The role of local governments in overcoming barriers to industrial symbiosis

Södergren, Karolina; Palm, Jenny

Published in:
Cleaner Environmental Systems

DOI:
10.1016/j.cesys.2021.100014

2021

Document Version:
Publisher's PDF, also known as Version of record

Cleaner Environmental Systems 2 (2021) 100014

Contents lists available at ScienceDirect

Cleaner Environmental Systems

journal homepage: www.journals.elsevier.com/cleaner-environmental-systems

The role of local governments in overcoming barriers to industrial symbiosis

Karolina Södergren *, Jenny Palm

The International Institute for Industrial Environmental Economics (IIIEE), Lund University, P O Box 196, SE-221 00, Lund, Sweden

ARTICLE INFO

Keywords:
Industrial symbiosis
Barriers
Local government
Local governance
Modes of governing

ABSTRACT

The industrial symbiosis (IS) landscape is evolving at high speed. There is a growing interest in knowledge sharing and partnering, as is evident from the establishment of multiple IS networks at local and regional level. This article investigates the role of local governments in industrial symbiosis. It aims to build a theoretical framework explaining how local governments can reduce barriers to implementation of IS by applying different modes of governing. Findings show that local governments can do many things to overcome barriers and thus enhance IS. In many instances, local governments can support IS in an enabling function, by coordinating relationships and material exchanges, providing infrastructure and funding. They can also apply authoritarian and self-governing principles to develop policies and regulations to support IS development, as well as planning and control mechanisms linked to their own material and resource flows. This article concludes by suggesting a number of policy recommendations, such as local governments establishing a clear strategy on IS, and including IS in physical planning.

1. Introduction

In a world with increasingly visible environmental, economic and socio-political challenges, the idea of transitioning into more sustainable production and consumption practices is gaining ground. Among the myriads of sustainable initiatives launched in recent years, the one striving towards a circular economy has gained particular popularity (Ellen MacArthur Foundation, 2013). Whether it is about "reducing, reusing, recycling" or "closing, narrowing or slowing resource loops" (Bocken et al., 2016), the concept seems to offer something for everyone, everywhere. Systemic solutions such as industrial symbiosis (IS) are therefore attracting interest from policy and practice (EU, 2019; European Commission, 2020). Indeed, governments around the world are now implementing IS as part of their transformation towards circular economies (International Institute for Sustainable Development, 2015).

Industrial symbiosis is presented as a tangible solution that enables circularity within and across value chains. The most typical example is Kalundborg in Denmark where companies have worked together since the 1970s, exchanging materials and by-products in a symbiotic manner (Kalundborg Symbiosis, 2020). Chertow (2004, p. 408) conducted pioneering research on the academic understanding of IS. She defined the concept as "place-based exchanges among different entities that yield a collective benefit greater than the sum of individual benefits that could be achieved by acting alone". In practice, IS is commonly set up in a way where one company's output can become another company's input, allowing for simultaneous improvements in resource efficiency and financial returns (Chertow, 2000).

Early IS studies kept a primarily industrial focus, looking into operational, financial and environmental concerns of IS material exchanges (Neves et al., 2020). Less attention has been given to public features such as specific or strategic government engagement (Velenturf, 2016). Another less researched area is how local government can contribute to and govern IS. Yet municipalities are key actors in their role as planners for sustainable urban development (Palm et al., 2019). They also have a responsibility to transform ambitious national and global goals and visions into local practices (European Environment Agency, 2019). Excluding municipalities or local governments from the debate – or minimizing their role in it – would therefore imply that local governance mechanisms affecting the IS landscape may be overlooked. It would also mean that the complexity and multi-actor characteristic of IS are not truly taken into account. Rather, it would create an imbalance in which actors and sectors are favoured – and are therefore studied further.

The aim of this article is to develop a theoretical framework to explain how local governments can reduce barriers to the implementation of IS through different modes of governing. A qualitative research methodology has been applied. Literature reviews and content analysis of previous studies on IS barriers and local government engagement in IS enables the uncovering of prominent themes. This, in turn, allows for a discussion on

* Corresponding author.
E-mail address: karolina.sodergren@iiiee.lu.se (K. Södergren).

https://doi.org/10.1016/j.cesys.2021.100014
Received 2 September 2020; Received in revised form 4 February 2021; Accepted 8 February 2021

the potential roles that local governments can adopt in the process of IS development, specifically in order to overcome barriers to IS.

The outline of the article is as follows: first, the theoretical foundations of IS and local governance are explored. Second, the methodology guiding this article is outlined. Then, the results and analysis are presented, including a theoretical framework for how local governments can address typical barriers to IS through different modes of governing. Finally, the article wraps up with a discussion and conclusion, including key thoughts to take away and suggestions for future research in IS.

2. Industrial symbiosis: addressing barriers through local governing modes

This section begins by outlining some of the basic theoretical underpinnings of IS. An overview of common barriers to IS is also provided. Previous research on public actor engagement in IS is then presented and connected to the field of local governance. We conclude with a proposed analytical framework for examining how local governments can reduce typical barriers to IS through different modes of governing.

2.1. Barriers to industrial symbiosis

Industrial symbiosis is a subfield of industrial ecology (Frosch and Gallopoulos, 1989) and an emerging concept in the field of circular economy (Bocken et al., 2016; Maranesi and De Giovanni, 2020). At core, "Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products" (Chertow, 2000, p. 314). Through this set-up, one company's use of virgin production inputs can therefore be swapped with waste materials and by-products generated by other companies. This allows for enhanced production efficiency, resulting in economic, environmental and social benefits for both the companies involved and the region in which they operate (Fraccascia, 2019). The idea behind IS therefore extends into all three dimensions of sustainability – profit, planet, and people (Herczeg et al., 2018). Traditionally, an IS network is defined as a network consisting of at least three companies exchanging at least two types of wastes (Chertow, 2004, 2007). It can be designed either in a planned, top-down approach (Heeres et al., 2004) or in a self-organized, bottom-up fashion (Chertow and Ehrenfeld, 2012).

Despite the promises inherent to IS, it seems that the potential for uptake of new regional synergies is limited by a range of technical and non-technical barriers (Golev et al., 2015), as discussed, among many others, by Mortensen and Kørnøv (2019), Walls and Paquin (2015) and Yu et al. (2014). The process of overcoming barriers can include removal, reduction or avoidance of barriers (Reddy, 2013) and local government can take different governing approaches. In this article, these studies were used as data sources to help meet the aim of analysing how different modes of local governance can be applied to overcome critical IS barriers.

Appendix A list barriers to industrial symbiosis by type and literature references. Economic barriers mentioned are high investment costs (Pajunen et al., 2013) and difficulties in acquiring external investment capital, for example to promote and disseminate information about IS (e.g. Chiu and Yong, 2004; Bacudio et al., 2016; Mortensen and Kørnøv, 2019). Other barriers are the potentially different investment cycles of organizations (Madsen et al., 2015), as well as not knowing how to divide incomes and costs between organizations (Fichtner et al., 2005). Moreover, there can be fluctuations in the demand for a particular commodity or product, as well as variations in the costs of resources in different regions (Tudor et al., 2007). Partaking in an IS network can also increase operational costs for the industries involved, linked to waste transportation and waste treatment costs. This partly contributes to what authors refer to as a "lack of knowledge about cost-benefit ratios" (Madsen et al., 2015; Fichtner et al., 2005; Islam et al., 2016).

Operational and management issues are what create most technical barriers (Herczeg et al., 2018; Corder et al., 2014). The use of by-products in IS makes it more difficult to design and operate effective production systems and storage facilities, notably because of the additional treatment processes and source tracking that is required (Herczeg et al., 2018). Material fluctuations can also create a mismatch between the demand and supply in an IS system (Fraccascia, 2019; Tudor et al., 2007). Moreover, technological advances and changes in production technology carry the risk of destroying markets of importance to the industries involved in the IS network (Tudor et al., 2007; Fraccascia, 2019). Problems also occur with the logistical integration between actors due to insufficient infrastructural set-ups (Mortensen and Kørnøv, 2019). Part of this is a recognized difficulty in motivating industries to relocate, and hence, resulting geographical distances (Mortensen and Kørnøv, 2019). Finally, a lack of technical knowledge, or of technology and infrastructure readiness, may be further problems (e.g. Golev et al., 2015).

Regulatory barriers are primarily linked to restrictive or unclear legislation, and a lack of guidance on compliance criteria (e.g. Boons et al., 2011; Li et al., 2015). There is also an issue with perceptions of conflicting waste practices and regulations (Corder et al., 2014). Partly linked to this is the difficulty to obtain approval for waste reuse projects from regulatory authorities (Golev et al., 2015). And from a reverse perspective, regulatory authorities sometimes themselves find it hard to plan, design and manage IS networks (Tudor et al., 2007; Corder et al., 2014).

In the category of social barriers, one concern is that companies often work in silos without enough contact with each other (Golev et al., 2015; Islam et al., 2016). There can be a lack of willingness to collaborate (Park et al., 2008; Fichtner et al., 2005), as well as a lack of engagement among the organizations – especially from top management. Low numbers of "IS promoters" within companies can also become a barrier to IS implementation and expansion (e.g. Chiu and Yong, 2004; Madsen et al., 2015). One of the most commonly mentioned social barriers is a lack of trust between organizations (e.g. Chertow and Ehrenfeld, 2012; Bossilkov et al., 2005). Trust is a prerequisite for collaboration (Bacudio et al., 2016). Indeed, since there often is a lack in cooperative mechanisms for making organizations collaborate, trust becomes the ultimate enabler. Other barriers include asymmetric interdependencies and power imbalances between actors (Herczeg et al., 2018), as well as a lack of institutional support (e.g. Ashton, 2011; Li et al., 2015).

As regards information-related barriers, a lack of information and training are typical problems (e.g. Walls and Paquin, 2015; Corder et al., 2014). Adopting IS requires technical and organizational knowledge and expertise (Bacudio et al., 2016). A lack of awareness of IS as a concept, as well as of neighbouring companies' materials and by-products, can also become barriers to further IS uptake (e.g. Chertow, 2007; Domenech Aparisi, 2010). This lack is typically related to poor contact, communication and information sharing between companies (Levänen and Hukkinen, 2013; Madsen et al., 2015). Another information-related barrier is a lack of broader community awareness (Golev et al., 2015).

Despite the broad discussion of IS barriers in the literature, Golev et al. (2015) point to a lack of real cases describing the process of investigation and overcoming these barriers. To this can be added a lack of discussion on which actors are most appropriate for overcoming what barriers. This article aims to investigate the role of local governments in this process, and the following section addresses this issue further.

