical infrastructures (eukn, n.d.)[1] and have contributed to fund projects in Händelo and Lindberg, where waste heat of a cardboard mill was sent to a district heating network.

IS initiatives in key sectors such as forest industry and paper, chemicals, metals, mining and construction materials have also developed in several regions. Examples of IS activity between the wood and pulp and paper sectors in countries like Sweden and Norway are common. In an analysis of the forest industry in Sweden, Wolf and Petersson (2007) found that over one-third of the Swedish forest industry investigated in the study maintained IS transactions with neighbouring companies, involving energy, heat and material exchange. Monteras network is an example of this (Baas, 2011).

From the analysis, **self-organised networks seem to share some commonalities**: 1) they operate at the industrial estate level or local level; 2) they are generally linked to a clustering of manufacturing activities, with some primary sectors involved; 3) they have emerged as business-as-usual transactions in countries where social licence to operate is shaped by higher environmental awareness and more stringent environmental regulatory frameworks; It is also common to be driven by private actors but with local government support and participation. Networks such as Kalundborg (Denmark), Harjavalta (Findland), Landskrona (Sweden), Kemi-Tornio (Findland) and Handelo (Sweden) follow this pattern.

Styria is another example of a long-standing self-organised network. Some coordination mechanisms have been developed over the years to promote further development of the network, however, most of the recycling/by-product activity is developed as bilateral market transactions (Posch, 2010). Styria in Austria sits in a large manufacturing cluster and the 'Green Tech Valley' and covers activities ranging from agriculture and food processing; wood, metal, paper, textile and plastic industries; and energy production. Self-organised IS activity has also been reported in the chemical clusters in Germany.

There is also evidence of IS activity that has developed in traditional manufacturing clusters as a consequence of the introduction of more stringent environmental regulation. Domenech and Davies (2011) report IS activity in a metal/cement cluster in Sagunto (Spain) driven by the introduction of stricter water, waste and air emissions regulation.

Facilitated networks and planned initiatives have also been developed across Europe. NISP UK is perhaps the most cited example of facilitated model for which there was monitoring of benefits achieved. NISP reported 45 million tonnes of waste diverted from landfill, 39 million tonnes in CO_2 savings, 58 million tonnes of virgin raw materials saved and cost-savings for industry of €1.21 billion over the period 2005–2013 (NISP, 2013). The facilitation model adopted by NISP has been replicated in other regions under different funding structures.

An example of a long-standing facilitated network in Europe is the IS Northern Ireland (previously NISP NI), funded by the business development agency Invest Northern Ireland. The programme, which is based on the NISP model, celebrated its tenth anniversary in 2017. IS NI has reported cost savings of around £9 million, additional sales of £13.5 million and private investment of £1.88 million since 2007. It diverted 392,000 tonnes from landfill and contributed to CO_2 reduction of 261,510 tonnes (Invest Northern Ireland, 2018). NISP Scotland (previously SISP) was initiated in 2007, also following the NISP model. The programme reported 312,295 tonnes of landfill diversion, 194,183 tonnes of CO_2e savings and costs savings to industry of around

[1] See http://www.eukn.eu/e-library/project/bericht/eventDetail/local-investment-programmes-lip-and-climate-investment-programmes-klimp-1-1-can-be-3/

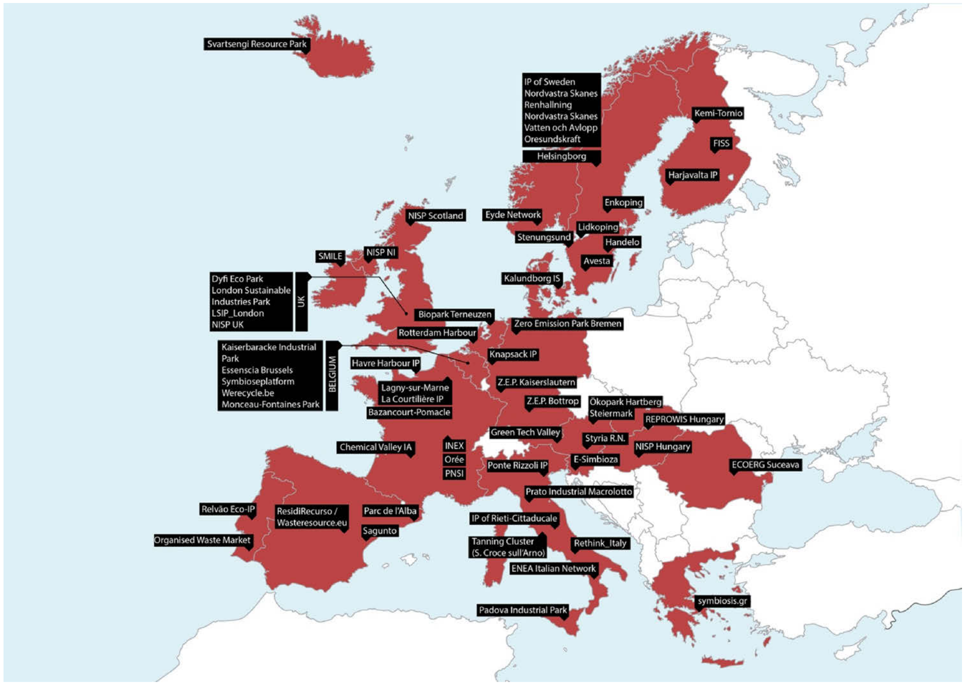

Fig. 2. Mapping of IS networks in Europe.
Source: authors elaborated.

€4.65 million from 2007 until its termination in 2012 (NISP, 2013).

Other facilitated initiatives have been launched in Europe in the last decade. They have different geographical scopes and are inspired by different facilitation models. Most of new facilitated activity has concentrated in eastern European countries (such as Poland, Hungary, Romania, Slovakia and recently Slovenia), with other relevant examples in northern and central Europe (Belgium, France, Denmark and Finland) and southern Europe (Italy, Spain).

Some of them have been active for a short period of time, linked to a project and specific funding stream (Life+, SPIRE, H2020, INTERREG and other European, regional and national funds), but have not managed to transition towards commercial models after funding has ended. Examples of this include programmes in Poland, Hungary, Romania and Finland. In the case of Hungary, Finland and Denmark potential follow-ups of the programmes are currently under discussion or awaiting budget approval.

Example of planned networks, can also be found in different areas in Europe. They generally take the form of eco-industrial parks or brownfield regeneration projects. The London Sustainability Industries Park (UK), in Dagenham Dock (London), is an example of top-down initiative to foster the regeneration of the industrial area part of the London Green Entrepreneurial District, initially led as part of the Thames Gateway Development Corporation and subsequently by the Borough of Barking and Dagenham and the Greater London Authority (GLA). The vision of the development dates back to 2005 and tried to foster a cluster of clean technologies that would take advantage of its location to transform waste streams from the city of London back into resources. Despite a slow start, construction work was completed in 2012 and the area has attracted multi-million facilities in the area of waste management and recycling, including a closed loop plastic recycler, a gasification plant and two AD bio reactors. Also in the UK, a small initiative with a focus on the provision of energy efficient business units is Dyfi Eco-industrial park in Wales. In Germany there have been a number of different initiatives to build Zero Emissions Parks in Bolton, Bremen and Kaiserslautern. In Portugal the Relvao industrial park was developed as a PPP to encourage the revitalisation of the area and the clustering of activities around the recycling and recovering of different types of materials including plastics, biomass, sanitary waste and textiles (Costa and Ferrao, 2010). Attempts to foster IS networks through planned initiatives can also be found in Central Europe, such as Eco-park Terneuzen, in The Netherlands, and in the South of Europe, such as Parc d'alba and the planned eco-industrial Torrent Estadella both in Catalonia (Spain) or the ecologically equipped industrial areas in Italy in the Marche region in Italy.

4.3. Geographical distribution and scope

The mapping reveals pockets of IS in different regions throughout Europe. As discussed above, northern and central Europe concentrate most of the examples of self-organised IS. However, the analysis also demonstrates that bi- and multi-lateral activity is common in manufacturing clusters across Europe, in many cases linked to more stringent regulation and incentives to divert waste from landfill. Attempts to replicate opportunities through facilitated networks have also developed around Europe, including eastern European countries and southern Europe. Performance of these initiatives varies considerably and will be discussed in more detail in the next section. Planned initiatives, generally at a local scale, have taken in most cases the form of eco-industrial park developments and ecologically equipped zones.

When looking at the geographical scope of the networks, this also varies considerably across typologies of networks. Self-organised networks tend to have a local scope. Most core members generally involve neighbouring companies, although, in some cases, transactions may go beyond network boundaries, depending on: 1) the type of waste stream/by-product; 2) transport costs and 3) market value of secondary materials. Planned networks are also predominantly local, as they generally include the sharing of infrastructures and services. Facilitated activity have demonstrated that can work at different scales with National programmes, such as the former National Industrial Symbiosis (NISP), in the UK, and programmes in Hungary, Finland, France or Denmark which have tried to promote IS synergies nationally, in many cases complemented by regional initiatives or programmes (following the methodology of the UK NISP).

