
How industrial symbiosis emerges through partnerships: actors, platforms, and stakeholder processes leading to collaborative business models in port industrial areas

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Abstract: The present paper explores how industrial symbiosis emergence unfolds within port industrial areas. A multiple case study shows how industrial symbiosis emerges through partnering and stakeholder processes that take the form of collaborative business models. Focusing on actors, platforms for collaboration, and content of stakeholder processes, the study identifies drivers for industrial symbiosis emergence, including the importance of geographical proximity and agglomeration, which identify port industrial areas as natural habitats for industrial symbiosis. A defining characteristic of industrial symbiosis emergence within port industrial areas is the collective effort of actors to bridge economic, environmental, and social objectives across private and public sectors. Finally, the paper suggests that future research on industrial symbiosis and the emergence thereof within port industrial areas may benefit from insights into corporate social responsibility and the emerging field of servitisation.

Keywords: industrial symbiosis; industrial symbiosis emergence; partnerships; sustainability; port industrial areas; collaborative business models.

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1 Introduction

Industrial symbiosis has become an important way by which business and society can deal with the depletion of planetary resources, pollution by waste, and the ensuing climate changes. Industrial symbiosis has the potential to create operational savings and resource efficiency, which lead to increased profitability, competitive advantage, and improved CO₂ footprint (Boons et al., 2017; Verguts et al., 2016; Massard et al., 2014; Behera et al., 2012; Becahara and Magrini, 2009). Furthermore, industrial symbiosis contribute to the development of socioeconomic sustainability across business and society, because industrial symbiosis embeds a strong tendency to increase quality of life and social development in terms of job creation and the quality of jobs, especially when it comes to physical working conditions (Behera et al., 2012; Gibbs and Deutz, 2007; Mirata, 2004; Cohen-Rosenthal, 2000).

The point of departure of this paper is three observations on industrial symbiosis that can be derived from contemporary scholarly writing.

First, industrial symbiosis is a networked activity among co-located companies and organisations that engage in non-traditional transactions in order to make use of underutilised flows of materials, energy, water, capacity, expertise, and assets (Lombardi and Laybourn, 2012a, 2012b; Chertow, 2000). The co-location and ensuing networked activity often take place within industrial symbiosis network or eco-industrial parks (Zhang et al., 2014).

Second, the networked character of industrial symbiosis implies that stakeholders must adopt a systemic view on how they can integrate activities and resource flows. They must be strategically and operationally aware of how to cooperate across organisational borders in order to create a context for collaboration that cannot be created automatically by ordinary transactions. Most importantly,

“there should be a network of actors that trust each other and have some level of mutual understanding (relational resources), that have shared definitions of problems and solutions, possibly codified in plans or even strategic visions (knowledge resources), and that among them there are actors with sufficient power and resources to mobilise others for action (mobilisation capacity).” (Spekkink, 2013, p.343)

Third, port industrial areas are natural habitats for industrial symbiosis. By port industrial areas we understand a co-location of a variety of companies and organisations that are able to achieve agglomeration benefits across a number of different activities. Port industrial areas are characterised by a great potential for collaborative business models by which companies and organisations develop new activities and sources of revenue (Gjerding and Kringelum, 2018; Kringelum et al., 2021), and, increasingly, they appear to be incubators for industrial symbiosis where port authorities are instrumental in the provision of coordination and financial resources (Mat et al., 2016; Cereau et al., 2014; Spekkink, 2013). This reflects that the co-location of companies and organisations, and the coordinative efforts of port authorities, stimulate partnering, the integration of services, cooperation across organisational boundaries, links between urban and regional development, and incentives for creating new business models (Ballot, 2017; Ghiara et al., 2014; Verhoeven, 2010; Beresford et al., 2004).

The present paper uses this point of departure to fill a gap in contemporary research on industrial symbiosis. Despite numerous examples of symbiosis and emerging networks around the world (Dominéch et al., 2019; Park et al., 2018; Behera et al., 2016; Park et al., 2016), and studies on enablers and barriers for industrial symbiosis (see e.g., Madsen et al., 2015; Tudor et al., 2007), the study of how the emergence of industrial symbiosis unfolds is still in its infancy (Mortensen and Kørnøv, 2019). Similarly, studies of industrial symbiosis emergence within port industrial areas are few in numbers (see e.g., Baas, 2011).

The research gap is pursued, because much can be learned from past and current experiences with industrial symbiosis emergence within port industrial areas. The creation of collaborative business models promoting sustainability and circular economy requires coordinative efforts, partnering and collaboration, for which port industrial areas are conducive. Explicating such experiences will provide a platform for learning and knowledge exchange across scholars, companies and organisations engaged in industrial symbiosis. Based on that, the present study seeks to answer the following research question: How do partnerships for industrial symbiosis emergence unfold in port industrial areas?