2.2. Local governments and local governing modes

While early IS literature largely focused on industries, later studies explored a broader range of actor roles including those of public organizations, local governments and municipalities (e.g. Paquin and Howard-Grenville, 2012; Gibbs and Deutz, 2007; Boons and Spekkink, 2012). Van Berkel et al. (2009), for example, addressed the role of public actors when describing the symbiotic relationships between industries and cities in Japan's government-led eco-town programme. Lenhart et al. (2015) studied how local authorities supported symbiotic resource exchanges in the city of Rotterdam, in the Netherlands. They found that

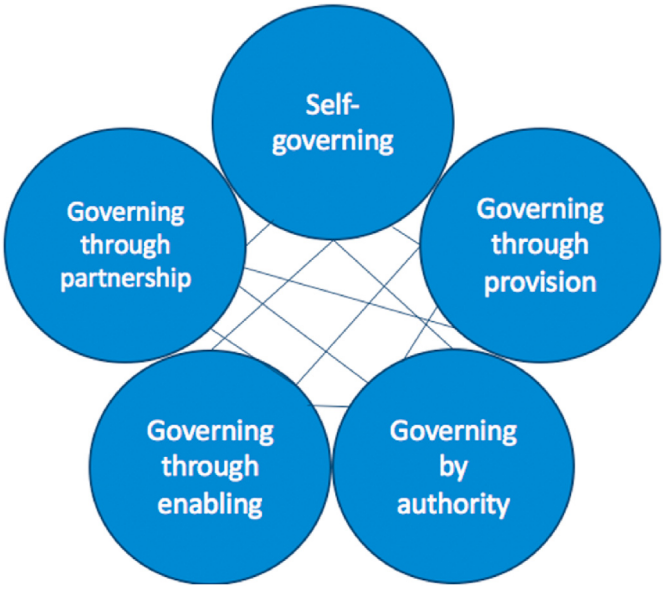

Fig. 1. Local climate governance strategies. Visual representation of typology developed by Bulkeley and Kern (2006) and Bulkeley et al. (2009).

local authorities were more active in designing urban symbiosis projects than in implementing them. The local authority served as coordinator, facilitator and information provider between different parties in the design phase, and then took a step back during the implementation phase.

Industrial symbiosis scholars have also tried to integrate symbiosis principles into local planning processes. Music (2019) describes the possibility of including IS into municipal spatial development plans in the city of Ljubljana. Likewise, Birmingham's Big City Plan has been cited as an interesting example of a planning document that merges city development with IS philosophy. Waste, infrastructure, procurement and industry are other examples of planning domains in which local authorities could integrate IS principles (Domenech et al., 2019).

While the importance of public actors, and specifically local governments, has been addressed in the literature, a more systematic understanding of how local governance can be applied to overcome typical IS barriers still needs to be developed. Velenturf (2016) provides an excellent introduction on this topic in her study of the governance system in the Humber region, UK. Focusing on regulatory barriers linked to the implementation of resource efficiency policy and regulation, she divides potential governmental roles and activities into four categories: strategic regulator, strategic facilitator, operational regulator, and operational facilitator.

In light of the differences in barriers experienced throughout IS development (see Appendix A), we suggest that an in-depth exploration of the potential roles and measures adopted by local governments is needed.

We suggest that the typology developed by Bulkeley and Kern (2006) can be used for this purpose, and extrapolated to IS. They previously studied local climate governance in energy, transport, and land use, and presented four modes of governing that local governments tend to adopt in various combinations as local climate governance strategies. These are: governing through provision, governing by authority, governing through enabling, and self-governing. A fifth category was later added by Bulkeley et al. (2009), namely, governing through partnership (see Fig. 1). Researchers applying this typology show how local governments manage and steer a sustainable transition. This includes Smedby and Quitzau (2016), who examined governance in the building sector, and Palm et al. (2019), Voytenko Palgan, McCormick et al. (2020) and Voytenko Palgan, Mont et al. (2020), who investigated governance in the sharing economy.

In this typology, *self-governing* is linked to the capacity of the local government to control or manage its own activities and operations. It is based on an organizational management approach, and includes measures such as developing internal procurement guidelines, energy standards, etc for municipal organizations and buildings. *Governing through provision* concerns the provision of different goods, services and resources. It is effectuated through material and infrastructural means, such as providing public transport services, infrastructure, and recycling and composting schemes for citizens and/or companies. *Governing by authority* concerns more traditional forms of authority, such as regulation, enforcement and the use of sanction. Typically, this type of governing is done through strategic planning and policy making that induces climate-friendly practices. *Governing through enabling* refers to the "role of local government in facilitating, coordinating and encouraging action through partnership with private- and voluntary-sector agencies, and to various forms of community engagement" (Bulkeley and Kern, 2006, p. 2242). It works through argument, persuasion, and inducements, for example when introducing energy efficiency campaigns, or granting distribution to promote renewable energy. Finally, *governing through partnership* describes a situation where state and non-state actors work together in an equal relationship. This can be done through project implementation, voluntary agreements, knowledge building and information sharing in situations where the local government has no formal governing power over other actors (Bulkeley et al., 2009). Within the different governing modes, local government can use different policy instruments and measures (UNEP, 2015).

In the following analysis we will lean on earlier research to examine the role of local governments in IS (Bulkeley and Kern, 2006; Bulkeley et al., 2009). We will then discuss how different governing modes, with available policy instruments, can contribute to reducing existing barriers to IS.

3. Material and methods

This study has an explorative purpose and follows a qualitative methodology (Creswell, 2008). The material is based on desk-based research, for which we have collected previous research materials from primarily Scopus and Web of Science (WoS) as two of the most recognized databases for obtaining high-quality articles. We conducted a number of searches, the last of which was conducted in June 2020.

In the search to identify previous studies that had summarized barriers to IS, we used the key words "industrial symbiosis", "barriers" and "barriers and review". This resulted in 74 unique hits. A refined search was conducted of these; we selected only those articles that included a review or mapping of different barriers to IS. Seventeen barrier-related articles remained. To these, nine articles were added from reference lists. The total of 30 articles are summarized and categorized in Appendix A.

We also searched for articles focusing on IS and local governments. Key words used were "industrial symbiosis" combined with "governing modes", "local government", "local authority/authorities" and "municipality/municipalities". In total, the Scopus and WoS searches yielded 121 hits. To these, another twelve articles were added from reference lists included in these articles. From a total of 133 articles, 23 articles were selected for the final sample.

We have not included articles that only mentioned that local governments, authorities and municipalities were part of a network, as we were interested in a more in-depth examination of the role of these actors. The analysis was not country-specific; rather, it included themes and categories across all documents, which were related to different modes of governance, instruments and measures, as mentioned in Section 2. The analysed articles were published between 2004 and 2019. This article therefore has a contemporary outlook on local governments and IS.

A systematic text analysis was then performed on the 23 documents. This is a descriptive type of analysis in which the aim is to highlight and explain the most essential content within each text. In practice, this can

be done by classifying content into intelligible categories and clarifying different thought structures therein (Esaiason et al., 2007). For the purpose of this paper, we used the typology developed by Bulkeley and Kern (2006), and Bulkeley et al. (2009) to code what governing modes have been used by local governments in earlier studies on IS. See Appendix 2 for a summary of the articles and manual coding. By combining earlier research on IS barriers with this categorization on governing modes, we could develop a framework for how local governments can approach different barriers to IS (see Table 1).

4. Results

The aim of this section is to provide an understanding of the role local governments play in IS, as described in the academic literature, and especially how this links to different governing modes, policy instruments and measures (see also Appendix B).

Results show that previous research has rarely focused on the role of local governments in IS. Rather, local governments are featured as one potential actor among an otherwise business-dominated partner network. The scant reference to local governments in texts also corresponds to the relatively small number of articles found in the literature searches (see "Methodology" above).

The literature provides few theoretical perspectives on governance (e.g. different governing approaches in IS networks) and even fewer perspectives on local governance and the meaning of creating public-private networks (e.g., Rhodes 1997; Sørensen and Torfing, 2007). Several articles had a conceptual approach combining economic evaluation, environmental assessment (e.g. CO_2 reduction), business, and modelling theories (Ban et al., 2015; Hashimoto et al., 2010; Heeres et al., 2004; Li, 2014; Phillips et al., 2006; Taddeo et al., 2017; Veleva et al., 2015). One study looked at IS through the lens of innovation (Taddeo et al., 2017). Three articles compared different IS developments in Europe and/or the US (Boons et al., 2015; Domenech et al., 2019; Heeres et al., 2004). Five articles referred to organizational (Walls and Paquin, 2015) and institutional theories (Wang et al., 2017). Out of these, two investigated the human dimension for capacity building and focused on social barriers (Wolf et al., 2005, 2007). One focused on knowledge brokering and informational barriers (Von Malmborg, 2004). Elaborated perspectives on public-private partnerships for IS were suggested by Horvath and Harazin (2015) and Qi et al. (2009). Lenhart et al. (2015) and Music (2019) examined the relationship between city planning and IS. Van Berkel et al. (2009), likewise, adopted a city perspective when studying the fundamentals of urban material and resource exchanges. Mapping city or local governments against strategies for local governance (Bulkeley and Kern, 2006; Bulkeley et al., 2009), however, appears to be a novel contribution to the field.

Fig. 2 shows the frequency of reporting governing modes in the literature sample. The strongest correlation between local governments and IS networks seems to be linked to *governing through enabling*. Through the integration and coordination of actors, local governments mainly address economic, regulatory, social and information barriers. Indeed, several of the articles refer to local governments as important co-ordinators for, or "anchor tenants" in, IS networks (Horvath and Harazin, 2015; Taddeo et al., 2017; Von Malmborg, 2004; Walls and Paquin, 2015; Wang et al., 2017; Wolf et al., 2005, 2007; Yu et al., 2014). In this role, local authorities initiate, facilitate, promote and maintain the development of material exchanges and services (Domenech et al., 2019; Lenhart et al., 2015; Van Berkel, Fujita, Hashimoto & Geng, 2009; Wolf et al., 2007; Xiang and Yuan, 2019; Yu et al., 2014). They engage in knowledge brokering, and they simplify administrative processes, set common goals, and work to attract new members and partners for the IS network (Horvath and Harazin, 2015; Li, 2014; Neves et al., 2019; Von Malmborg, 2004; Wolf et al., 2005). To overcome information-related barriers such as lack of information exchange, a common strategy has been to provide a platform for data sharing (Wolf et al., 2005). Lenhart et al. (2015, p. 595) address several of these factors when claiming that –

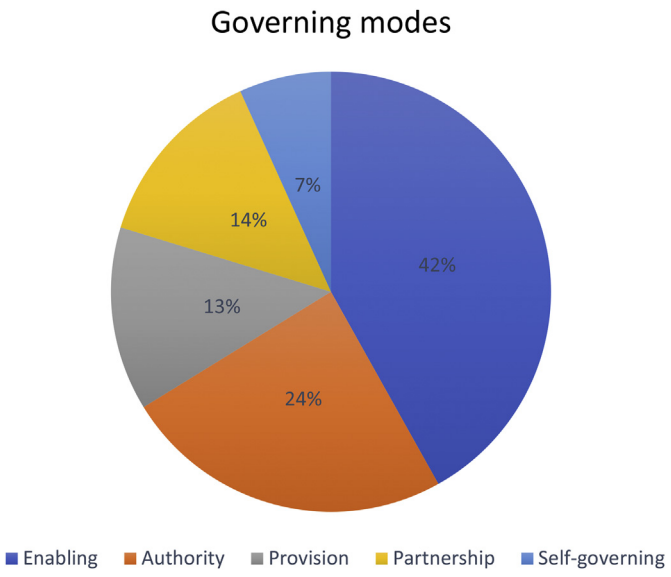

Fig. 2. Frequency of reporting governing modes in the literature.