The scale of IS networks is dependent upon: 1) information flows with regards to types of waste/by-products produced by other companies/facilities; 2) understanding of opportunities derived from IS transactions and 3) know-how and resources for implementing the IS synergies. These elements require a degree of collaboration among businesses to favour communication and willingness to find collective solutions. These elements are likely to emerge spontaneously between companies which are co-located, but less likely to happen when activities are not co-located unless there is a third party which acts as co-ordinator and centralises information to identify opportunities. Another key factor influencing the geographical scale of networks is transaction costs, which include not only transport costs but also intermediation and negotiation costs. This is very relevant in the case of IS, where marginal value of the waste streams tends to be low or even zero or negative in some cases (e.g. C&D waste).

4.4. *Types of waste streams and distance*

Types of waste streams exchanged in the network are dependent on the sectorial composition of the network. Among main resources reported in the survey, which are common to most networks, are chemicals (e.g. chemical base products), biomass and agriculture by-products, wood and wood pellets, plastics, reusable construction materials, equipment, inert waste and then water (different qualities including industrial water), residual heat and steam.

Interviewees and focus groups have highlighted that the role of distance is highly dependent on the resource type, with different resource having substantially different radius for IS activity. Qualitative findings from this research, suggest that the geographical scope for different types of resources depends on: 1) type of waste stream and its physical and chemical characteristics; 2) value of the waste stream and 3) geographical distribution of resource recovery facilities. In general terms, bulky low value waste, such as construction and demolition (C&D) waste, tends to be restricted to local (city/ metropolitan area) transactions, while low volume high value resources, such as cobalt, may have an international market. Steam and waste heat exchanges are necessarily restricted to the local level, as they cannot be transported over long distances. Common metals such as steel and aluminium are generally traded in local/regional markets while more valuable and scarce metals and minerals can travel considerable distances, as shown in Fig. 3.

Although, empirical research in this area is scarce, these findings seem to be in line with Jensen (2016), which explores the role of geographical distance and industrial diversity as key variables influencing travel radius of resources exchanged. Jensen (2016) found: 1) high correlation between area of industrial activity and presence of completed synergies; 2) distance travelled by resources was an average of 34 km; 3) synergies where the distance was greater than 34 km tend to occur in areas with lower geospatial diversity (Jensen, 2016). Similarly, Velenturf and Purnell (2017), based on a case study in the Humber region (UK), concludes that: 1) most companies can identify potential users of their resources and by-products from direct contacts and 2) that 73% synergies tend to happen within a 75-mile (120 km) radius. Findings from the mapping and survey seem to align with these results, also demonstrating that **self-organised IS activity is present in manufacturing clusters across Europe**, and density of transactions tend to diminish with distance.

4.5. *Size of networks*

Size of networks also differs considerably across initiatives in Europe. Variation tends to happen depending on the geographical scope of the network (Jensen et al., 2011). Regional/national networks naturally tend to have a higher number of members while local networks tend to be smaller in size (measured by number of members but also volumes of transactions). Networks included in the mapping exercise, for which there is data, had an average size of 473 members, but the median is approx. 100 members, which indicates the variability of sizes and significance of networks with local scope. Comparing network size and number of synergies does not seem to follow a linear patter, as some networks seem to be more successful in recruiting members and forging synergies between them. While previous research (Jensen, 2016) found high correlation between the size of the network, diversity of sector/activities and number of transactions, the scope was restricted to data from NISP regional programmes, which all followed a harmonised framework of implementation and quantitative reporting of synergies. In here, the wider scope of this study, which includes different typologies of networks (self-organised, facilitated and planned), makes the comparison between size and performance more complex, as other factors surrounding the structure of the network and its scope seem to play a role. Data gaps and lack of harmonised quantitative indicators limit the analysis and the ability to derive ultimate conclusions regarding the role of the size in network performance. The question whether larger networks (with more members) are more successful in promoting synergies than local, closely-knitted networks, such as Kalundborg, remains unanswered. One may argue that there may also be a trade-offs between the size of the network and the ambition and complexity of the project they embark with. Domenech and Davies (2011), suggest that closely-knitted networks can lead to embeddedness favouring initiation and development of IS synergies. Facilitation models have tried to reproduce embeddedness mechanisms in larger networks. From the review of networks in Fig. 2 (and Table A1 in Appendix A), the performance of the network in terms of number of synergies and reported impact does not necessarily seem to correlate with the number of members in the networks. Nevertheless, the lack of standardised measures of the performance of networks constitutes a main obstacle in establishing the role of size and diversity in the realisation of synergies.

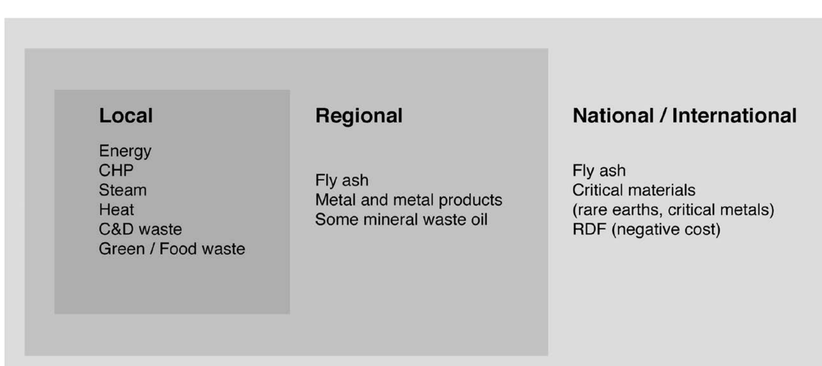

Fig. 3. Types of resources traded by area.
Source: Authors' own elaboration as part of EC project "Cooperation fostering industrial symbiosis: market potential, good practice and policy actions".

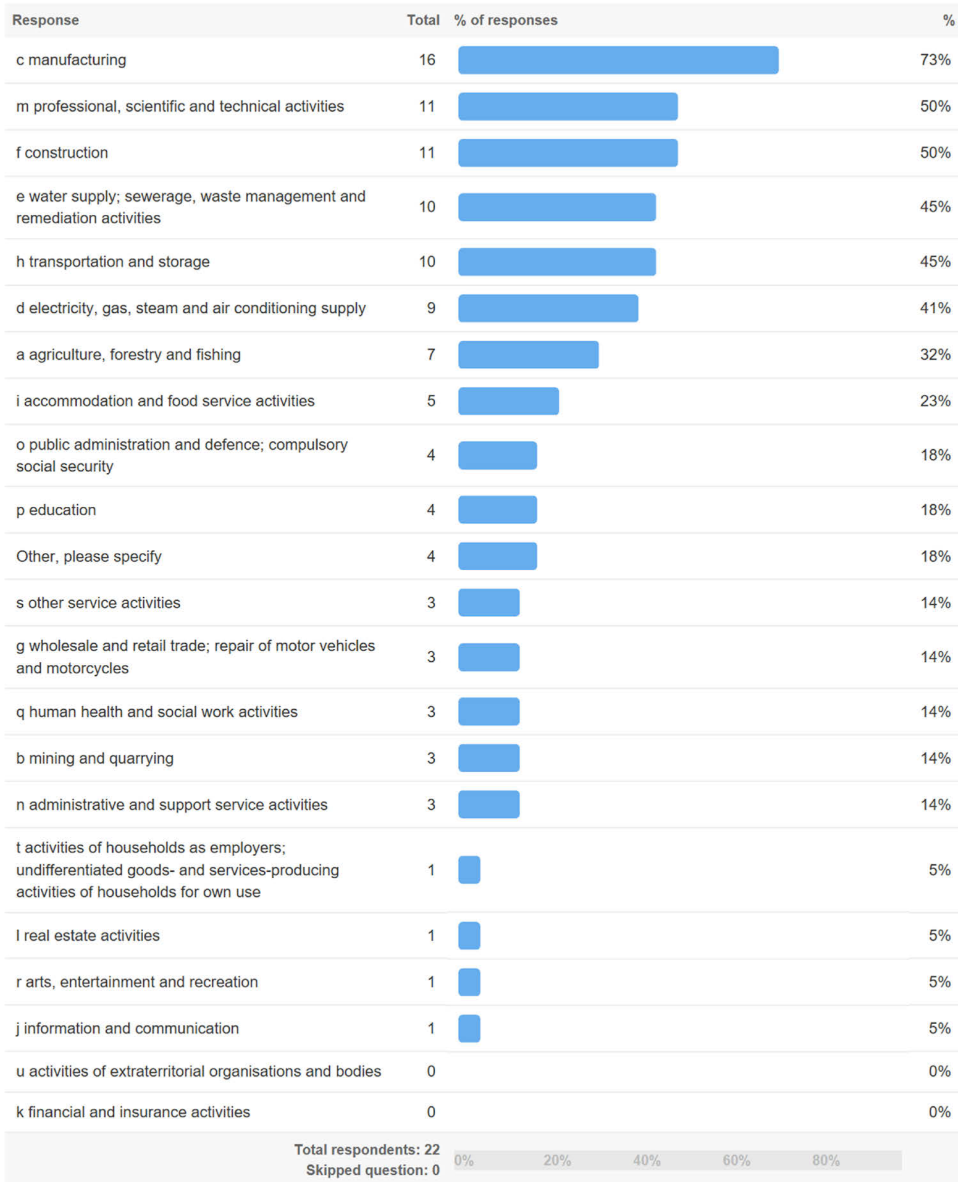

Fig. 4. Main sectors represented in IS networks.
Source: Authors' own elaboration as part of EC project "Cooperation fostering industrial symbiosis: market potential, good practice and policy actions".