In the following, we present a conceptual framework by which industrial symbiosis is understood in terms of collaborative business models that unfold in port industrial areas. Based on this framework, we present experiences from three international ports within which substantial industrial symbiosis has emerged as a combination of deliberate agency, and coevolution of companies and organisations. We focus on the “gestation period” (Van de Ven et al., 1999, p.23) that occurs before any bi-lateral synergistic relation is formed (Sun et al., 2017), i.e., “the dynamic (social) process, where actors are engaged in processes of building awareness and interest in industrial symbiosis, reaching out to new possible partners through interaction that encourage the exploration of new possible connections, and organising new symbiotic ties” (Mortensen and Kørnøv, 2019, p.58). We observe that partnerships are dynamic, supported by various platforms, to an important extent staged by port authorities, and driven by influential people who desire to

produce an environmental, economic and social impact on the region in which the industrial symbiosis takes place.

In effect, the present paper contributes to the scholarly literature on

- how industrial symbiosis is initiated, and fostered by partnerships and platforms
- how partnerships contribute to collaborative partnerships for sustainability
- how port industrial areas can provide contexts for industrial symbiosis emergence. In deriving these contributions, we present a mapping of stakeholder engagement that may inspire theorising and future case studies of specific contexts for industrial symbiosis emergence.

2 Industrial symbiosis, port industrial areas and partnerships: a conceptual framework

The argument presented in this section is that industrial symbiosis is, inherently, a networked activity that involves collaborative business models which in most cases presupposes co-location of companies and organisations. Business models of a circular persuasion outside industrial symbiosis do exist, of course, in the form of internal exchange where a company converts its own waste into new use by using a by-product of one process as input in another process, or by using a by-product in developing new products (Fraccascia et al., 2016; Chertow, 2000). However, for symbiosis to exist, business models of a circular persuasion must be inter-organisational in nature, thus comprising external exchange. According to Fraccascia et al. (2016), external exchange occurs where the by-product of one company is used

- a as input of another company
- b to develop new products or services in another company, or
- c to set up a new company for generating new products and services.

de Araujo et al. (2011) also point to joint provisions of services and the sharing of infrastructure, which might include equipment and technology. Furthermore, sharing of office space (Boons et al., 2017), and of expertise, knowledge and information (Lombardi and Laybourn, 2012a) are also important aspects of industrial symbiosis. In sum, industrial symbiosis comprise a variety of inter-organisational arrangements, ranging from exchange relationships to intertwined technological and organisational structures.

2.1 Industrial symbiosis and collaborative business models

Due to the collaborative nature of business models in industrial symbiosis, the value proposition of business models is systemic and benefits more actors than just the focal company as value can only be created through collaboration and partnerships (Brocken et al., 2014). Benefits are achieved by mutual action among companies where “the value created by them becomes greater than the sum of the eventual value created by each one individually (de Araujo et al., 2011, p.564), often involving that the “value proposition reflects a business-society dialogue concerning the balance of economic, ecological, and social needs” (Boons and Lüdeke-Freund, 2013, p.13). Geographical proximity is of

importance to the emergence of industrial symbiosis (FORA, 2010), because co-location increases the opportunities for new synergistic flows (Park et al., 2016; Spekkink, 2015; Mannino et al., 2015; Cutaia et al., 2015; Ashton, 2009) and ease the inter-organisational flow of resources due to smaller transportation costs (van Beers et al., 2009). The probability of new flows is increased, because the diversity of companies and organisations stimulates business opportunities (Sharib and Halog, 2017; Madsen et al., 2015; Massard et al., 2014) and attracts new companies and organisations (Ashton, 2009).

Analysing collaborative business models requires an approach different from conventional business model theorising which are often firm-centric (Zott et al., 2011). Instead, collaborative business models reflects a process where “multiple organisations that might differ in type (industry, public research, and non-profit), their position in the value chain (manufacturing, service, etc.), and industry (energy, ITC, etc.) work together to create a value creation system” (Rohrbeck et al., 2013, p.8). Collaboration on business models must comprise four properties. First, collaboration requires that commitment is established and interests are aligned, and that actions are adjusted across the collaborating parties in order to sustain alignment and promote mutual learning on how operations can be harmonised (Gulati et al., 2012; Heikkilä and Heikkilä, 2013). Second, collaboration must be driven by intrinsic motivation and caring trust between the collaborators (Miles et al., 2005), to an important extent based on shared values (Breuer and Lüdeke-Freund, 2017) that support alignment and mitigate the detrimental effects of wicked problems (Rittel and Webber, 1973). Third, collaboration must be subjected to governance structures that strike a balance of what is needed in terms of integration and formalisation in order to maintain consensus on decision making, while at the same time allowing the potential inclusion of relevant stakeholders that might contribute to the dynamics and development of collaboration (Todeva and Knoke, 2005; Vangen et al., 2015). Fourth, collaboration must be open to changes, e.g., in terms of business model innovation and adjustment of the organisational set-up (Malhotra, 2000; Heikkilä and Heikkilä, 2013).