> Locally, public authorities often provide an initiating/coordinating function to steer urban symbiosis and facilitate action. […] They may serve as symbiosis facilitator or promoter: taking responsibility, providing information, discussing economic advantages with private actors, identifying champions or encouraging legislation […]. As local authorities are accountable to their citizens and businesses, they must provide transparent information and foster trust amongst a broad range of urban stakeholders.

Local governments usually do not have an equally prominent role in legislation and regulation as the national government, which makes it more difficult for some local governments to overcome regulatory barriers. In the IS literature, however, there are numerous examples of local governments *governing by authority*, by developing legal frameworks, policies and strategies, and planning documents for regulating the local and regional IS landscape (e.g. Ban et al., 2015; Domenech et al., 2019). In this context, Xiang and Yuan (2019, p. 277) suggest that, "to meet the needs of smart industrial parks, local governments should design targeted incentive policies to encourage information sharing, attract talent, save energy, reduce emissions, and protect the environment".

Governing through provision was another common strategy identified in previous studies. The role played by local governments in dealing with barriers related to lack of technology and infrastructure has been described by Veleva et al. (2015), Xiang and Yuan (2019) and Yu et al. (2014), while others have discussed barriers such as inappropriate institutional and structural capacity, including meeting venues (Neves et al., 2019; Wang et al., 2017). Through municipally owned waste and energy companies, local government can sustain IS networks by providing both goods and services. Moreover, local governments have been reported to manage economic barriers, provide advertising and assess regional markets for positive or negative competition (e.g. Heeres et al., 2004; Qi et al., 2009; Von Malmborg, 2004).

Governing through partnership was mainly described in situations where local authorities had an active participatory role in the IS network (e.g. Domenech et al., 2019; Neves et al., 2019). More elaborated perspectives on public-private partnerships for IS have also been suggested by Horvath and Harazin (2015). For example, to overcome economic and social barriers, local governments could act as consumers of materials and by-products offered by corporate members of the IS network (Horvath and Harazin, 2015). Or they can engage in close collaboration with neighbouring local governments to strengthen an existing IS through urban and regional planning (Music, 2019). Governing by partnership was also used as strategy to overcome information-related barriers (Wolf

Table 1
Local governance strategies for overcoming barriers to industrial symbiosis (IS).

Category	Barrier	Governing mode/ strategy	Example of instruments/ measures applied to industrial symbiosis
Economic	- High investment costs. Increase in operational costs (i.e. waste transportation and waste treatment costs). - Difficulty in acquiring external investment capital; lack of funding, resources and time.	- Governing through provision	- Local government seeking or providing funding. - Local government providing appropriate infrastructure.
	- Division of income and costs between organizations and across regions, benefit sharing between companies. - Difficulties in motivating the co-location of firms; geographical distance. - Different investment cycles. - Fluctuations in demand of a particular commodity or product. - Unknown cost-benefit ratio.	- Governing through provision - Governing through enabling	- Local government acting as a broker between organizations, providing institutional and structural capacities. - Local government promoting communication between organizations, acting as a broker, and providing institutional and structural capacities.
Technical	- Operational and management issues. - The use of by-products increases the effort in designing and operating production systems (additional treatment processes, tracking of sourcing, etc) and storage facilities. - Mismatch between demand and supply; vulnerabilities due to material fluctuations. - Variations in, or issues related to, waste quality. - Potential fragility of the system. - Insufficient logistical integration between actors; lacking infrastructure. - Low use of the waste exchange website/ platform, which limits IS uptake for new actors.	- Governing through provision - Governing by authority	- Local government acting as a knowledge broker, and providing a platform for joint data and information sharing. - Local government providing or funding appropriate infrastructure. - Local government developing policies that specify local and regional IS regulations.
	- Changes in production technology creating/ destroying markets or inputs. - Lack of technology and infrastructure readiness.	- Governing through partnership - Governing by authority - Self-governing	- Local governments collaborating with each other in urban and regional planning. - Local government developing policies that specify local and regional IS regulations. - Local government as producer and consumer of materials and by-products enabled through IS exchanges. - Local government contracting IS businesses to provide public services.
Regulatory	- Restrictive environmental legislation; lack of legislative incentives. - Uncertain legislation, or lack of guidance (on compliance criteria, best environmental practices, permit conditions, etc). - Difficulties in obtaining approvals for waste reuse projects from the regulatory authorities. - Difficulties in planning, designing and managing IS. - Changing policy priorities affecting investment cycles. - Problems balancing the conflicting principles of the environment and ecology. - Perceptions of conflicting local and national government waste codes and regulations.	- Governing by authority - Governing through enabling - Governing through partnership	- Local government developing policies that specify local and regional IS regulations. - Local government recruiting partner organization(s) for lobbying. - Local government providing a platform for joint data and information sharing and, further, providing insights into legal issues and policy developments.
Social	- Social isolation between organizations. - Lack of willingness to collaborate.	- Governing through enabling - Governing through provision	- Local government coordinating between organizations, and working to attract new members for the IS network. - Local government promoting and advertising IS services to attract local industries and organizations. - Local government building trust over time in its role as "anchor tenant" or coordinator.
	- Lack of engagement by the organizations; lack of top management support. - Other priorities in the company/companies. - Lack of institutional support for integration, coordination and communication.	- Governing through enabling - Governing through partnership	- Local government promoting and facilitating the IS network. - Local government adopting a role as "anchor tenant" or IS network coordinator. - Local government initiating, facilitating and maintaining IS network. - Local government providing

(*continued on next page*)

Table 1 (*continued*)

Category	Barrier	Governing mode/ strategy	Example of instruments/ measures applied to industrial symbiosis
			institutional support and a platform for joint data and information sharing.
	- Lack of trust between organizations. - Asymmetric interdependencies and power imbalances between actors.	- Governing through enabling - Governing through partnership	- Local government building trust over time in its role as "anchor tenant" or coordinator, when initiating, facilitating and maintaining the IS network. - Local government coordinating and facilitating the IS network. - Local governing entering IS as partner organization to level power imbalances.
Information	- Lack of necessary information, lack of training for implementing IS. - Lack of facilitation; insufficient information system that collects, stores, and works with operational data. - Lack of awareness of the IS concepts, lack of information about other companies' by-products and waste flows. - Lacking contact and communication between companies; lack of information sharing.	- Governing through provision - Governing through enabling - Governing through partnership	- Local government acting as a knowledge broker, constituting a platform for joint data and information sharing. - Local government promoting IS. - Local government initiating, facilitating and maintaining the IS network. - Local government setting up common goals for delivering on IS services. - Local government advertising IS services to attract local industries and organizations.
	- Unclear roles of public and private actors involved in the IS.	- Governing through provision	- Local government providing information on actor roles and responsibilities.
	- Lack of community awareness and technical knowledge.	- Governing through provision - Governing through partnership	- Local government acting as a knowledge broker, and providing a platform for joint data and information sharing.

et al., 2005).

Although less common, the literature sample also provided some examples of local governments engaging in IS through *self-governing*. This occurred especially in situations where local governments had started to implement their own symbiosis solutions, or where they owned facilities that were crucial to the functioning of the IS (e.g. Boons et al., 2015; Lenhart et al., 2015). In this instance, the traditional business-to-business (B2B) approach in IS evolved into an authority-to-business (A2B) approach (Horvath and Harazin, 2015). City authorities thus established a relationship between their material (e.g. waste) flows and other industrial organizations. Self-governing was also practised in situations where organizational management processes were strengthened in urban and regional planning to specifically benefit IS implementation (Ban et al., 2015).

Table 1 connects different governing modes to IS barriers, and examples of instruments and measures that can be applied to overcome them. For simplicity, we have grouped those barriers that fall within the same category and can be addressed by the same governing modes.

5. Discussion

Results show that all governing modes have a function and local governments can make use of several modes in combination to support the emergence and development of IS. Fig. 3 summarizes the theoretical framework developed in Table 1, and recapitulates the barriers addressed by local governments through different modes of governing. These frameworks can be used as inspiration for future activities, and be developed by adding or combining more examples of governing strategies.

Governing by self-government includes activities where the city has full control and manages its own operations. This can be an attractive tool if a municipality wants to push a market or a certain action (Bulkeley and Kern, 2006; Palm et al., 2020). However, this governing mode has been practised surprisingly little in IS. It was only found in relation to technical barriers, such as a lack of technology and infrastructure readiness (e.g. Bacudio et al., 2016). The reason for this is probably that there is no formal requirement for local governments to implement IS; and that implementation requires collaboration and sharing of resources between several actors.

Governing by authority, where local governments use strategies and sanctions to mandate an action (Domenech et al., 2019), was primarily practised in relation to regulatory barriers. However, it was also applied to technical barriers such as lack of infrastructure development (Veleva et al., 2015). Examples from previous research include situations where local governments have developed supportive local policies and programmes (Xiang and Yuan, 2019). Most of the regulatory barriers were related to unclear legislation (Boons et al., 2011), conflicting waste codes and regulations (Corder et al., 2014) and difficulties to obtain legal approval (Golev et al., 2015). Commonly, these barriers must be approached by national rather than local governments, which can explain why local governments have not been more active in this mode (Aid et al., 2017).

Governing by enabling refers to the capacity to persuade and encourage action through, e.g., subsidies, information, or facilitation of different initiatives (Palm et al., 2019). Governing by enabling could be identified in several of the earlier studies and was used in relation to economic, regulatory, social and information barriers. By taking a proactive role and establishing meeting arenas and test beds, local authorities facilitated and actively contributed to exchanges of resources between actors (Lenhart et al., 2015). Local governments also enabled knowledge and information exchange and made it easier for local and regional actors to come together in the pursuit of IS (Horvath and Harazin, 2015).

Governing by provision was used to approach four of the five barriers: technical, economic, social and information-related ones. Even if governing by provision deals with many different barriers, more or less similar measures are used across all cases. The strategy is to provide services and goods supporting IS. This can spur resource exchanges and circular solutions, but it can also negatively affect the market and outcompete local actors (Lenhart et al., 2015; Palm et al., 2020).

Governing by partnership was likewise connected to several barrier categories. Compared with governing by enabling, this governing mode is based on a more equal relationship between local government and the other actors. While the local government has a distinct "external" role in

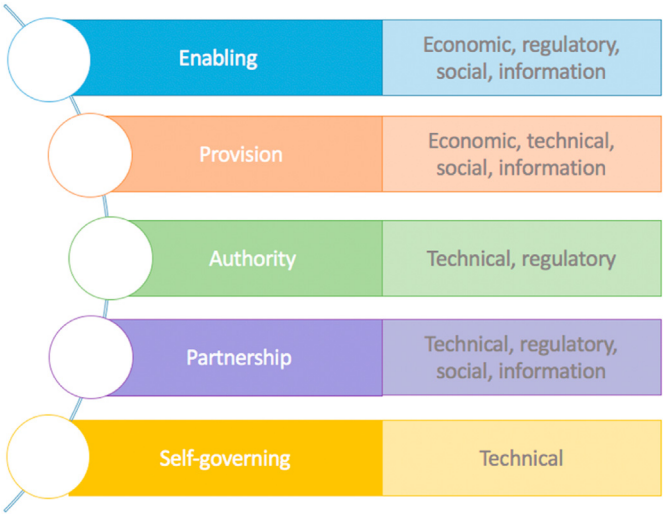

Fig. 3. Barriers addressed by local governments through different governing modes.

governing through enabling (with responsibility to contribute, e.g., resources), governing by partnership allows investments to be evenly shared between partners. When this was used as a strategy, the main resource invested by the local government was time. The municipal administration thus engaged in different collaborations, gathering and circulating information to various stakeholders (Horvath and Harazin, 2015).