4.6. *Key sectors*

In terms of key sectors, there is also considerable variation. Fig. 4 reflects findings from the survey in terms of representation of sectors of activity in facilitated networks and highlights the relevance of manufacturing activities. In terms of specific activities within the manufacturing sector, primary sectors such as pulp and paper, power production, metal, mining and construction materials tend to play an important role in IS networks, acting, in many cases, as anchor tenants of the network (see, for example, Kalundborg, Monteras and the chemical clusters in Germany). However, a characteristic of IS networks is the diversity of sectors involved and the opportunities created across activities and supply chains. Sectors such as waste and water management and recycling are also important players in IS networks.

Diversity, which was also found to be a crucial factor promoting IS according in Jensen (2016), has been stressed in the interviews for the networks investigated as playing a primary role in developing successful synergies. Table A1 in Appendix I provides further detail of sectors represented in the different networks included in the mapping.

4.7. *Economic, environmental and social benefits*

The survey to IS networks reported economic, environmental and social benefits associated with IS activity (see Fig. 5). In most cases, the networks report resources exchanged and CO_2 savings associated with IS activity as main environmental benefits. On the economic and social side, most networks report costs savings and other additional benefits such as jobs created and safeguarded and new revenue streams. Thus, IS can deliver numerous co-benefits towards a low carbon development as proposed by the IPCC.

As mentioned above, the mapping exercise has identified important data gaps in the way IS networks are monitored and evaluated. Fig. 5 also highlights by the big % in grey lack of accountable data for the monitoring of impact of IS networks. Very few studies and initiatives have provided quantification of IS benefits in Europe (Karlsoon and Wolf, 2008; Van Berkel, 2010; Sokka et al., 2011). Quantification methods have used a combination of tools from the industrial ecology field and have generally been applied to regional or local networks. Wolf and Karlsson (2008) use an optimisation method to assess

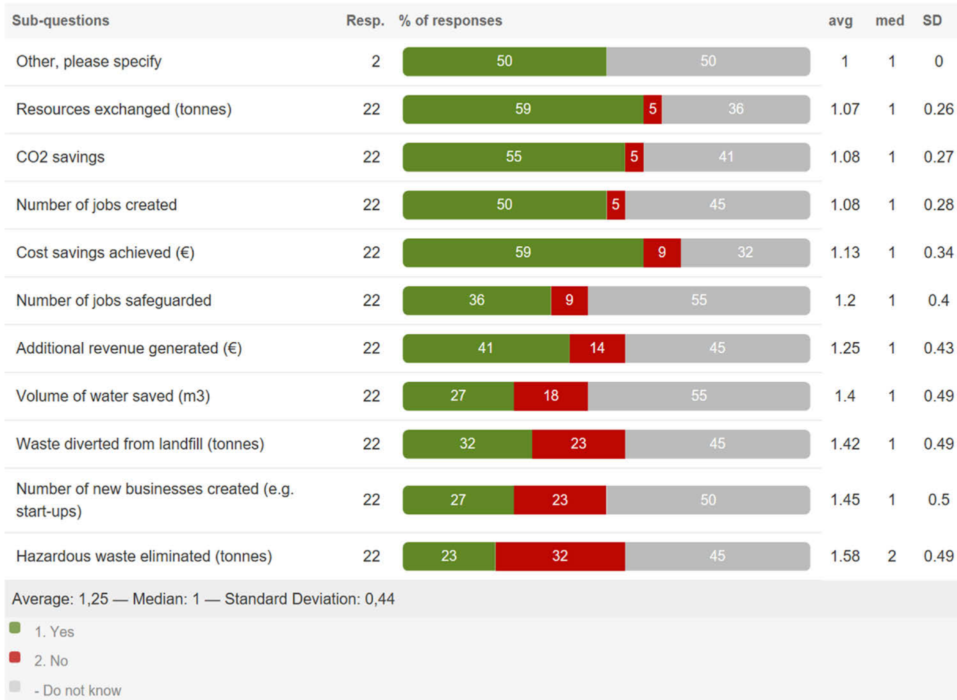

Fig. 5. Key economic, social and environmental impacts of IS.
Source: Authors' own elaboration as part of EC project "Cooperation fostering industrial symbiosis: market potential, good practice and policy actions".

Table 1
Reported Impact of Facilitated IS Networks in Europe.
Source: authors compiled as part of EC funded project "Cooperation fostering industrial symbiosis: market potential, good practice and policy actions".

	NISP Scotland	NISP Hungary	NISP UK	Romania ECOERG	Invest NI	PNSI	SMILE[a]
Period	2007-1011	2010-2012	2005-2012	2009-2011	2007-2017	2015-2017*	2016-2017
Network size		800 +	15.000 +	200 +	1.900 +	588 +	1.581 +
Number of synergies (realised)	127 completed	72 completed		200 synergies	448.00	958 potential	1882 potential
Scope	regional	regional / national	regional / national	regional / national	national	regional / national	regional / national
Landfill diversion (t)	62,459.00	594.16	6,428,571.42	265,000.00	39,200.00	13,954.50	7342.00
GHG savings (t CO2)	38,836.60	1875.67	5,571,428.57	65,000.00	34,000.00	1081.50	
Virgin raw materials saved (t)		619.00	8,285,714.28		24,000.00	3920.00	
Hazardous waste saved (t)			285,714.28		1270.00		
Water savings (m3)		13,017.98	10,142,857.14				
Cost savings (Mill EUR)	0.93		172.85		2.77	0.25	1.25
Additonal sales (in mill EUR)	0.4				1.79	3.47	
Private investment (in mill. EUR)	1.602		243		0.211	0.037	
Jobs (number)						3	
Total Budget (in mil. Euros)	0.256	0.396	6.341	0.4403			0.15

[a] The programme has been running 2010-2017. 2010-2016 just as a web-based platform with little to no facilitation. 2016–2017 the network provided technical support. Budget is approx. €150,000 per year and about €600,000 in total. Here the calculations are based for 2016–2017 where there was technical support (comparable to the rest of the networks considered).

reduction of GHG associated to IS compared to standalone activity in the forest industry, covering the activity of a pulp mill, paper mill and biofuel production. Van Berkel (2010) and Jacobsen (2006) use direct estimation of benefits associated with IS activity for Kalundborg. Following Van Berkel (2010), the quantification may refer to three different processes that may occur through the synergies: conversion, substitution and avoidance. Conversion refers to processes related to transforming a previously-wasted material, water or energy from its source to its treatment and processing to be transformed into a suitable feedstock. The substitution process refers to substitution of original (virgin) stock by a secondary source and adjustments of processes/ quantities if required to compensate for the lower grade of the resource and, finally, avoidance processes that refer to the elimination or reduction of disposal costs. NISP developed possibly the most comprehensive method of monitoring impact in Europe based on identification of realised benefits across a number of social, economic and environmental indicators. NISP monitoring system has been adopted by other facilitation initiatives in Europe that have followed the NISP model. Table 1 includes main impacts reported by facilitated activity in Europe.

In most of the mapped cases, however, networks do not have any monitoring framework in place and lack harmonised mechanisms of data collection and quantification of benefits. Opportunities exploited through the network are largely unquantified, although generally, some general understanding of areas of benefits are perceived by members and facilitators. This happens across all categories of potential benefits (environmental, social and economic). This has been confirmed by the survey and interview findings, suggesting substantial economic, environmental and social benefits associated with IS activity, which go largely unreported for a number of different reasons, such as resistance of companies to provide data, lack of coordination mechanisms that collect and maintain the data and lack of technical capability and time

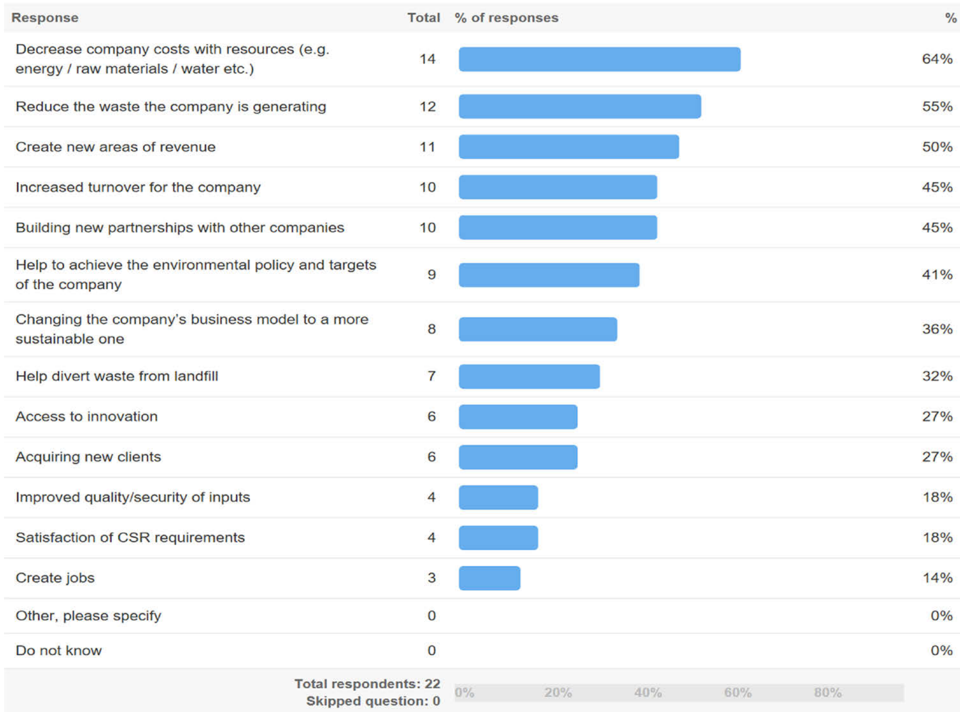

Fig. 6. Key drivers for IS activity.
Source: Authors' own elaboration as part of EC project "Cooperation fostering industrial symbiosis: market potential, good practice and policy actions".