These properties are essential when it comes to addressing how industrial symbiosis emergence unfolds in spaces characterised by geographical proximity. The success of establishing industrial symbiosis is highly dependent on the engagement, participation, and coordination of a multitude of actors (Park et al., 2016; Costa and Ferrão, 2010; van Beers et al, 2009; van Berkel et al., 2009; Heeres et al., 2004). The set of actors is characterised by very different stakeholders such as private companies, public bodies, knowledge and research institutions, interest organisations, consultancies, and community representatives (Wang et al., 2017; Sharib and Halog, 2017; Sun et al., 2017), who all hold different aspirations and goals. Consequently, the emergence of industrial symbiosis in a setting of multiple stakeholders necessitates strong management and coordination (van Berkel et al., 2009). Management and coordination can to some extent be achieved by co-location, because co-location is conducive to network conditions, where the actors benefit not only from geographical proximity, but also social proximity. Social proximity can be understood in terms of embeddedness (Doménech and Davies, 2011; Boons and Howard-Grenville, 2009), where a multitude of actors enjoy among them short mental distances, trust, and mutual understanding, which leads to the sharing of visions and reflect a common culture of collaboration and cooperation (Paquin and Howard-Grenville, 2012; Boons and Howard-Grenville, 2009; Ashton, 2008; Heeres et al., 2004). In the case of industrial symbiosis, network conditions are seen to facilitate trust-based communication, knowledge sharing, and actors’ capacity building (Spekkink,

2013, 2015; Taddeo et al., 2012; Ashton, 2008). Furthermore, physical and institutional anchors may provide management and coordination (Sun et al., 2017; von Malmborg, 2004). Physical anchors are actors that create opportunities for industrial symbiosis by offering resource flows and providing physical infrastructure. Institutional anchors are actors that influence the context of industrial symbiosis, support capacity building, provide financial support and safety, promote the benefits of industrial symbiosis, and engage other actors in activities. How the anchors drive the organisational set-up of an industrial symbiosis depends on the need for balancing integration and formalisation.

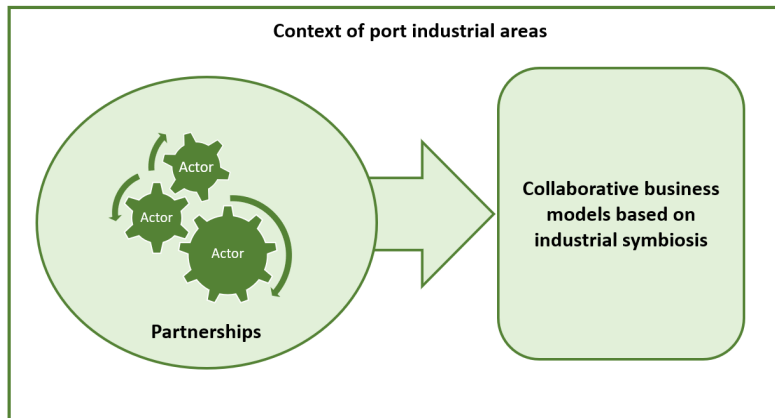
2.2 Ports as habitats for industrial symbiosis

Ports, which are found to have significant potential for contributing to sustainable development through industrial symbiosis (Mat et al., 2016; Cerceau et al., 2014; Merk, 2013), are conducive to the management and coordination of networked activities. Ports exhibit co-location of industrial activities, integration of public and private interests at port industrial areas, and facilitation of business development and networking, which make port a potent context for the evolution of collaborative business models (Gjerding and Kringelum, 2018; Verhoeven, 2010; Notteboom and Rodrigue, 2005). The facilitating role, which is most often conducted by port authorities, reflects that ports are platforms for cross-sectoral cooperation, and that port authorities are required to manage diverse strategic objectives for value creation and the achievement of sustainability (Kringelum, 2019; Lee and Lam, 2016; Suykens and Van de Voorde, 1998).

During recent years, global and regional inter-port competition has increased, and ports have, in general, been pressed to become more commercially focused (de Langen and van der Lugt, 2017; Parola et al., 2017). At the same time, ports are as important infrastructural actors expected by the political system to contribute to social and political needs (de Langen and Hazendonck, 2012), which include focus on environmental and social issues (Schiller et al., 2014; ESPO, 2012; de Langen and van der Lugt, 2006). In effect, ports must deviate from the traditional business model of ports that focus on regulatory issues and asset heavy logistics (Carpenter et al., 2018; Kringelum, 2017), and try to balance both private and public interests, combining economic and social objectives (van der Lugt et al., 2013). In this endeavour, ports are increasingly adopting sustainability as a strategic option and turning industrial symbiosis into a viable business case (Cerceau et al., 2014; Merk, 2013). Initiatives for creating industrial symbiosis are widely carried out as collaborative efforts between private companies, public bodies, research institutions, and ports (Spekkink, 2013, 2015; Merk, 2013; ESPO, 2012; Costa and Ferrao, 2010), where port authorities often assume a management and coordination role as proactive facilitators of communication and collaboration across a variety of actors within the port perimeter, and as economic facilitators that contribute financially to the implementation of environmental initiatives.