Fig. 3 shows how different modes of governing can address typical IS barriers. For example, if a barrier of economic nature arises, local governments can look specifically into applying enabling or provisionary governing measures. This is intended to help companies and policymakers towards the implementation of industrial symbiosis.

6. Conclusions

This article has described a theoretical framework explaining how local governments can reduce barriers to the implementation of IS through different modes of governing: governing through enabling, provision, and partnership, governing by authority, and self-governing. The results show that local governments can adopt different governing roles to engage in IS through their means of operation. Commonly, local governments support IS in an enabling or providing function by promoting, coordinating and maintaining IS networks as well as by providing information, infrastructure and funding. They also leverage authoritarian and self-governance mechanisms, developing IS-relevant policies and regulation, and planning and controlling their own activities linked to material and resource flows. In doing so, they address economic, technical, regulatory, social and information-related barriers to IS in different ways.

In terms of policy recommendations for the future, we suggest that local governments establish a strategy on IS, including clearly defined goals and responsibilities, and methods to achieve these goals. Table 1 and Fig. 3 can be used as inspiration and tools for this purpose. Political support plays an important role both in legitimacy and for creating trust in a market or activity that the local government will invest in. Another recommendation is to strengthen governing by authority, by including physical planning as an instrument to coordinate actions across sectors. Another way forward is for local governments to demand certain IS services and, in this way, create an interest in IS solutions on the market. Alternatively, if resources exist, local governments could also initiate pilot projects.

For future research, it would be interesting to deepen the analysis of the potential policy instruments and measures that can be applied in relation to each of the five governing modes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This research was funded by the Swedish Energy Agency, project number 46016–1. We would like to thank the anynomous reviewers for their suggestions and valuable comments which helped us improve the article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cesys.2021.100014.

References

Aid, G., Eklund, M., Anderberg, S., Baas, L., 2017. Expanding roles for the Swedish waste management sector in inter-organizational resource management. Resour. Conserv. Recycl. 124, 85–97. https://doi.org/10.1016/j.resconrec.2017.04.007.

Ashton, W.S., 2011. Managing performance expectations of industrial symbiosis. Bus. Strat. Environ. 20 (5), 297–309. https://doi.org/10.1002/bse.696.

Bacudio, L.R., Benjamin, M.F.D., Eusebio, R.C.P., Holaysan, S.A.K., Promentilla, M.A.B., Yu, K.D.S., Aviso, K.B., 2016. Analyzing barriers to implementing industrial symbiosis networks using DEMATEL. Sustain. Prod. Consumpt. 7, 57–65. https://doi.org/10.1016/j.spc.2016.03.001.

Ban, Y.U., Jeong, J.H., Jeong, S.K., 2015. Assessing the performance of carbon dioxide emission reduction of commercialized eco-industrial park projects in South Korea. J. Clean. Prod. 114, 124–131. https://doi.org/10.1016/j.jclepro.2015.09.083.

Bocken, N., De Pauw, I., Bakker, C., Van der Grinten, B., 2016. Product design and business model strategies for a circular economy. J. Indust. Prod. Eng. 33 (5), 308–320.

Boons, F., Spekkink, W., 2012. Levels of institutional capacity and actor expectations about industrial symbiosis. J. Ind. Ecol. 16, 61–69.

Boons, F., Spekkink, W., Mouzakitis, Y., 2011. The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review. J. Clean. Prod. 19 (9–10), 905–911. https://doi.org/10.1016/j.jclepro.2011.01.003.

Boons, F., Spekkink, W., Isenmann, R., Baas, L., Eklund, M., Brullot, S., Deutz, P., Gibbs, D., Massard, G., Romero Arozamena, E., Ruiz Puente, C., Verguts, V., Davis, C., Korevaar, G., Costa, I., Baumann, H., 2015. Comparing industrial symbiosis in Europe: towards a conceptual framework and research methodology. In: Deutz, P., Lyon, D.I., Jun, B. (Eds.), International Perspectives on Industrial Ecology. Studies on the Social Dimensions of Industrial Ecology Series. Edward Elgar Publishing, Cheltenham, UK, pp. 69–88. https://doi.org/10.4337/9781781003572.00013.

Bossilkov, A., Van Berkel, R., Corder, G., 2005. "Regional Synergies for Sustainable Resource Processing: a Status report." Centre for Sustainable Resource Processing. Retrieved on 5 July 2020 from: https://www.researchgate.net/publication/270340839_Regional_Synergies_for_Sustainable_Resource_Processing_a_Status_Report.

Bulkeley, H., Kern, K., 2006. Local government and the governing of climate change in Germany and the UK. Urban Stud. 43 (12), 2237–2259.

Bulkeley, H., Schroeder, H., Janda, K., et al., 2009. Cities and climate change: the role of institutions, governance and urban planning. In: Paper Presented at the World Bank Fifth Urban Research Symposium: Cities and Climate Change. Marseille, France. June 2009.

Chertow, M., 2000. Industrial symbiosis: literature and taxonomy. Annu. Rev. Energy Environ. 25 (1), 313–337.

Chertow, M., 2004. Industrial symbiosis. Encyclopedia Energy 3, 407–415.

Chertow, M., 2007. "Uncovering" industrial symbiosis. J. Ind. Ecol. 11 (1), 11–30.

Chertow, M., Ehrenfeld, J., 2012. Organizing self-organizing systems: toward a theory of industrial symbiosis. J. Ind. Ecol. 16 (1), 13–27. https://doi.org/10.1111/j.1530–9290.2011.00450.x.

Chiu, A.S.F., Yong, G., 2004. On the industrial ecology potential in Asian developing countries. J. Clean. Prod. 12 (8–10), 1037–1045. https://doi.org/10.1016/j.jclepro.2004.02.013.

Corder, G.D., Golev, A., Fyfe, J., King, S., 2014. The status of industrial ecology in Australia: barriers and enablers. Resources 3, 340–361. https://doi.org/10.3390/resources3020340.

Creswell, J.W., 2008. The selection of a research design. In: Research Design. Qualitative, Quantitative, and Mixed Methods Approaches, third ed. Sage Publications, Thousand Oaks, CA.

Domenech, T., 2010. Social Aspects of Industrial Symbiosis Networks. Doctoral thesis. University College London, London.

Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D., Roman, L., 2019. Mapping industrial symbiosis development in Europe – typologies of networks,