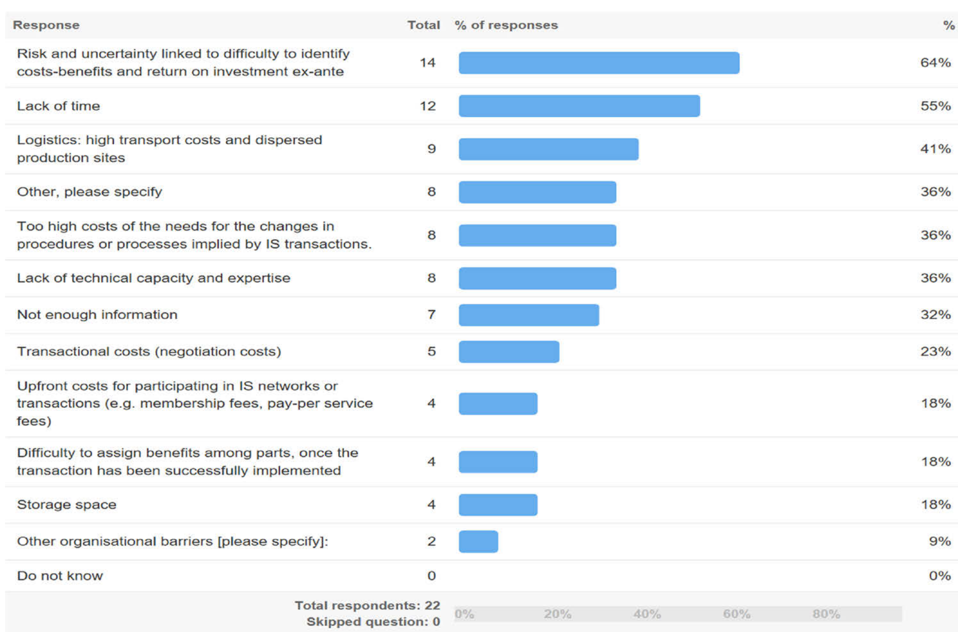

Fig. 7. Key barriers to IS.
Source: Authors' own elaboration as part of EC project "Cooperation fostering industrial symbiosis: market potential, good practice and policy actions".

to analyse the data. Benefits include costs savings linked to reduced waste and environmental management costs but also savings in sourcing of primary materials. This is consistent with the information collected for the few data points where information exists, and include both spontaneous and facilitated networks. Some examples of benefits reported by self-organised activity are summarised in Table.

5. Barriers, drivers and challenges

The mapping and insights from interviews also suggested that Key drivers for companies to engage in IS networks are a combination of economic and environmental concerns, as shown in Fig. 6. It is interesting to note the strengths of the economic drivers here.

As highlighted in the interviews many of these drivers are closely connected with framework conditions and the role of policies shaping the playing field of economic actors. A number of facilitated and planned initiatives promoted by ad hoc policies and supported by PPPs and public investment have also had difficulties to continue operating as purely commercial programmes (e.g. NISP, UK or FISS, Finland). Although a lack of harmonized framework for measuring and reporting performance have resulted in the lack of quantitative indicators to measure IS activity impact, current initiatives seem to generate environmental benefits and cost savings, yet probably not at a scale that is feasible if such indicators existed.

Current difficulties to scale up IS activity are acknowledged in the interviews. Speaking of the complexity of realizing IS synergies one IS practitioner commented:

> "(…even when there are potential matches….the success rate is around 10% due to the fact that there are many conflictual aspects. Main obstacles may include technical, logistic, regulatory issues; also, the companies may not have the time or resources to embrace the project or it's too expensive or simply they have not found the right company to make it happen. The regulatory issues however seem to be the most prominent ones. It would be much easier if the regulations could be more flexible (here referring to the concept of waste in current EU legislation). The end of waste criteria has helped but there are still a lot of issues that remain".

Fig. 7 shows main obstacles reported by IS facilitators in the survey. Obstacles range from risks and uncertainty issues linked to IS exchanges to lack of time (specially in the case of SMEs) and a range of transaction costs including transport and learning costs.

Tackling these main obstacles calls for novel ways to ease transactions, supported by integrated policy mixes that address main systemic factors negatively affecting the adoption of IS solutions in Europe. The interviewees referred to specific instruments such as policies to reduce CO_2 and measures to promote landfill diversion (e.g. landfill tax) playing an important role in shaping the feasibility of IS projects. However, they also pointed at measures such as simplifying the process of acquiring end-of-waste criteria, harmonizing the legal definition of by-product, advanced assessment frameworks and cost-benefit analysis and other measures to ease transaction costs such as facilitated networks and resource knowledge IT systems as potential catalyzers to acceleration adoption of IS practices.

In here, learnings from pioneering policies in other parts of the world such as China (see, for example, Matthew and Tan, 2011; Jiao et al., 2018 and Su et al., 2013) and Korea (see, Behera et al., 2012) could help to identify favorable framework conditions, some of which could be adapted to the EU institutional framework and inspire areas of policy intervention. Some first steps in this direction have been promoted by the recently launched CE circular Economy package, which for the first time explicitly refers to IS as core strategy to promote circularity.

6. The contribution of IS to promote CE in the manufacturing sector

As mentioned above, IS has now been officially recognized as a practical approach to promote CE and is embedded in EU law through the final ratification of the EU CE package in July 2018. The new EU circular economy package refers to IS in connection to two main areas:

- As a way to increase circularity in production processes, through more efficient use of by-products, through clarifications in the definition of by-products and further harmonization of practices across MSs
- As a key theme of the innovation, investment and horizontal measures, through expanding the base of knowledge in H2020 projects and as part of R&I investment for cohesion funds and policies

As part of the package, the revised legislative proposals have now included a revised Art. 5 of the waste framework Directive (WFD) to ensure that MSs take action to ensure '*that a substance or object resulting from a production process the primary aim of which is not the production of that substance or object is considered not to be waste, but to be a by-product*' when a number of conditions are met. Further clarification to achieve end-of-waste status have also been added for waste that have undergone recovery processes.

These changes partly address the difficulties highlighted by interviewees stemming from the lack of legislative clarity about the status of industrial by-products and the criteria when a waste ceases to be a waste. It is still unclear, though, how the transposition of these revision to current waste legislative sector will impact the feasibility of IS projects in Europe.

The mapping exercise presented here, has unveiled three key areas where IS has played a role in contributing to a more circular manufacturing in Europe:

- Creating opportunities to increase the reutilization of components and materials through the use of by-products and waste to substitute primary raw materials. The survey pointed to different categories of resources exchanged through IS networks, preventing them to become waste, which included different types of chemicals, plastics, woods of different qualities, biomass, redundant stock, reusable construction materials but also water, steam and energy.
- Identifying ways to reduce structural waste through optimal utilization of underutilized resources and assets (including infrastructures, buildings and space). The study revealed that this was a common feature in eco-industrial parks and other planned activities but also common in networks composed by SME's such as the Tanning cluster in Santa Croce Sull'Arno, in Tuscany, reported by Daddi et al. (2016,2017), where SMEs share wastewater plant and other treatment facilities.
- Promoting projects to reduce overall volume of waste and emissions generated by manufacturing activities. Both Table 1 and Table A1 above report contribution of both self-organized and facilitated IS activity in Europe amounting to several million tonnes fo landfill diversion and GHG emissions saved.

However, for these opportunities to materialize and reach full potential, facilitation and direct support to IS initiatives through specific support mechanisms and policies, including increasing the costs of landfilling and incineration, is needed to enable action and to address key barriers to IS upscaling as discussed in Fig. 7 above.

7. Conclusions

The research presented in this paper has focused on mapping the existing IS initiatives in Europe and identifying their key characteristics. The mapping indicates pockets of IS activity all across Europe, although varying in nature, resources exchanges and geographical scale. The mapping has revealed significant number of self-organised networks in Northern Europe, in countries like Sweden, Denmark or Finland, but also revealed activity in other traditional industrial clusters, including Germany and Italy. An example of a large scale facilitated network was implemented in the United Kingdom (UK), through the National Industrial Symbiosis Programme (NISP), which received investment from the UK government in 2007–2013 and managed to achieve significant environmental and economic returns. The longest standing facilitated IS network is the Industrial Symbiosis Service in Northern Ireland, which has followed the NISP model. Outside the UK, there are examples of the facilitation structures in Finland, Denmark, Belgium, Italy and France, as well as in Central and Eastern Europe (Hungary, Romania, Poland, Slovenia). The latter might be relevant in regards to current political challenges in Europe and the creation of opportunities for those countries to reduce the eco-innovation gap in Europe. While these programmes exhibit large variation in terms of focus and geographical scope, the approach to facilitation has been based on adapting several elements of the UK NISP model. Planned initiatives are not uncommon but generally have a reduced in scale and take the form of eco-industrial parks and environmentally equipped industrial areas. Examples can be found scattered around

Europe (UK, Germany, The Netherlands, Italy and others).

Assessment models for IS activity are rather fragmented and data not always available or consistent across initiatives. However, reported impact suggests that IS activity produced important environmental, economic and social benefits and contributed to increase the circularity of the manufacturing sector, by reducing dependence of primary raw materials and minimizing waste from the system. Thus it could contribute significantly to wider goals of resource security and climate action. However, results from the survey and interviews indicate that IS exchanges still face a number of obstacles in Europe, some of them related to risk and uncertainty and others with low commercial margins of IS projects and transaction costs. Better policies that foster collaborations, bring down transaction costs e.g. via indicators and encourage ambitious targets, are therefore pivotal to disseminate IS and promote more large-scale undertakings.

This research has highlighted three main areas of future research to stimulate IS in Europe: 1) the development of harmonized frameworks of assessment to quantitatively assess the impact of IS in the transition towards Circular Economy, and increase the ability to compare performance against different networks typologies and institutional frameworks; 2) The further understanding of the dynamics of IS emergence to foster the upscaling of IS initiatives and 3) the role of public policy and the key features of institutional frameworks conducive to IS.

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Table A1
Benefits reported by self-organised networks.
Source: compiled by authors based on Jacobsen (2006); Martin et al. (2014); Posch (2010) and Nordregio et al. (2015).

Network	Benefits reported
Kalundborg Source: Jacobsen, 2006	2 million cubic meter/year ground water saved; 1 million cubic meter/year surface water saved; 200,000 t natural gipsum saved 200,000 t fly ash used as secondary material 2,800 tonnes of sulphur saved
Styria Network Source: Posch (2010)	approx. 1 million tonnes of by-products gathered, 780,000 tonnes recycled, 200,000 tons landfilled or incinerated; 25,000 tonnese handed to professional waste management Further, 330,000 tonnes were further identified as potential secondary materials 70 % recycling rate 42 % CO_2 emissions saved 25 % of final energy consumption from renewable sources
Harjavalta Source: Nordregio (2015)	Long-term waste management waste from process (iron cake, etc): 19,000 t/y hazardous waste: 121 t/y Utilisation / special processes energy waste: 351 t/y metals: 181 t/y lead: 83 t/y hazardous waste: 124 t/y recycled paper: 15 t/y household waste: 16 t/y "Utilisation level": 81.8 %
Handelo Source: Martin et al. (2014)	Using an LCA based approach, Martin et al. (2014) identifies benefits associated with integration of bioethanol and biogas in Handelo and associated exchange of by-products and waste materials. The analysis quantifies a significant reduction of GHG emissions in the existing scenario (pre-2009) compared to stand alone production and 3 scenarios point to further opportunities derived from reutilisation of by-products and waste streams for biofuel production. Savings can amount up to 35 % reduction compared to stand alone production. The analysis also shows potential for reduction of acidification, although this depends on the system of reference adopted and a potential negative trade-off with the eutrophication impact category.

Appendix B

See Table B1

Table B1
Mapping of IS networks in Europe.
(Source: authors' elaborated).

Network	Network size	Network scope (local / regional / national)	Number of IS synergies identified	Number of IS synergies completed	Facilitated / planned / self organised	Economic benefits quantified	Social benefits (job creation)	Environmental benefits quantified	Further references to primary data collection
Kalundborg	9 industries	regional	N/A	approx. 50	self-organised	N/A	4.614 jobs	Avoided waste (1997): - 1million m3 of water treatment sludge - 200.000 tons of fly ash and clinker - 80.000 tons of scrubber sludge - 2.800 tons of sulfur CO2 emissions reduced by approx. 300.000 tons annually	Domenech, T., & Davies, M. (2011). Structure and morphology of industrial symbiosis networks: The case of Kalundborg. Procedia - Social and Behavioral Sciences, 10, 79–89. http://doi.org/10.1016/j.sbspro.2011.01.011 Jacobsen, N. B. (2006). Industrial symbiosis in Kalundborg, Denmark. Journal of Industrial Ecology, 10(1), 239–255. http://doi.org/10.1162/108819806775545411 Mikkola, N., & Randall, L. (2016). Growth in Nordic Regions. Nordregio, Johnsen, I. H. G., Berlina, A., Lindberg, G., Mikkola, N., Olsen, L. S., & Teräs, J. (2015). The potential of industrial symbiosis as a key driver of green growth in Nordic regions. Retrieved from http://www.nordregio.se/en/Publications/Publications-2015/The-potential-of-industrial-symbiosis-as-a-key-driver-of-green-growth-in-Nordic-regions/
Kemi-Tornio	7 industries	regional	N/A	5 (riffler waste, ash and ash-mixtures, solid waste, CO2)	mixed model with anchor tenant	estimated at 200 million EUR annually	N/A	N/A	Mikkola, N., & Randall, L. (2016). Growth in Nordic Regions. Nordregio, Johnsen, I. H. G., Berlina, A., Lindberg, G., Mikkola, N., Olsen, L. S., & Teräs, J. (2015). The potential of industrial symbiosis as a key driver of green growth in Nordic regions. Retrieved from http://www.nordregio.se/en/Publications/Publications-2015/The-potential-of-industrial-symbiosis-as-a-key-driver-of-green-growth-in-Nordic-regions/
Handelo	difficult to count due to unclear geographic boundaries; basic interaction between 3 industries	local	N/A	6 (CO2, solid waste, grain, organic waste, wastewater, household waste)	self-organised with anchor tenant	N/A	not substantial job creation from IS	N/A	Eklund, & Gustafsson. (2015). Ten challenges for a sustainable Norrköping (translated from Swedish. in Johnsen et al. 2015). Mikkola, N., & Randall, L. (2016). Growth in Nordic Regions. Nordregio, Johnsen, I. H. G., Berlina, A., Lindberg, G., Mikkola, N., Olsen, L. S., & Teräs, J. (2015). The potential of industrial symbiosis as a key driver of green growth in Nordic regions. Retrieved from http://www.nordregio.se/en/Publications/Publications-2015/The-potential-of-industrial-symbiosis-as-a-key-driver-of-green-growth-in-Nordic-regions/
Eyde Network	33 industries	regional	N/A	N/A	facilitated	not yet clear	3.794 jobs	projects are in early stages, not yet quantified	Nordregio, Johnsen, I. H. G., Berlina, A., Lindberg, G., Mikkola, N., Olsen, L. S., & Teräs, J. (2015). The potential of industrial symbiosis as a key driver of green growth in Nordic regions. Retrieved from http://www.nordregio.se/en/Publications/Publications-2015/The-potential-of-industrial-symbiosis-as-a-key-driver-of-green-growth-in-Nordic-regions/
Svartsengi	11 industries	local	N/A	5 (lukewarm seawater, geothermal brine, electricity and heating water, fish oils, fish offal)	planned with anchor tenant	N/A	630 jobs	N/A	Albertsson, A., & Jónsson, J. (2010). The Svartsengi Resource Park. 10World Geothermal Congress 2010, (April), 1–2.GEKON. (2011). Suðurnes Resource Park, (December).

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Table B1 (*continued*)