characteristics, performance and contribution to the circular economy. Resour. Conserv. Recycl. 141, 76–98.
Ellen MacArthur Foundation, 2013. Towards a circular economy: economic and business rationale for an accelerated transition. Available at. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf.
Esaiasson, P., Gilljam, M., Oscarsson, H., Wängnerud, L., 2007. Metodpraktikan: Konsten Att Studera Samhälle, Individ Och Marknad. Norstedts Juridik, Stockholm.
EU, 2019. Circular economy. Implementation of the circular economy action plan. Available at. http://ec.europa.eu/environment/circular-economy/index_en.htm.
European Commission, 2020. A New Circular Economy Action Plan for a Cleaner and More Competitive Europe. See also the Annex to the Communication, Brussels.
European Environment Agency, 2019. The European Environment – State and Outlook 2020. EEA, Copenhagen, Denmark.
Fichtner, W., Tietze-Stöckinger, I., Frank, M., Rentz, O., 2005. Barriers of interorganisational environmental management: two case studies on industrial symbiosis. Progr. Indust. Ecol. Int. J. 2 (1), 73–88.
Fraccascia, L., 2019. The impact of technical and economic disruptions in industrial symbiosis relationships: an enterprise input-output approach. Int. J. Prod. Econ. 213, 161–174. https://doi.org/10.1016/J.IJPE.2019.03.020.
Frosch, R.A., Gallopoulos, N.E., 1989. Strategies for manufacturing. Sci. Am. 261 (3), 144–152.
Gibbs, D., Deutz, P., 2007. Reflections on implementing industrial ecology through eco-industrial park development. J. Clean. Prod. 15 (17), 1683–1695. https://doi.org/10.1016/j.jclepro.2007.02.003.
Golev, A., Corder, G.D., Giurco, D.P., 2015. Barriers to industrial symbiosis: insights from the use of a maturity grid. J. Ind. Ecol. 19 (1), 141–153. https://doi.org/10.1111/jiec.12159.
Hashimoto, S., Fujita, T., Nagasawa, E., 2010. Realizing CO_2 emission reduction through industrial symbiosis: a cement production case study for Kawasaki. Resour. Conserv. Recycl. 54, 704–710.
Heeres, R.R., Vermeulen, W.J.V., De Walle, F.B., 2004. Eco-industrial park initiatives in the USA and The Netherlands: first lessons. J. Clean. Prod. 12, 985–995.
Herczeg, G., Akkerman, R., Hauschild, M.Z., 2018. Supply chain collaboration in industrial symbiosis networks. J. Clean. Prod. 171, 1058–1067. https://doi.org/10.1016/j.jclepro.2017.10.046.
Horvath, G.A., Harazin, P., 2015. A framework for an industrial ecological decision support system to foster partnerships between businesses and governments for sustainable development. J. Clean. Prod. 114, 214–223.
International Institute for Sustainable Development, 2015. IISD Report March 2015. Development of Eco-Efficient Industrial Parks in China: A Review. Retreived on 20 June 2020 from. https://www.iisd.org/system/files/publications/development-eco-efficient-industrial-parks-china-review-en.pdf.
Islam, K., Rahman, M., Islam, K., 2016. Industrial symbiosis: a review on uncovering approaches, opportunities, barriers and policies. J. Civil Eng. Environ. Sci. 2 (1), 011–019.
Lenhart, J., Van Vliet, B., Mol, A., 2015. New roles for local authorities in a time of climate change: the Rotterdam Energy Approach and Planning as a case of urban symbiosis. J. Clean. Prod. 137, 593–601.
Levänen, J.O., Hukkinen, J.I., 2013. A methodology for facilitating the feedback between mental models and institutional change in industrial ecosystem governance: a waste management case-study from northern Finland. Ecol. Econ. 87, 15–23. https://doi.org/10.1016/j.ecolecon.2012.12.001.
Li, G., 2014. A Paradigm of Constructing Industrial Symbiosis and Coupling in China's County-Region Economic Sustainable Development. Chapter 68 in Sustainable Practices: Concepts, Methodologies, Tools, and Applications. Information Resources Management Association, USA, pp. 1218–1231. https://doi.org/10.4018/978-1-4666-4852-4.ch068.
Li, J., Pan, S.Y., Kim, H., Linn, J.H., Chiang, P.C., 2015. Building green supply chains in eco-industrial parks towards a green economy: barriers and strategies. J. Environ. Manag. 162, 158–170. https://doi.org/10.1016/j.jenvman.2015.07.030.
Madsen, J.K., Boisen, N., Nielsen, L.U., Tackmann, L.H., 2015. Industrial symbiosis exchanges: developing a guideline to companies. Waste and Biomass Valorization 6 (5), 855–864. https://doi.org/10.1007/s12649-015-9417-9.
Maranesi, C., De Giovanni, P., 2020. Modern circular economy: corporate strategy, supply chain, and industrial symbiosis. Sustainability 12. https://doi.org/10.3390/su12229383. www.mdpi.com/journal/sustainability.
Mortensen, L., Kørnøv, L., 2019. Critical factors for industrial symbiosis emergence process. J. Clean. Prod. 212, 56–69. https://doi.org/10.1016/J.JCLEPRO.2018.11.222.
Music, B., 2019. Urban planning and industrial symbiosis in Slovenia. IOP Conf. Ser. Mater. Sci. Eng. 471, 1–9, 112084.
Neves, A., Godina, R., Azevedo, S.G., Matias, J.C.O., 2019. Current status, emerging challenges, and future prospects of industrial symbiosis in Portugal. Sustainability 11 (19), 1–23.
Neves, A., Godina, R., Azevedo, S.G., Matias, J.C.O., 2020. A comprehensive review of industrial symbiosis. J. Clean. Prod. 247, 1–44. https://doi.org/10.1016/j.jclepro.2019.119113.
Pajunen, N., Watkins, G., Husgafvel, R., Heiskanen, K., Dahl, O., 2013. The challenge to overcome institutional barriers in the development of industrial residue based novel symbiosis products – experiences from Finnish process industry. Miner. Eng. 46–47, 144–156.
Palm, J., Smedby, N., McCormick, K., 2019. The role of local governments in governing sustainable consumption and sharing cities. In: Mont, O. (Ed.), A Research Agenda for Sustainable Consumption Governance. Edward Elgar Publishing, Cheltenham.
Palm, J., Södergren, K., Bocken, N., 2020. Emergence of carsharing business models and sustainability impacts in Swedish cities. Sustainability 12 (4), 1594.
Paquin, R.L., Howard-Grenville, J., 2012. The evolution of facilitated industrial symbiosis. J. Ind. Ecol. 16, 83–93.
Park, H.S., Rene, E.R., Choi, S.M., Chiu, A.S.F., 2008. Strategies for sustainable development of industrial park in Ulsan, South Korea – from spontaneous evolution to systematic expansion of industrial symbiosis. J. Environ. Manag. 87 (1), 1–13. https://doi.org/10.1016/j.jenvman.2006.12.045.
Phillips, P.S., Barnes, R., Bates, M.P., Coskeran, T., 2006. A critical appraisal of an UK county waste minimisation programme: the requirement for regional facilitated development of industrial symbiosis/ecology. Resour. Conserv. Recycl. 46, 242–264.
Qi, Y., Li, H., Wang, J., 2009. Promoting Industrial Symbiosis Network through Public–Private Partnership: a Case Study of TEDA. 2009 3rd International Conference on Bioinformatics and Biomedical Engineering. Institute of Electrical and Electronics Engineers, pp. 1–4. https://doi.org/10.1109/ICBBE.2009.5163251.
Reddy, B.S., 2013. Barriers and drivers to energy efficiency – a new taxonomical approach. Energy Convers. Manag. 74, 403–416.
Rhodes, R.A.W., 1997. Understanding Governance: Policy Networks, Governance, Reflexivity and Accountability. Open University Press, Buckingham.
Smedby, N., Quitzau, M.B., 2016. Municipal governance and sustainability: the role of local governments in promoting transitions. Environ. Pol. Governance 26, 323–336.
Sørensen, E., Torfing, J., 2007. Theories of Democratic Network Governance. Palgrave Macmillian, Basingstoke.
Symbiosis, Kalundborg, 2020. Explore the Kalundborg Symbiosis. Retrieved on 17 June 2020 from: http://www.symbiosis.dk/en/.
Taddeo, R., Simboli, A., Ioppolo, G., Morgante, A., 2017. Industrial symbiosis, networking and innovation: the potential role of innovation poles. Sustainability 9 (2), 1–17. https://doi.org/10.3390/su9020169.
Tudor, T., Adam, E., Bates, M., 2007. Drivers and limitations for the successful development and functioning of EIPs (eco-industrial parks): a literature review. Ecol. Econ. 61, 199–207. https://doi.org/10.1016/J.ECOLECON.2006.10.010.
UNEP – United Nations Environment Programme, 2015. District energy in cities. Unlocking Potential Energy Eff. Renew. Energy 1–137. Retrieved on 3 July 2020 from. https://wedocs.unep.org/handle/20.500.11822/9317.
Van Berkel, R., Fujita, T., Hashimoto, S., Geng, Y., 2009a. Industrial and urban symbiosis in Japan: analysis of the Eco-Town program 1997–2006. J. Environ. Manag. 90, 1544–1556.
Velenturf, A., 2016. Analysing the governance system for the promotion of industrial symbiosis in the Humber region, UK. People, Place Pol. 10 (2), 146–173. https://doi.org/10.3351/ppp.0010.0002.0003.
Veleva, V., Todorova, S., Lowitt, P., Neely, D., 2015. Understanding and addressing business needs and sustainability challenges: lessons from Devens eco-industrial park. J. Clean. Prod. 87, 375–384.
Von Malmborg, F., 2004. Networking for knowledge transfer: towards an understanding of local authority roles in regional industrial ecosystem management. Bus. Strat. Environ. 13, 334–346.
Voytenko Palgan, Y., McCormick, K., Leire, C., Lund, T., Öhrwall, E., Sandoff, A., Williamsson, J., 2020a. Mobile Lab on Sharing in Gothenburg. Retrieved on 5 July 2020 from: https://portal.research.lu.se/portal/files/78015547/Mobile_Lab_report_Sharing_in_Gothenburg_FINAL.pdf.
Voytenko Palgan, Y., Mont, O., Sulkakoski, S., 2020b. Governing the sharing economy: towards a comprehensive analytical framework of municipal governance. Cities 108, 1–13.
Walls, J.L., Paquin, R.L., 2015. Organizational perspectives of industrial symbiosis: a review and synthesis. Organ. Environ. 28 (1), 32–53. https://doi.org/10.1177/1086026615575333.
Wang, Q., Deutz, P., Chen, Y., 2017. Building institutional capacity for industrial symbiosis development: a case study of an industrial symbiosis coordination network in China. J. Clean. Prod. 142, 1571–1582.
Wolf, A., Eklund, M., Söderström, M., 2005. Towards cooperation in industrial symbiosis: considering the importance of the human dimension. Progr. Indust. Ecol. Int. J. 2 (2), 185–199.
Wolf, A., Eklund, M., Söderström, M., 2007. Developing integration in a local industrial ecosystem – an explorative approach. Bus. Strat. Environ. 16, 442–455.
Xiang, P., Yuan, T., 2019. A collaboration-driven mode for improving sustainable cooperation in smart industrial parks. Resour. Conserv. Recycl. 141, 273–283.
Yu, C., Dijkema, G.P.J., De Jong, M., 2014. What makes eco-transformation of industrial parks take off in China? J. Ind. Ecol. 19 (3), 441–457.

Appendix A. Barriers to industrial symbiosis (IS), by type and literature reference.

Category	**Barriers**	**References**
Economic barriers	High investment costs	Madsen et al, 2015; Pajunen et al, 2013
	Difficulty in acquiring external investment capital; lack of funding, resources and time	Chiu & Yong, 2004; Bacudio et al, 2016; Tudor et al, 2007; Corder et al, 2014; Mortensen & Kørnøv, 2019
	Division of income and costs between organizations	Fichtner et al, 2005
	Different investment cycles	Madsen et al, 2015; Mortensen & Kørnøv, 2019
	Fluctuations in demand for a particular commodity or product	Tudor et al, 2007
	Variation in cost of resources across regions	Tudor et al, 2007
	Increase in operational costs (i.e. waste transportation and waste treatment costs)	Fraccascia, 2019
	Unknown cost-benefit ratio	Madsen et al, 2015; Fichtner et al, 2005; Islam et al, 2016
	Changes in benefit-sharing policies negotiated by companies	Fraccascia, 2019
	Difficulties in motivating the co-location of firms; geographical distances	Tudor et al, 2007; Mortensen & Kørnøv, 2019
Technical barriers	Operational and management issues	Herczeg et al, 2018; Corder et al, 2014
	The use of by-products increases the effort of designing and operating production systems (additional treatment processes, tracking of sourcing, etc) and storage facilities	Herczeg et al, 2018
	Mismatch between demand and supply; vulnerabilities due to material fluctuations	Fraccascia, 2019; Tudor et al, 2007
	Variations in, or issues related to, waste quality	Prosman & Wæhrens, 2019; Fraccascia, 2019
	Potential fragility of the system	Tudor et al, 2007
	Changes in production technology creating/destroying markets or inputs	Tudor et al, 2007; Fraccascia, 2019
	Insufficient logistical integration between actors; lack of infrastructure	Herczeg et al, 2018; Mortensen & Kørnøv, 2019
	Low use of the waste exchange website/platform, resulting in limited IS uptake for new actors	Corder et al, 2014
	Lack of technology and infrastructure readiness	Bacudio et al, 2016; Costa & Ferrão, 2010; Li et al, 2015; Islam et al, 2016
Regulatory barriers	Restrictive environmental legislation; lack of legislative incentives	Bacudio et al, 2016; Boons et al, 2011; Li et al, 2015; Walls & Paquin, 2015; Fichtner et al, 2005; Golev et al, 2015; Madsen et al, 2015; Islam et al, 2016; Corder et al, 2014

	Uncertain legislation or lack of guidance (on compliance criteria, best environmental practices, permit conditions, etc)	Pajunen et al, 2013; Watkins et al, 2013
	Perceptions of conflicting local and national government waste codes and regulations	Corder et al, 2014
	Difficulties in obtaining approval for waste reuse projects from the regulatory authorities	Golev et al, 2015
	Difficulties in planning, designing and managing IS	Tudor et al, 2007; Corder et al, 2014
	Changing policy priorities affecting investment cycles	Fraccascia, 2019
	Problems balancing the conflicting principles of the environment and ecology	Tudor et al, 2007; Corder et al, 2014
Social barriers	Social isolation between organizations	Golev et al, 2015; Islam et al, 2016
	Lack of willingness to collaborate	Bacudio et al, 2016; Park et al, 2008; Fichtner et al, 2005; Mortensen & Kørnøv, 2019
	Lack of engagement by the organizations; lack of top management support	Chiu & Yong, 2004; Bacudio et al, 2016; Fichtner et al, 2005; Madsen et al, 2015
	Other priorities in the company/companies	Madsen et al, 2015
	Lack of trust between organizations	Gibbs & Deutz, 2007; Chertow & Ehrenfeld, 2012; Walls & Paquin, 2015; Bacudio et al, 2016; Fichtner et al, 2005; Golev et al, 2015; Madsen et al, 2015; Islam et al, 2016; Bossilkov et al, 2005; Domenech, 2010
	Asymmetric interdependencies and power imbalances between actors	Herczeg et al, 2018
	Lack of institutional support for integration, coordination and communication	Bacudio et al, 2016; Ashton, 2011; Li et al, 2015; Mortensen & Kørnøv, 2019
Information-related barriers	Lack of necessary information or data; lack of training for implementing IS	Gibbs & Deutz, 2007; Li et al, 2015; Walls & Paquin, 2015; Bacudio et al, 2016; Golev et al, 2015; Corder et al, 2014
	Lack of facilitation; insufficient information systems for collecting, storing and working with operational data	Herczeg et al, 2018; Mortensen & Kørnøv, 2019
	Lack of awareness of IS concepts; lack of information about other companies' by-products and waste flows	Bacudio et al, 2016; Chiu & Yong, 2004; Gibbs & Deutz, 2007; Madsen et al, 2015; Islam et al, 2016; Chertow, 2007; Domenech, 2010; Tudor et al, 2007
	Lack of contact and communication between companies; lack of information sharing	Levänen & Hukkinen, 2013; Bacudio et al, 2016; Fichtner et al, 2005; Madsen et al, 2015; Tudor et al, 2007
	Unclear roles of public and private actors involved in the IS	Tudor et al, 2007