NISP-Hungary	496 industries	national	72 synergies identified during the workshop	N/A	facilitated (EU Life+)	N/A	N/A	3.751 tons of CO2 prevented 1.238 tons of virgin resources saved 26.035 m3 of water saved 1.200 tons of waste diverted from landfill	European Commission. (2011). LIFE08 ENV / H / 000291 Mid-term Report ISIM-TCC-Industrial Symbiosis an Innovative Method in Tackling Climate Change Data Project. European Commission. (n.d.). ISIM-TCC - Industrial Symbiosis as an Innovative Method in Tackling Climate Change. Retrieved from http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3398&docType=pdf European Commission. (2012). Final Report ISIM-TCC-Industrial Symbiosis an Innovative Method in Tackling Climate Change, 1–57. Retrieved from http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=LIFE08_ENV_H_000291_FTR.pdf NISP. (2012). Industrial Symbiosis as an Innovative Method in Tackling Climate change.
REPROWIS	N/A	national	N/A	N/A	facilitated (EU Life+)	N/A	N/A	N/A	European Commission. (2015). Construction and Demolition Waste management in Hungary, (September).
Styrian recycling network	28 companies part of the recycling network;	regional	N/A	14 (district heating, fly ash, gypsum, wood shaving, waste wood, fibre sludge, waste paper, waste oil, scrap tires, scrap iron, cinder sand, excavated material)	self-organised, driven by individual business interests		22.943 jobs	approx. 1 million tons of by-products gathered, 780.000 tons are recycled; 200.000 tons are landfilled or incinerated; 25.000 tons are handed to professional waste management (1996). Further 330.000 tons were identified in 1998. 70% recycling rate 42% CO2 emissions saved 25% of final energy consumption is renewable	Oliva, J. (n.d.). By-Product Recycling Network Trust is an important determinant factor of knowledge transfer in company recycling networks . Posch, A. (2010). Industrial Recycling Networks as Starting Points for Broader Sustainability-Oriented Cooperation? Journal of Industrial Ecology, 14(2), 242–257. http://doi.org/10.1111/j.1530-9290.2010.00231.x Schwarz, E. J., & Steininger, K. W. (1997). Implementing nature's lesson: the industrial recycling network enhancing regional development. Journal of Cleaner Production Cleaner Production, 5(12), 47–56. http://doi.org/10.1016/S0959-6526(97)00009-7
GreenTech Cluster	200 companies part of the "Green Tech Valley" of Styria	regional	numerous	numerous	facilitated	15% growth in investment per year 18% growth in employees per year	createion of more than 1.000 jobs/year		Green Tech Cluster. (n.d.). The Green Tech Valley. Retrieved from https://www.greentech.at/en/green-tech-valley-2/
Essenscia Brussels	240 participation organisations	regional	1.500 streams	N/A	facilitated	N/A	N/A	N/A	
ECOERG	241 industries	national	638 resource flows, 246 potential synergies	194 synergies completed	facilitated (EU Life+)	N/A	38 jobs	139.000 tons of GHG saved537.000 tons of waste reused (including 30.000 tons of construction and demolition waste, 500.000 tons of wood waste, 2.891 tons of animal and food waste, 245 tons of plastic waste, and 20 tons of Waste Electrical and Electronic Equipment - WEEE)3.000 ha of forest preserved	European Commission. (n.d.). ECOREG - Application of industrial ecosystems principles to regional development - ECOREG LIFE07 ENV/RO/000690. Retrieved from http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=LIFE07_ENV_RO_000690_AfterLIFE.pdf
Bratislavsky Kraj / ERDF	N/A	N/A	N/A	N/A	facilitated	N/A	N/A	N/A	
werecycle.be	19 industries	national	N/A	23 resources are actively circulated within the network	web based facilitated	N/A	N/A	111.357 tons of plastic recycled (2015) 70.403 tons of tyres recycled (2015)	FebelAuto. (2011). Collecting results end-of-life vehicles in Belgium Recycling-reuse-recovery results for Belgium – evolution 2006-2011, 2008–2012. Recupel. (2015). 2015 Annual Report BASTION OF In 2015 , Recupel was able to motivate every Belgian to bring in an average 10kg of electrical and electronic waste . RecyTyre. (2015). Annual Report 2015.
EUR-IS Wroklaw	N/A	N/A	N/A	N/A	facilitated	N/A	N/A	N/A	
PNSI	N/A	national	more than 600 process identified through workshops	N/A	planned	N/A	N/A	N/A	PNSI. (n.d.). Programme National de Synergies Inter-Entreprises. Retrieved from www.pnsi.fr
Silver Project	N/A	N/A	N/A	N/A	facilitated	N/A	N/A	N/A	

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Table B1 (*continued*)

Rotterdam Harbour	69 potential industries	local	N/A	N/A	facilitated	N/A	N/A	N/A	Baas, L. (2008). Industrial symbiosis in the Rotterdam Harbour and Industry Complex: Reflections on the interconnection of the techno-sphere with the social system. Business Strategy and the Environment, 17(5), 330–340. http://doi.org/10.1002/bse.624 Baas, L. W. (2007). Industrial Ecology as Regional Corporate Sustainability System. Sustainable Social and Ecosystem Stewardship. Baas, L. W., & Huisingh, D. (2008). The synergistic role of embeddedness and capabilities in industrial symbiosis: illustration based upon 12 years of experiences in the Rotterdam Harbour and Industry Complex. Progress in Industrial Ecology, An International Journal, 5(5/6), 399. http://doi.org/10.1504/PIE.2008.023408 European Commission. (2015). A framework for Member States to support business in improving its resource efficiency. Retrieved from http://ec.europa.eu/environment/enveco/resource_efficiency/pdf/business/RE_in_Business_M1_IndustrialSymbiosis.pdf Weterings RAPM. (2000). Agroproductieparken – Perspectieven en Dilemma's. Rapportage in Opdracht van Innovatie Netwerk Groene Ruimte en Agrocluster. TNO: Apeldoorn.
FISS	586 industries	national	4.418 resources	N/A	facilitated	N/A	N/A	N/A	Finnish Industrial Symbiosis System. (n.d.). Retrieved from http://www.industrialsymbiosis.fi/
ENEA Italian Network	568 industries in Sicily258 in Catania and Siracusa districs (major districts of network)	regional	21 resources shared Catania: 88 input, 187 outputSiracusa: 91 input, 187 output	Catania: 165 matchesSiracusa: 529 matches	facilitated	N/A	N/A	N/A	Cutaia, L., Barberio, G., Luciano, A., Manusco, E., Sbaffoni, S., La Monica, M., & Scagliarino, C. (2014). A systematic Methodology for Industrial Symbiosis Approach Development at a Regional Scale, (Eu 2008), 1–7. Cutaia, L., Luciano, A., Barberio, G., Sbaffoni, S., Mancuso, E., Scagliarino, C., & La Monica, M. (2015). The experience of the first industrial symbiosis platform in Italy. Environmental Engineering and Management Journal, 14(7), 1521–1533. Cutaia, L., Mancuso, E., Sbaffoni, S., Luciano, A., & Barberio, G. (2014). First results of the implementation of the Industrial Symbiosis Platform in Italy, 1–8. Mancuso, E., & Luciano, A. (2014). Experiences of Industrial Symbiosis in Italy. In ENEA at Ecomondo.
Industrial Park of Rieti-Cittaducale	240 industries	local	N/A	N/A	facilitated in an established industrial estate	N/A	4.300 jobs (estimation)	N/A	Tarantini, A. M., Paolo, A. Di, Dominici, A., Peruzzi, A., Isola, M. D., Cucchi, E. E., … Cutaia, L. (n.d.). Guidelines for the Settlement and the Management of the Sustainable Industrial Areas. The experience of the LIFE SIAM Project. Consorzio Industriale. (n.d.). Retrieved from http://www.consorzioindustriale.com
Green Industrial Symbiosis Denmark	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

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EUR-ISA	N/A	national	N/A	N/A	facilitated with specialists from the private sector	N/A	N/A	N/A	European Commission. (2015). Fostering Industrial Symbiosis for a Sustainable Resource Intensive Industry Across the Extended Construction Value Chain. Retrieved from https://cordis.europa.eu/project/rcn/196821_en.html European Commission. (2012). European Resource Efficiency Platform (EREP). Retrieved from http://ec.europa.eu/environment/resource_efficiency/re_platform/index_en.htm Sanchez, B. J., Munoz de la Torre, D. H., Cepria Pamplona, J. J., & Bustamante, E. G. (n.d.). FISSAC: Fostering Industrial Symbiosis for a Sustainable Resource Intensive Industry Across the Extended Construction Value Chain.
Harjavalta	13 industries	local	N/A	6 (copper sulphate, iron sand, copper telluride, selenium, nickel matte, PGM concentrates) 8 waste management processes	self-organised	N/A	1.000 jobs (estimation)	Long term waste management. 81,8% utilisation level of waste: - 351 t/y from energy waste - 181 t/y from metal waste -83 t/y from led waste - 124 t/y from hazardous waste - 15 t/y from paper waste -16 t/y from household waste	Heino, J., & Koskenkari, T. (2004). Industrial ecology and the metallurgy industry. The Harjavalta industrial ecosystem. Proceedings of the Waste Minimization and Resource Use Optimization, (Erkman), 143–151. Retrieved from http://www.oulu.fi/resopt/wasmin/heino2.pdf Norilsk Nickel. (2011). Corporate Social Responsibility Report MMC Norilsk Nickel. Suurteollisuuspuisto, H. (2010). Historian vuosikymmenet.
Wildling Butler	1 industry	local	N/A	N/A	self-organised	N/A	N/A	N/A	
ZeroWin	10 case studies	N/A	N/A	N/A	N/A	N/A	N/A	341 TWh of energy saved (estimation by 2020)	den Boer, E., Williams, I. D., Curran, T., & Kopacek, B. (2014). Briefing: Demonstrating the circular resource economy – the Zerowin approach. Proceedings of the Institution of Civil Engineers - Waste and Resource Management, 167(WR3). http://doi.org/10.1680/warm.14.00005 Horvath, C. (n.d.). The ZeroWIN Production Model. A new kind of production model. Retrieved from www.zerowin.eu O'Connor, C., Hestin, M., & Kuehr, R. (2010). ZeroWin Policy Synthesis Report. Retrieved from http://www.4980.timewarp.at/sat/ZeroWIN/pdf_secure/D.8.1 Policy Synthesis Report.pdf Saraev, A., & Obersteiner, G. (2014). Assessing Sustainability in Industrial Networks . Based on the Experience From Zerowin Project . Williams, I. (2014). ZeroWIN Practical Demonstrators: Demolition and New Buildings in Germany, Portugal and the United Kingdom. Retrieved from www.zerowin.eu Williams, I., & Curran, T. (2010). Literature Review "Approaches To Zero Waste." Williams, I., Curran, T., & Ongondo, F. (2011). Report on the Zerowin Vision Conference.
SMILE	N/A	national	N/A	N/A	facilitated / web-based	N/A	N/A	N/A	
Knapsack	27 industries	local	N/A	N/A	self-organised	N/A	2.200 jobs	N/A	Knapsack Park http://www.chemiepark-knapsack.de Infraserv Knapsack http://www.infraserv-knapsack.de/

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Table B1 (*continued*)

Bazancourt-Pomacle	58 total (20 industrial corporations, 38 SMEs)	local	N/A	8 major symbiotic processes (water, steam, effluents, products, R&D, energy, organisation, drilling)	self-organised	N/A	1.200 - 2.000 jobs	N/A	A-R-D Innovation in Green. (n.d.). Bio-raffinerie Recherces et Innovations. Retrieved from http://www.a-r-d.fr/ARD-filiales-et-partenaires-Bio-raffinerie-Recherches-et-Innovations-BRI-68.html Chauvet, J.-M. (n.d.). The Biorefinery of Pomacle Bazancourt and the BRI platform. Retrieved from www.a-r-d.fr Chauvet, J.-M. (n.d.). La bioraffinerie de Bazancourt-Pomacle: un modèle d ' intégration au cœur du pôle IAR. formule-verte.com. (n.d.). Bazancourt-Pomacle, une des 17 grandes plateformes chimiques du territoire. Retrieved from http://formule-verte.com/bazancourt-pomacle-une-des-17-grandes-plateformes-chimiques-du-territoire/ French Ministry of Agriculture and Food. (2016). Transformer la Bioraffinerie de Bazancourt Pomacle. Retrieved from http://agriculture.gouv.fr/transformer-la-bioraffinerie-de-bazancourt-pomacle%0A Grand Reims Communauté Urbaine. (n.d.). La bioraffinerie de Bazancourt - Pomacle. Retrieved from http://www.grandreims.fr/les-competences/enseignement-superieur-recherche-innovation/recherche-et-innovation/la-bioraffinerie-de-bazancourt-pomacle-7912.html IAR. (2012). Le complexe agro-industriel des Sohettes.
Symbioseplatform	300 organisations	regional	N/A	2.000 streams and technologies	planned / web-based	N/A	N/A	goal of achieving 15% less waste	Flanders. (n.d.). Flanders' recycling ecosystem. Retrieved from https://www.flandersinvestmentandtrade.com/invest/en/sectors/sustainable-materials/recycling-industry/recycling-ecosystem OVAM. (n.d.). Ecoclusters: bevordering van industriële symbiose. Retrieved from http://www.ovam.be/ecoclusters-bevordering-van-industriele-symbiose
Biopark Terneuzen	22 industries (7 of which part of a symbiosis network)	local	N/A	14 (biomass, wastewater, clean water, heat, CO2, electricity, steam, starch residues, energy)	planned	N/A	N/A	N/A	Biopark Terneuzen. (n.d.). Biopark Terneuzen. Retrieved from http://www.bioparkterneuzen.com/en/biopark.htm%0A Ghent Bio-Economy Valley. (n.d.). Biopark Terneuzen. Retrieved from http://www.gbev.org/en/members/biopark-terneuzen
Organised Waste Market	N/A	national	N/A	N/A	planned / web-based	N/A	N/A	N/A	Mercado Organizado de Residuos. (n.d.). Mercado Organizado de Residuos. Retrieved from http://www.moronline.pt/UK/index.asp
ResidiRecurso	4.700 companies involved	regional	N/A	~ 260 announcements (75% supply and 25% demand) as of May 2013	facilitated / web-based	N/A	N/A	N/A	Jurado, L. (2012). 85a Jornada Tècnica : La gestió de residus Funcionament de la Borsa de Subproductes de Catalunya. ResiduoRecurso. (n.d.). WasteResource raw material and by-product exchange. Retrieved from http://www.residuorecurso.com/en/inici
symbiosis.gr	164 industries	national	(there is no mention of any number of synergies in any report I've read)38,5% synergies at the stage of idea	23,1% of synergies completed23,1 % of synergies in negotiations7,7 % of synergies in discussion7,6% of synergies implemented	facilitated (EU Life+) / web-based	N/A	N/A	N/A	Cecelja, F., Raafat, T., Trokanas, N., Innes, S., Smith, M., Yang, A., ... Kokossis, A. (2015). e-Symbiosis: Technology-enabled support for Industrial Symbiosis targeting Small and Medium Enterprises and innovation. Journal of Cleaner Production, 98, 336–352. http://doi.org/10.1016/j.jclepro.2014.08.051 eSymbiosis. (2014). eSYMBIOSIS Deveopment of knowledge-based web services to promote and advance Industrial Symbiosis in Europe. Layman's Report. European Commission. (2014). eSymbiosis: Development of knowledge-based web services to promote and advance Industrial Symbiosis in Europe: AFTER-LIFE Communication Plan. Retrieved from www.esymbiosis.gr Markatos, N. (n.d.). eSYMBIOSIS - Development of knowledge-based web services to promote and advance Industrial Symbiosis in Europe. Retrieved from http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3680&docType=pdf
Manresa	N/A	regional	N/A	N/A	facilitated	N/A	N/A	N/A	

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Table B1 (*continued*)

NISP NI	1.900+ members	regional	N/A	448 completed synergies	facilitated	£25 million business cost savings £16.2 million additional sales £1.9 million private investment	35 jobs created 61 jobs secured	(2007-2017) - 392.000 tonnes of waste diverted - 12.700 tonnes of hazardous waste saved - 240.000 tonnes of virgin raw materials saved - 340.000 tonnes of CO2 saved	
NISP Scotland	N/A	regional	N/A	127 synergies completed (around 35 per year)	facilitated	£4.19 million cost savings to industry £7.22 million private investment 1.8 million additional sales	38 jobs created	312.295 tonnes of waste diverted from landfill 194.183 tonnes of CO2 saving	Scottish Government. (n.d.). Scottish Industrial Symbiosis Programme. Retrieved from https://www.gov.scot/Topics/Environment/SustainableDevelopment/funding/Aggregatesprojects2002-07/IS Scottish Government. (n.d.). Industrial Symbiosis Project 2007-08. Retrieved from https://www.gov.scot/Topics/Environment/SustainableDevelopment/funding/Aggregatesprojects2007-08/industrialsymbiosis07-08
Slovenia E-Symbioza	around 20 companies have listed materials / waste demands	regional	N/A	N/A	facilitated / exclusively web based	N/A	N/A	N/A	
LISP - London	3 on-site facilities 5+3 more under planning permission)	local	N/A	on-going development	planned eco-industrial park	N/A	60-100 jobs	35.000 tonnes/year of plastic bottle recycling 35.000 tonned/year of food and green waste into 31.000 MWH per annum and achieves savings of 16.325 CO2 per year (only from AD)	
Rethink_Italy	25 members	regional	N/A	5 synergies	facilitated / web-based	N/A	N/A	N/A	Rethink. (n.d.). Rethink - Sustainable Solutions. Retrieved from https://www.rethink.srl/
Orée	15 members	N/A	N/A	4 synergies	facilitated	N/A	N/A	N/A	Orée Entreprises territoires et environement. (n.d.). Industrial and territorial ecology. Retrieved from http://www.oree.org/en/sustainable-management-of-industrial-parks-and-industrial-ecology.html
Inex	100 members	N/A	N/A	15 synergies	facilitated	N/A	N/A	N/A	
Monsteras	N/A	N/A	N/A	10-20 active synergies	facilitated	N/A	N/A	N/A	
Industrial Park of Sweden	17 industries	local	N/A	N/A	planned industrial park	difficult to calculate	3.794 jobs	7.500 tonnes/year of Carbon Dioxide Emissions reduced 1,6 million tonnes of CO2 emissions reduced Reductions in GHG, Nitrogen and Phosphorus enabled by: - reduction of fossil fuels used - reduced need for artificial fertiliser - increased use of locally produced biogas - reduced amount of waste placed in landfills - increased environmental awareness	Industriellekologi. (n.d.). Industry Park of Sweden. Retrieved from http://www.industriellekologi.se/symbiosis/ipos.html Allard, V., Broberg, N., Danielsson, E., Elmtoft, E., Lindström, G., Nelénius, M., ... Österqvist, J. (2016). Industry Park of Sweden. Retrieved from http://www.industriellekologi.se/documents/IPOS.pdf
Oresundskraft	6 production plants	regional	N/A	7 active synergies	self-organsied	N/A	N/A	N/A	Öresundskraft årsredovisning 2013 (Öresundskraft annual report 2013). (2013). Retrieved from oresundskraft.se
Nordvastra Skanes Renhallning	N/A	regional	N/A	7 active synergies	self-organised	N/A	N/A	N/A	
Nordvastra Skanes Vaten och Avlopp	N/A	regional	N/A	4 active synergies	self-organised	N/A	N/A	N/A	

(*continued on next page*)