	Lack of community awareness and technical knowledge	Golev et al, 2015

References

Ashton, W.S. (2011). Managing performance expectations of industrial symbiosis. *Business Strategy and the Environment, 20*(5), 297–309. doi:10.1002/bse.696

Bacudio, L.R., Benjamin, M.F.D., Eusebio, R.C.P., Holaysan, S.A.K., Promentilla, M.A.B., Yu, K.D.S., & Aviso, K.B. (2016). Analyzing barriers to implementing industrial symbiosis networks using DEMATEL. *Sustainable Production and Consumption, 7*, 57–65. doi: https://doi.org/10.1016/j.spc.2016.03.001

Ban, Y.U., Jeong, J.H., & Jeong, S.K. (2015). Assessing the performance of carbon dioxide emission reduction of commercialized eco-industrial park projects in South Korea. *Journal of Cleaner Production, 114*, 124–131. doi: 10.1016/j.jclepro.2015.09.083

Boons, F., Spekkink, W., & Mouzakitis, Y. (2011). The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review. *Journal of Cleaner Production, 19*(9–10), 905–911. doi:10.1016/j.jclepro.2011.01.003

Bossilkov, A., Van Berkel, R., & Corder, G. (2005). "Regional synergies for sustainable resource processing: a status report." Centre for Sustainable Resource Processing. Retrieved on 5 July 2020 from: https://www.researchgate.net/publication/270340839_Regional_Synergies_for_Sustainable_Resource_Processing_a_Status_Report

Chertow, M. (2007). "Uncovering" industrial symbiosis. Journal of Industrial Ecology, 11(1), 11–30.

Chertow, M., & Ehrenfeld, J. (2012). Organizing self-organizing systems: toward a theory of industrial symbiosis. *Journal of Industrial Ecology, 16*(1), 13–27. doi:10.1111/j.1530–9290.2011.00450.x

Chiu, A.S.F., & Yong, G. (2004). On the industrial ecology potential in Asian developing countries. *Journal of Cleaner Production, 12*(8–10), 1037–1045. doi:10.1016/j.jclepro.2004.02.013

Corder, G.D., Golev, A., Fyfe, J., & King, S. (2014). The status of industrial ecology in Australia: barriers and enablers. *Resources, 3*, 340–361. doi:10.3390/resources3020340

Costa, I., & Ferrão, P. (2010). A case study of industrial symbiosis development using a middle-out approach. *Journal of Cleaner Production, 18*(10–11), 984–992. doi:10.1016/j.jclepro.2010.03.007

Creswell, J.W. (2008). The selection of a research design. In: *Research Design. Qualitative, Quantitative, and Mixed Methods Approaches,* 3rd ed. Thousand Oaks, CA: Sage Publications.

Domenech, T. (2010). “Social aspects of industrial symbiosis networks.” Doctoral thesis. London: University College London.

Fichtner, W., Tietze-Stöckinger, I., Frank, M., & Rentz, O. (2005). Barriers of interorganisational environmental management: two case studies on industrial symbiosis. *Progress in Industrial Ecology, an International Journal, 2*(1), 73–88.

Fraccascia, L. (2019). The impact of technical and economic disruptions in industrial symbiosis relationships: an enterprise input-output approach. *International Journal of Production Economics*, *213*, 161–174. doi:10.1016/J.IJPE.2019.03.020

Gibbs, D., & Deutz, P. (2007). Reflections on implementing industrial ecology through eco-industrial park development. *Journal of Cleaner Production, 15*(17), 1683–1695. doi:10.1016/j.jclepro.2007.02.003

Golev, A., Corder, G.D., & Giurco, D.P. (2015). Barriers to industrial symbiosis: insights from the use of a maturity grid. *Journal of Industrial Ecology*, *19*(1), 141–153. doi:10.1111/jiec.12159

Herczeg, G., Akkerman, R., & Hauschild, M.Z. (2018). Supply chain collaboration in industrial symbiosis networks. *Journal of Cleaner Production, 171*, 1058–1067. doi:10.1016/j.jclepro.2017.10.046

Islam, K., Rahman, M., & Islam, K. (2016). Industrial symbiosis: a review on uncovering approaches, opportunities, barriers and policies. *Journal of Civil Engineering and Environmental Sciences, 2*(1), 011–019.

Levänen, J.O., & Hukkinen, J.I. (2013). A methodology for facilitating the feedback between mental models and institutional change in industrial ecosystem governance: a waste management case-study from northern Finland. *Ecological Economics, 87*, 15–23. doi:10.1016/j.ecolecon.2012.12.001

Li, J., Pan, S.Y., Kim, H., Linn, J.H., & Chiang, P.C. (2015). Building green supply chains in eco-industrial parks towards a green economy: barriers and strategies. *Journal of Environmental Management, 162*, 158–170. doi:10.1016/j.jenvman.2015.07.030

Madsen, J.K., Boisen, N., Nielsen, L.U., & Tackmann, L.H. (2015). Industrial symbiosis exchanges: developing a guideline to companies. *Waste and Biomass Valorization, 6*(5), 855–864. doi:10.1007/s12649-015-9417-9

Mortensen, L., & Kørnøv, L. (2019). Critical factors for industrial symbiosis emergence process. *Journal of Cleaner Production, 212*, 56–69. doi:10.1016/J.JCLEPRO.2018.11.222

Ness, D.A., & Xing, K. (2017). Toward a resource-efficient built environment: a literature review and conceptual model. *Journal of Industrial Ecology, 21*, 572–592.

Pajunen, N., Watkins, G., Husgafvel, R., Heiskanen, K., & Dahl, O. (2013). The challenge to overcome institutional barriers in the development of industrial residue based novel symbiosis products – experiences from Finnish process industry. *Minerals Engineering, 46–47*, 144–156.

Paquin, R.L., & Howard-Grenville, J. (2012). The evolution of facilitated industrial symbiosis. *Journal of Industrial Ecology, 16*, 83–93.

Park, H.S., Rene, E.R., Choi, S.M., & Chiu, A.S.F. (2008). Strategies for sustainable development of industrial park in Ulsan, South Korea – from spontaneous evolution to systematic expansion of industrial symbiosis. *Journal of Environmental Management, 87*(1), 1–13. doi:10.1016/j.jenvman.2006.12.045

Prosman, E.J., & Wæhrens, B.V. (2019). Managing waste quality in industrial symbiosis: insights on how to organize supplier integration. *Journal of Cleaner Production*, *234*, 113–123. doi:10.1016/J.JCLEPRO.2019.06.169

Tudor, T., Adam, E., & Bates, M. (2007). Drivers and limitations for the successful development and functioning of EIPs (eco-industrial parks): a literature review. *Ecological Economics, 61*, 199–207. doi:10.1016/J.ECOLECON.2006.10.010

Walls, J.L., & Paquin, R.L. (2015). Organizational perspectives of industrial symbiosis: a review and synthesis. *Organization and Environment, 28*(1), 32–53. doi:10.1177/1086026615575333

Watkins, G., Husgafvel, R., Pajunen, N., Dahl, O., & Heiskanen, K. (2013). Overcoming institutional barriers in the development of novel process industry residue based symbiosis products – case study at the EU level. *Minerals Engineering*, *41*, 31–40.

Appendix B. Mapping articles to governing modes.

	Author & title	*Governing mode*	*Quotations**
1	Ban et al (2015). Assessing the performance of carbon dioxide emission reduction of commercialized eco-industrial park projects in South Korea.	1. Governing by authority	1. "Local governments should cooperate with each other to perform EIP [eco-industrial park] projects as a joint effort and **prepare a system that can support urban and regional planning** associated with the EIP projects before they **establish master plans** for constructing environmentally and economically sustainable cities. Furthermore, to mitigate climate change at the administrative district level, the EIP projects need to be associated and promoted with many other projects conducted by the local governments." (p. 130)
2	Boons et al (2015). Comparing industrial symbiosis in Europe: towards a conceptual framework and research methodology.	1. Governing through enabling	1. "Local authorities, Chambers of Commerce, universities and other bodies with a connection to the place are likely to be involved; **participation**, and **leadership**, can change as the network develops …" (p. 84)
		2. Self-governing	2. "The set of actors included in the system first of all consists of those responsible for the transformation of material and the use of energy. These are key actors in the sense that without them, there would be no material and energy flows. Whilst these will often be firms, such production facilities may also be **owned** by governments or other types of actors." (p. 74)
3	Domenech et al (2019). Mapping industrial symbiosis development in Europe – typologies of networks, characteristics, performance and contribution to the circular economy.	1. Governing by authority/governing through partnership	1. "Local authorities are invited to **develop local strategies in collaboration** with local stakeholders in projects that generally have a 3–4-year span." (p. 77)
		2. Governing through enabling/governing through partnership	2. "… **self-organized networks** seem to share some commonalities: […] 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**." (p. 77)
4	Hashimoto et al (2010). Realizing CO_2 emission reduction through industrial symbiosis: a cement production case study for Kawasaki.	1. Governing by authority	1. "… city governments **should introduce a detailed separation program** for garbage collection so that wastes collected can be effectively recycled." (p. 709)
		2. Self-governing	2. "… industrial companies are responsible for managing their industrial wastes, while municipal governments are **responsible for managing** municipal solid waste." (p. 709)
5	Heeres et al (2004). Eco-industrial park initiatives in the USA and the Netherlands: first lessons.	1. Governing through partnership	1. "The literature study also revealed that successful development of an EIP [eco-industrial park] would require **active participation from a number of stakeholders**:

			• public sector stakeholders from local, regional and national government agencies; • …" (p. 987)
6	Horvath & Harazin (2015). A framework for an industrial ecological decision support system to foster partnerships between businesses and governments for sustainable development.	1. Self-governing/ governing through partnership	1. "… local authorities ought to consider a more **active participation** in industrial ecological systems, transcending the traditional role of legislator, and assuming one as **consumer of by-products** of industrial processes, in order to better fulfil their responsibilities where this is feasible." (p. 215)
		2. Governing by authority	2. "… local governments need to take a proactive role in creating **streamlined decision-making** mechanisms to facilitate closing open loops." (p. 215)
		3. Governing through enabling	3. "… through a more proactive and **coordinative** role of the local authority, the intensity of industrial ecology is increased. Planning and advanced coordination are a prerequisite." (p. 217)
7	Lenhart et al (2015). New roles for local authorities in a time of climate change: the Rotterdam Energy Approach and Planning as a case of urban symbiosis.	1. Governing through enabling/governing through partnership	1. "REAP [Rotterdam Energy Approach and Planning] incorporates energy and water reuse in an urban area, using by-products as resources in different urban functions. [This] is **coordinated** by Rotterdam's local authority, **in partnership** with architects and academic institutions in its design, and housing corporations and energy companies in its implementation." (p. 593)
		2. Governing though enabling	2. "Locally, public authorities often provide an **initiating**/**coordinating** function to steer urban symbiosis and facilitate action … They may serve as symbiosis **facilitator** or **promoter**: taking responsibility, providing information, discussing economic advantages with private actors, identifying champions or encouraging legislation […]. As local authorities are accountable to their citizens and businesses, they must **provide transparent information** and **foster trust** amongst a broad range of urban stakeholders." (p. 595)
		3. Governing through enabling/self-governing	3. "In its initial stage(s), REAP is predominantly 'led' by the local authority, with architects and academics included in the design stage. In later stages, housing corporations, energy companies and infrastructure providers were brought in. The local authority serves as **coordinator**, **facilitator** and **information provider**. This is in part because of REAP's nature, which attempts to address energy and urban planning simultaneously; and the possible ambiguity of this approach, which could lead to internal fragmentation if different departments (with competing perspectives and priorities)

			disagree. […] To limit competing perspectives or possible (internal) fragmentation, the local authority **initially acted rather introverted, developing an internal vision among its departments**; external partners were engaged only later." (p. 599)
		4. Governing through enabling	4. "Moving from design to implementation, the local authority took a step back in the case of REAP: **providing information, support and stimulation**, but making limited use of regulatory measures." (p. 596)
8	Li (2014). A paradigm of constructing industrial symbiosis and coupling in China's county-region economic sustainable development.	1. Governing by authority	1. "The **local government should guide the scientific planning of county-region industries' layout, structure, symbiosis, and coupling relationships**. By means of environmental cost internalization, region industries' symbiosis and coupling size, roles of social network, cultivation of innovative culture, guidance of government subsidy, pressure from public monitoring, the market mechanism, and economic incentives will play roles in resource allocation." (p. 1218)
		2. Governing through enabling	2. "In practice, the local government or industrial authority can **design the 'lack in' value chain parts and package them into some feasible and profitable projects open to the market investors, encourage firms to participate [in] regional industrial symbiosis and coupling, and construct a complete industrial chain or network**, in order to realize the integration of closed-circuit industry, higher value-added ecological agriculture, tourism and related service sectors, creative economic industrial park[s], urbanization, and [the] ecological environment. This will **avoid the heavy damage from traditional industrialization and urbanization** on [the] county-regional ecological environment, and then realize the harmony development of [a] county-regional recycle economy, society, and environment." (p. 1218)
9	Music (2019). Urban planning and industrial symbiosis in Slovenia.	1. Governing by authority	1. "… integration of the CE [circular economy] and IS model is not possible if conditions in the Municipal Spatial Development Plans are not established. For successful implementation, the CE and IS concepts need to be integrated into **spatial development plans** and other related development **strategies**, **programs and plans** as a development goal, both on the local and [at] the regional level. Since local authorities play a major role in **decision-making** processes, especially in the process of preparing documents such as the Municipal Spatial Development Plan, it is important that they **adapt** and **integrate** CE and IS concepts and implement them also in other sectors." (p. 8)

10	Neves et al (2019). Current status, emerging challenges, and future prospects of industrial symbiosis in Portugal.	1. Governing through partnership/ governing through enabling/governing through provision	1. "The largest and most organized network of industrial symbiosis in Portugal is Relvão Eco Industrial Park in Chamusca. This was the result of the **interaction** between national, local government, industries, and other entities who, from a set of **concerted actions**, such as the **provision** of a large area at lower prices for industri[al] implementation, **holding meetings** to inform and promote relationships between agents, and through waste management **facilities**, provide a cluster for waste treatment and recovery, **attract more companies** to the site and make them participate in the industrial symbiosis network, and thus contribute to the development of the municipality …" (p. 9)
		2. Governing through enabling	2. "… it was important to have a facilitating entity that analyzed the possible symbioses in advance with the quantification of some of the potential benefits to be achieved and promoted […] trusting relationships [with the companies] that served as the foundation of the industrial symbiosis networks. This **facilitating** role can be performed by different entities, whether public or private, such as local authorities and private or public organizations … Regional governments can also play an important role in **creating industrial symbiosis relationships** because they are closer to businesses and have an interest in developing the municipality from an economic and environmental point of view." (p. 16)
		3. Governing through enabling	3. "Further, the example of Relvão Eco Industrial Park illustrates how important local government is and how it can **act as a driving force** for symbiosis relations. However, there is a need for the central government to provide information and sensitization to local authorities so that they are **motivated** to take action to **trigger the establishment** of industrial symbiosis networks." (p. 16)
11	Phillips et al (2006). A critical appraisal of an UK county waste minimisation programme: the requirement for regional facilitated development of industrial symbiosis/ecology.	1. Governing through partnership	1. "In the Waste Strategy for England and Wales […], sustainable development is placed at the centre of waste management policy. It is stated that: 'If we are to deliver sustainable development it is crucial that we begin to tackle our growing mountain of waste. This means designing products which use fewer materials and using processes that produce less waste.' — To engineer this step change in the way we think about waste we must **work in partnership** — with businesses, local authorities, community groups and the public." (p. 244)
		2. Governing through partnership	2. "New **partnerships** mean Local Authorities working with a range of powerful change agents and Service Providers." (p. 245)
		3. Governing through partnership	3. "The key to the development of such [waste minimization] clubs, as the case of

			Northamptonshire shows, is the formation of Local and Regional **partnerships** of: facilitators, regulators and service providers." (p. 264)
12	Qi et al (2009). Promoting industrial symbiosis network through public–private partnership: a case study of TEDA.	1. Governing through provision	1. "The **fund** source mainly includes financial funds from local government; special funds sent by central government and Tianjin city ..." (p. 3)
13	Taddeo et al (2017). Industrial symbiosis, networking and innovation: the potential role of innovation poles.	1. Governing through enabling	1. "More effective could be an approach where the […] governance body plays a role as a **facilitator** […], **encouraging and supporting** initiatives and increasing the **awareness** that IS can be an element of strategic competitive advantage and growth for the whole territory." (p. 13)
14	Van Berkel, Fujita, Hashimoto & Geng (2009). Industrial and urban symbiosis in Japan: analysis of the Eco-Town program 1997–2006.	1. Governing by authority	1. "Local governments (municipality or prefecture level) **formulate Eco-Town Programs in consultation with local stakeholders** from [the] private sector, research institutes, community groups and citizens. Upon their submission the Eco-Town plans were reviewed by the national government, and, if considered appropriate, jointly endorsed by [the] METI [Ministry of Economy, Trade and Industry] and MoE [Ministry of Environment]. […] Upon approval of the Eco-Town Plan, [the] MoE provided a grant to the respective local authority to **execute the town planning**." (p. 1545)
		2. Governing through provision	2. "The METI grant would be matched by an **investment** subsidy from the local government, typically in the range of 1–10% of the METI grant …" (p. 1546)
		3. Governing by authority	3. "During its 10 years of operation, 26 Eco-Town plans were **approved** and **endorsed** for implementation by the responsible local government authority." (p. 1546)
		4. Governing by authority	4. "… the presence of an environmental black spot, like a polluted river or abandoned hazardous waste site, has encouraged local governments to develop Eco-Town plans, as a practical way to r**egain confidence from the residents and improve their quality of life** ..." (p. 1549)
		5. Governing through enabling	5. "In all Eco-Towns, local government is involved as a **facilitator** and **promoter** ..." (p. 1553)
		6. Governing through enabling	6. "… there is equal participation of [the] private and civil sectors, with a more profound **coordinating** and **implementing** role of the local government." (p. 1554)
		7. Governing through enabling	7. "At the top end, the Eco-Town initiative is driven by the private sector, [and] **facilitated** by local government, with minimal or no involvement of civil society." (p. 1554)
15	Vanhamäki et al (2020). Transition towards a circular economy at a regional level: a	1. Governing by authority	1. "In practice, a circular economy **strategy** was set up through a road map process involving stakeholders from local government,

	case study on closing biological loops.		industry and academia. The strategy aims to strengthen circular economy implementation in real-world systems through five identified goals. […] a move towards a circular economy is supported through **regional strategy implementation**. […] **Regulations** need to support the implementation of effective symbioses emerging from new solutions, but are also needed to safeguard the environment and human health when closing biological loops." (p. 1)
		2. Governing by authority	2. "… the Finnish governance system with its multi-stakeholder co-operation is interesting from the point of view of CE [circular economy] implementation because Finnish municipalities are **granted a high level of authority**, while regional governments consist of a consortium of such municipalities […]. The key role of municipalities has been acknowledged in, for instance, climate change mitigation, where they have been **leading** the way with stricter greenhouse gas emission reduction **targets** than those developed at the national level ..." (p. 2)
		3. Governing through enabling	3. "… to achieve a CE, it is essential for national, regional and local authorities and governments to **enable** such transition […]. This means that a CE requires efforts at macro, meso and micro levels in order to promote the change." (p. 1)
16	Veleva et al (2015). Understanding and addressing business needs and sustainability challenges: lessons from Devens eco-industrial park.	1. Governing through provision/governing by authority	1. "… local government efforts to develop Devens **infrastructure** and establish supportive sustainability **policies and programs** were in line with business needs and a key factor for Devens' success." (p. 375)
		2. Governing by authority	2. "Local governments can play a particularly important role in **promoting cluster development** and firm **competitiveness** by **setting clear and measurable social goals** which can promote social development and business sustainability (e.g. around energy use, health and safety or infrastructure improvement) ..." (p. 377)
17	Von Malmborg (2004). Networking for knowledge transfer: towards an understanding of local authority roles in regional industrial ecosystem management.	1. Governing through enabling	1. "LAs [local authorities], besides initiating networks and being **network brokers and managers**, can act as '**knowledge banks**' or '**knowledge brokers**'. As a 'knowledge bank', officers in the LA hold the knowledge transferred to companies and engage closely with the companies in small active networks. As 'knowledge brokers', LA officers are less active and mainly help companies to get in contact with consultants and technical experts who hold the knowledge needed for developing environmental management in the companies. In all, the roles identified could be seen as more specific approaches to be taken by the LA when playing the overall role of an **institutional anchor tenant**, **facilitating**

			development and management of regional industrial ecosystems." (p. 334)
		2. Governing by authority/governing through enabling/ governing through partnership/self-governing	2. "LAs have long since been involved in the greening of industry and environmental governance in general, but are now playing more diverse roles than in the early days of environmental policy. In Sweden and many other European countries, LAs have changed from serving primarily as **regulatory supervisors**, controlling hierarchically what is going on in industry, to **also serve as agitators and role models** towards other actors in the local communities, as well as **mutually dependent collaborating partners** in regional networks for environmental management […]. The central participation of LAs in industrial ecosystem development and management is not only hypothetical. In fact, LAs are taking an **active part** in the real-world **development** of eco-industrial parks ..." (p. 336)
		3. Governing through partnerships/ governing through provision	3. "… LAs **initiate the PPPs** [public-private partnerships] **and facilitate the creation** of regional networks with an expectation to contribute to the development of economic and particularly social structures of the regions, as a means to enable a positive regional welfare development. Moreover, they act as **network hub actors** and they care for the leadership of the collaborative actions. They also play an important role in **providing funding** [for] the collaborative activities, though many companies have to invest themselves, and substantial support is provided by grants from the national business development agency …" (p. 339)
		4. Governing through enabling	4. "Acting as a **knowledge broker**, the LA, or rather some of its units, plays a central role in the process of individual and organizational learning among the companies in the network. However, it does not engage operatively in the specific knowledge creation and transfer process. Rather, it acts to enable the ones that [are] in need of knowledge and ideas, i.e. the companies that are to develop their environmental management, to get in contact with the actors that hold the relevant knowledge, information and ideas to help the companies, i.e. the external consultancies." (p. 339)
		5. Governing through enabling	5. "… the LA, or rather some of its units, also plays a central role in the process of individual and organizational learning among the companies in the network when it acts as a **knowledge bank**. […] however, the LA now engages actively and operatively in the specific knowledge creation and transfer process, providing the knowledge needed in the companies that are to develop their environmental management." (p. 340)