Table B1 (*continued*)

Lidkoping IS Network	11 industries with symbiotic processes	regional	N/A	22 symbiotic processes	self-organised	N/A	N/A	CO2 emissions linked to heating reduced from 64 296 t/y in 1985 to to 4 700 t/y in 2006 – a reduction of 93%. Reductions of around 18 000 tonnes/year of CO2 equivalent are enabled by the production of biogas and its use as a transport fuel Between 1985 and 2006, SOx emissions were reduced from 355 t/y to 55 t/y, and NOx emissions were reduced from 146 t/y to 8 t/y. 30 000 m3 of oil is avoided by the district heating system. With the use of biogas, 6 500 m3 less diesel is needed in the region. 90 000 tonnes/year of landfill reduced	Angren, J., Arnoldsson, J., Arvidsson, J., Baumgarten, S., Dijkstra, S., Högström, C., ... Willman, A. (2012). Exploring the Industrial Symbiosis in Lidköping, Sweden. Retrieved from http://www.industriellekologi.se/documents/Lidkoping.pdf Industriellekologi. (n.d.). Lidköping Industrial Symbiosis Network. Retrieved from http://www.industriellekologi.se/symbiosis/lidkoping.html
Enkoping IS Network	N/A	regional	N/A	5 major synergies within the network. 10 synergies outside the network	self-organised	CHP is believed to have reduced its cost for fuels by 2,5 MSEK/year Several economic benefits from the use of alternative resources but not quantified	N/A	Recovery of Phosphorus and Nitrogen: By using sewage water as fertilizer more than 1 ton of phosphorus is recovered back into the cultivated system. Through the use of effluents in willow plantations, the WWTP has reduced the nitrogen discharges by 30 t/year– corresponding to a 25% reduction. Removal of Cadmium from soil Reduction in GHG	Industriellekologi. (n.d.). Enköping Industrial Symbiosis Network. Retrieved from http://www.industriellekologi.se/symbiosis/enkoping.html Sööder, F., Nilsson, M., Olevik, J., Forsberg, J., Jacobsson, A., Holm, L., ... Ekman, O. (2014). Industrial Symbiosis in Enköping.
Stenungsund IS Network	7 industries	regional	N/A	7 synergies	self-organised	N/A	N/A	15.000 tonnes/year of GHG emissions reducedChemical industries use of 424.000 tonnes of natural gas instead of fuel gas	Industriellekologi. (n.d.). Industrial Symbiosis in Stenungsund. Retrieved from http://www.industriellekologi.se/symbiosis/stenungsund.html
Avesta IS Network	8 industries	regional	N/A	13 synergies	self-organised	N/A	N/A	N/A	Industriellekologi. (n.d.). Industrial Symbiosis in Avesta. Retrieved from http://www.industriellekologi.se/symbiosis/avesta.html
Heidelberg industrial estate of Pfaffengrund	18 enterprises participating in symbiotic processes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Rhein Neckar	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Ökopark Hartberg Steiermark	30 companies	regional	N/A	N/A	facilitated	N/A	200 jobs	N/A	
Kaiserbaracke Industrial Park	4 companies	regional	N/A	N/A	facilitated	N/A	70 jobs	N/A	
Monceau-Fontaines Park	16 companies	regional	N/A	N/A	N/A	N/A	150 jobs	N/A	Monceau-Fontaines ASBL. (2014). Activity Report 2014 (Rapport d'activités 2014). in french. Retrieved from https://www.monceau-fontaines.be/wp-content/uploads/2017/07/Rapport-dactivités-2014.pdf
Chemical Valley Industrial Area	12 companies	N/A	N/A	N/A	N/A	N/A	6.500 jobs	N/A	
Havre Industrial-Harbour Park	N/A	regional	N/A	N/A	facilitated	N/A	1.000 jobs	N/A	HAROPA. (2014). Bilan Des Emissions De Gaz a Effet De Serre (Ges). Retrieved from http://www.haropaports.com/sites/haropa/files/u21/synthese_reglementaire_v2014_bilan_ges_gpmh.pdf ECSPP. (n.d.). Chemical Parks of Europe. Port of Le Havre. Retrieved from https://chemicalparks.eu/parks/port-of-le-havre
Lagny-sur-Marne and La Courtilière Industrial Parks	230 companies	regional	N/A	N/A	facilitated	N/A	3.200 jobs	N/A	

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Table B1 (*continued*)

Zero Emission Park Bottrop	250 companies	regional	N/A	N/A	planned	N/A	2.500 jobs	N/A	
Zero Emission Park Bremen	300 companies	regional	N/A	N/A	planned	N/A	6.200 jobs	N/A	
Zero Emission Park Kaiserslautern	25 companies	regional	N/A	N/A	planned	N/A	200 jobs	N/A	
Padova Industrial Park (Zona Industriale di Padova, ZIP)	1.700 companies	regional	N/A	N/A	planned	N/A	70.000 jobs	N/A	ZIP Padova. (n.d.). ZIP Padova. Retrieved from https://www.zip.padova.it/index.php
Ponte Rizzoli Industrial Park (Area Industriale di Ponte Rizzoli)	170 copmanies	regional	N/A	N/A	planned	N/A	N/A	N/A	
Prato 1st Industrial Macrolotto (1° Marcolotto Industriale di Prato)	350 copmanies	regional	N/A	N/A	planned	N/A	3.000 jobs	N/A	Igeam. (2006). 1° Macrolotto Industriale Di Prato Sustainability Analysis. Retrieved from http://www.life-siam.bologna.enea.it/files/definitivi/task4/doc_finali/asfinali/as_PO_def.pdfCONSER. (2018). What is the 1st Industrial Macrolotto of Prato (CHE COS'È IL 1° MACROLOTTO INDUSTRIALE DI PRATO). in italian. Retrieved from http://www.conseronline.it/index.php?option=com_content&view=article&id=25&Itemid=18
Relvão Eco-Industrial Park	26 companies	regional	N/A	N/A	planned	N/A	N/A	N/A	Benedetti, M. (2017). The Portuguese experience of the Relvão Eco Industrial Park: influencing contextual factors to overcome legislative barriers. Retrieved from https://maestri-spire.eu/case-17-industrial-park-planned-national-level-portuguese-experience-relvao-eco-industrial-park/
Parc de l'Alba	N/A	regional	N/A	N/A	N/A	N/A	40.000 jobs	N/A	Parc de l'Alba. (n.d.). ¿QUÉ ES EL PARQUE? (What is the park). in Spanish. Retrieved from https://www.parcdelalba.cat/ES/2006/menu/presentacion.html#2134
Dyfi Eco Park	N/A		N/A	N/A	N/A	N/A		N/A	Ecodyfi. (n.d.). Ecodyfi. Retrieved from http://www.ecodyfi.org.uk/
London Sustainable Industries Park	N/A	local	N/A	N/A	planned	N/A	N/A	N/A	
Tanning Cluster in Tuscany (S. Corce sull'Arno)	22 members	local - regional	N/A	6 exchanges (recovery of waste water, recovery of sludge as inert material, chromium recovery, recovery of fleshings, fat and proteins, sludge recovery as fertiliser)	N/A	N/A	N/A	Reduction in environmental impacts in the following categories: Climate change - 21,87% Ozone depletion - 1,48% Human toxicity, non-cancer effects - 1,48% Human toxicity, cancer effects - 7,00% Particulate matter 15,38% Ionizing radiation HH - 10,10% Ionizing radiation E (interim) - 10,24% Photochemical ozone formation - 13,86% Acidification - 11,69% Terrestrial eutrophication - 18,52% Freshwater eutrophication - 12,09% Marine eutrophication - 6,54% Freshwater ecotoxicity - 7,66% Land use - 4,61% Water resource depletion - 1,75% Mineral, fossil & ren resource depletion - 1,58%	Daddi, T., Nucci, B., Iraldo, F., Testa, F (2016). Enhancing the Adoption of Life Cycle Assessment by Small and Medium Enterprises Grouped in an Industrial Cluster: A Case Study of the Tanning Cluster in Tuscany (Italy), Journal of Industrial Ecology, 20 (5):1199-1211. Daddi, T., Nucci, B., Iraldo, F. (2017). Using Life Cycle Assessment (LCA) to measure the environmental benefits of industrial symbiosis in an industrial cluster of SMEs, Journal of Cleaner Production, 147: 157-164.
Sagunto	12 members	local - regional	N/A	17 operative synergies (Fly ash from steel blast furnace to Cement factory, Acid recovery, Iron oxide, Zinc	self-organised	N/A	N/A	Reduction in the cost of inputs Reduction in waste management New revenues from by-products	Domenech, T. (2010). Social Aspects of Industrial Symbiosis Networks, PhD Thesis, University College London.

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Table B1 (*continued*)

				recovery, Scrap metal to blast furnace, Scrap metal to scrap dealers, Oil recovery and reuse, Full hard steel to galvanising unit, Solvent recovery, Wood pallets reuse, Sharing of waste water treatment plant, Sharing of access infrastructures (to reduce atmospheric emissions of particulate), Use of sawdust as fuel for cement production, Use of coal fly ash for cement production, Use of pain residues and solvents in cement production, Animal meal as fuel for cement production, Glass)					

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