18	Walls & Paquin (2015). Organizational perspectives of industrial symbiosis: a review and synthesis.	1. Governing through enabling	1. "IS [industrial symbiosis] actors such as anchors also play an important **coordinating** role for the entire system […]. Other types of **intermediaries** include municipalities, business association[s], or brokers, as well as NGOs [non-governmental organizations], steering committees or advisory boards, regional programs, and so on." (p. 40)
19	Wang et al (2017). Building institutional capacity for industrial symbiosis development: a case study of an industrial symbiosis coordination network in China.	1. Governing through enabling	1. "… local governments can play a vital role in **building and maintaining** an IS **coordination** network ..." (p. 1571)
		2. Governing through provision/governing by authority/ governing through enabling	2. "The local government […] has played a **crucial role for enhanced institutional capacity** for IS development from the following perspectives: • **Recruiting** local, national or international coordinating organizations possessing necessary policy, technological and network coordination knowledge for IS development; • **Setting up common goals** and appointing a non-profit organization to deliver the network services […] to industries; • **Advertising** network services to gain attention from local industries and the society; • **Seeking funding** opportunities for sustaining the coordination network and fulfilling network goals." (p. 1580)
		3. Governing through enabling	3. "The method adopted to overcome the lack of expertise and manpower for **facilitating** local IS was to **develop an eco-centre** supported by the local government to **organise** knowledge resources." (p. 1557)
20	Wolf et al (2005). Towards cooperation in industrial symbiosis: considering the importance of the human dimension.	1. Governing through enabling	1. "… the municipal authority could have a role as **coordinator** of local integration projects." (p. 185)
		2. Governing through enabling	2. "… a municipal authority can act as an initiating, coordinating and educating institution and [can] gather and distribute data and offer decision support. The reason for the unique role of the municipalities is […] that they are the only actor that should consider economical, ecological, and social factors simultaneously, whereas a single company usually focuses mainly on its own economic well-being." (p. 195)
21	Wolf et al (2007). Developing integration in a local industrial ecosystem – an explorative approach.	1. Governing through enabling	1. "… the municipality could act as a driving force in **maintaining and managing** the local industrial ecosystem in the future." (p. 446)
22	Xiang & Yuan (2019). A collaboration-driven mode for improving sustainable cooperation in smart industrial parks.	1. Governing through enabling	1. "… the key **collaborative promoters** in smart industrial parks are park management committees, enterprises, local government, and research institutions and the promoted objects are the public, information service

			companies, and supervision departments ..." (p. 277)
		2. Governing through provision	2. "The Ministry of Environmental Protection of China, industrial associations, and local governments have been identified as playing a critical role in building smart industrial parks, as top-down policy guidance greatly affects the sustainable development of smart industrial parks in China and provides critical resources, such as **leasing the territory for the infrastructure** ..." (p. 274)
		3. Governing through enabling/governing by authority	3. First, the local government and enterprises should **strengthen information exchange** by defining clear responsibilities and rights. Meanwhile, local government should **simplify administrative procedures** […]. Second, to meet the needs of smart industrial parks, local governments should **design targeted incentive policies** to encourage information sharing, attract talent, save energy, reduce emissions, and protect the environment ..." (p. 277)
		4. Governing through provision	4. "Besides, it is necessary to develop relative strategies for local governments to reasonably **supply land** and **promote public participation**." (p. 277)
		5. Governing by authority	5. "… it is generally accepted that public participation is conducive to realizing information-sharing goals, but local government, research institutions, and enterprises of smart industrial parks still play the main roles in **decision making** ..." (p. 274)
		6. Governing through enabling/governing through provision/ governing by authority	6. The local government is an important **collaborative driver** that can **affect the usage of land and energy, attract investment, provide financial support, and affect the prices of materials in smart industrial parks** ..." (p. 282)
23	Yu et al (2014). What makes eco-transformation of industrial parks take off in China?	1. Governing through enabling	1. "Local authorities usually play multiple roles: **administrator, investor, planner, and facilitator**." (p. 442)
		2. Governing through enabling	2. "In China, the **facilitated model** has been explored through the **coordinating roles** of local authorities or other third-party organizations ..." (p. 442)
		3. Governing through provision	3. "… the DDA [Dalian Development Area] local authority **invested** in a 30-km-long pipeline as an auxiliary project." (p. 447)

*Bold = our emphasis.
Literature review updated on 22 June 2020.

References

Ban, Y.U., Jeong, J.H., & Jeong, S.K. (2015). Assessing the performance of carbon dioxide emission reduction of commercialized eco-industrial park projects in South Korea. *Journal of Cleaner Production, 114*, 124–131. doi: 10.1016/j.jclepro.2015.09.083

Boons, F., Spekkink, W., Isenmann, R., Baas, L., Eklund, M., Brullot, S., Deutz, P., Gibbs, D., Massard, G., Romero Arozamena, E., Ruiz Puente, C., Verguts, V., Davis, C., Korevaar, G., Costa, I., & Baumann, H. (2015). Comparing industrial symbiosis in Europe: towards a conceptual framework and research methodology. In: Deutz, P., Lyon, D. I., & Jun, B. (eds.) *International Perspectives on Industrial Ecology. Studies on the Social Dimensions of Industrial Ecology series.* pp. 69-88. Edward Elgar Publishing. Cheltenham, UK. doi: 10.4337/9781781003572.00013

Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D., & Roman, L. (2019). Mapping industrial symbiosis development in Europe – typologies of networks, characteristics, performance and contribution to the circular economy. *Resources, Conservation & Recycling, 141*, 76–98.

Hashimoto, S., Fujita, T., & Nagasawa, E. (2010). Realizing CO_2 emission reduction through industrial symbiosis: a cement production case study for Kawasaki. *Resources, Conservation and Recycling, 54*, 704–710.

Heeres, R.R., Vermeulen, W.J.V., & De Walle, F.B. (2004). Eco-industrial park initiatives in the USA and the Netherlands: first lessons. *Journal of Cleaner Production, 12*, 985–995.

Horvath, G.A., & Harazin, P. (2015). A framework for an industrial ecological decision support system to foster partnerships between businesses and governments for sustainable development. *Journal of Cleaner Production,* 114, 214-223.

Lenhart, J., Van Vliet, B., & Mol, A. (2015). New roles for local authorities in a time of climate change: the Rotterdam Energy Approach and Planning as a case of urban symbiosis. *Journal of Cleaner Production, 137*, 593–601.

Li, G. (2014). A paradigm of constructing industrial symbiosis and coupling in China's county-region economic sustainable development. Chapter 68 in *Sustainable Practices: Concepts, Methodologies, Tools, and Applications*. pp. 1218-1231. Information Resources Management Association. USA. doi: 10.4018/978-1-4666-4852-4.ch068

Music, B. (2019). "Urban planning and industrial symbiosis in Slovenia." *IOP Conference Series: Materials Science and Engineering,* 471, 112084, p. 1-9.

Neves, A., Godina, R., Azevedo, S.G., & Matias, J.C.O. (2019). Current status, emerging challenges, and future prospects of industrial symbiosis in Portugal. *Sustainability*, *11*(19), 1-23.

Phillips, P.S., Barnes, R., Bates, M.P., & Coskeran, T. (2006). A critical appraisal of an UK county waste minimisation programme: the requirement for regional facilitated development of industrial symbiosis/ecology. *Resources, Conservation and Recycling, 46*, 242–264.

Qi, Y., Li, H., & Wang, J. (2009). Promoting industrial symbiosis network through public–private partnership: a case study of TEDA. 2009 3rd International Conference on Bioinformatics and Biomedical Engineering. pp. 1-4. Institute of Electrical and Electronics Engineers. doi: 10.1109/ICBBE.2009.5163251

Taddeo, R., Simboli, A., Ioppolo, G., & Morgante, A. (2017). Industrial symbiosis, networking and innovation: the potential role of innovation poles. *Sustainability, 9*(2), 1–17. doi: 10.3390/su9020169

Van Berkel, R., Fujita, T., Hashimoto, S., & Geng, Y. (2009). Industrial and urban symbiosis in Japan: analysis of the Eco-Town program 1997–2006. *Journal of Environmental Management, 90*, 1544–1556.

Vanhamäki, S., Virtanen, M., Luste, S., & Manskinen, K. (2020). Transition towards a circular economy at a regional level: a case study on closing biological loops. *Resources, Conservation and Recycling, 156*: 1-11.

Veleva, V., Todorova, S., Lowitt, P., & Neely, D. (2015). Understanding and addressing business needs and sustainability challenges: lessons from Devens eco-industrial park. Journal of Cleaner Production, 87, 375–384.

Von Malmborg, F. (2004). Networking for knowledge transfer: towards an understanding of local authority roles in regional industrial ecosystem management. *Business Strategy and the Environment, 13*, 334–346.

Walls, J.L., & Paquin, R.L. (2015). Organizational perspectives of industrial symbiosis: a review and synthesis. *Organization and Environment, 28*(1), 32–53. doi:10.1177/1086026615575333

Wang, Q., Deutz, P., & Chen, Y. (2017). Building institutional capacity for industrial symbiosis development: a case study of an industrial symbiosis coordination network in China. *Journal of Cleaner Production, 142,* 1571–1582.

Wolf, A., Eklund, M., & Söderström, M. (2005). Towards cooperation in industrial symbiosis: considering the importance of the human dimension. *Progress in Industrial Ecology – An International Journal, 2(2),* 185-199.

Wolf, A., Eklund, M., & Söderström, M. (2007). Developing integration in a local industrial ecosystem – an explorative approach. *Business Strategy and the Environment, 16*, 442–455.

Xiang, P., & Yuan, T. (2019). A collaboration-driven mode for improving sustainable cooperation in smart industrial parks. *Resources, Conservation and Recycling, 141*, 273–283.

Yu, C., Dijkema, G.P.J., & De Jong, M. (2014). What makes eco-transformation of industrial parks take off in China? *Journal of Industrial Ecology, 19*(3), 441-457.