2.3 Conceptual framework

Summing up on the discussion so far, we have arrived at the following insights: In order to understand and explain the phenomenon of industrial symbiosis emergence, as also visualised in Figure 1, we must conceive industrial symbiosis as the outcome of stakeholder processes by which partnerships are established in the form of collaborative business models.

Figure 1 Conceptual framework (see online version for colours)

Source: Developed by authors

Partnerships may be a result of self-organisation, planned and/or facilitated processes. However, facilitated processes build partnerships based on intentional interventions which develop cooperation that stimulates mutual trust and the alignment of business strategies and cognitions on business opportunities. As facilitated dynamics of industrial symbiosis emergence and development (Boons et al., 2017) are recognised as being more effective and productive (Paquin and Howard -Grenville, 2012) the facilitated processes aiming at industrial symbiosis emergence became the subject of this study.

The conceptual framework presented in Figure 1 and argued for in previous sections emphasises the need for achieving management and coordination when creating industrial symbiosis. Management and coordination are defining properties of industrial symbiosis which are networked activities among co-located firms where stakeholders adopt a systemic view on how to integrate activities and resource flows. Turning the systemic view into concrete actions is highly dependent on geographical and social proximity, and the existence of physical and institutional anchors. The port industrial area, including the facilitating and coordinating role of port authorities, constitutes a context favourable to industrial symbiosis. Based on this conceptual framework, the remaining part of the paper focuses on *actors*, *activities*, *partnerships*, and *contexts* in order to illustrate how partnerships for industrial symbiosis unfold in port industrial areas. Table 1 unfolds the aspects addressed regarding these elements.

Analysing industrial symbiosis means uncovering phenomena that are highly context-specific. Undertaking comparative studies give rise to the “problem of equivalence,” i.e., “the difficulty of finding concepts that identify equivalent empirical phenomena in different countries” (Boons et al., 2017, p.938). That important qualification is of relevance to the present paper as our study focusses on three different ports, in three different countries, comprising three different contexts of industrial areas.

The points of interest that we suggest are sufficiently broad to encompass the requirements of comparative analysis suggested by Boons et al. (2017), and furthermore, they do lend themselves to the kind of backward, forward, and counterfactual approaches

that have been suggested by Boons et al. (2014). The focus is on how contextualised facilitative processes form industrial symbiosis by institutionalising partnerships and creating collaborative business models.

Table 1 Points of interest and specific aspects addressed by this study based on the conceptual framework

<i>Points of interest</i>	<i>Specific aspects</i>
<i>Actors</i>	<ul style="list-style-type: none"> • Who are the stakeholders involved? • Which roles do they assume? • How do they develop joint interests and mutual goals?
<i>Activities</i>	<ul style="list-style-type: none"> • What activities support and facilitate partnerships' formation? • What capacities do these activate and mobilise?
<i>Partnerships</i>	<ul style="list-style-type: none"> • Which kinds of partnerships are present? • What are the rationales of the partnerships? • How do they develop?
<i>Context</i>	<ul style="list-style-type: none"> • How do port industrial areas provide inter-organisational arrangements and coordination that support partnerships and the agency of actors?

3 Methodology

As industrial symbiosis emergence is a complex social phenomenon, a qualitative approach is applied (Yin, 2018; Flyvbjerg, 2006), based on the assumption that a qualitative approach is particularly well-suited to embrace and uncover the kind of collaborative processes and partnering that pertain to industrial symbiosis emergence.

The study covers a variety of institutional settings by adopting a multiple case study design (Yin, 2009). Such an approach is a recognised one for both descriptive – ‘what’ types of questions- and/or explanatory research – ‘how’ types of questions (Yin, 2018). Within this study the ‘how’ addresses the mechanisms that facilitate industrial symbiosis emergence.

In order to identify relevant information-rich cases, literature on European cases was screened through a process of purposeful sampling (Patton, 2002). To relate to this study's scope, the following *criteria for selecting cases* were applied:

- *The cases represent a European port industrial area.* Although the study of industrial symbiosis has been around for some time it has mainly focused on USA, China, Taiwan, etc. (Li et al., 2020). Thus, there is a need for focusing more on European cases, which this paper addresses.
- *The cases comprise a facilitative process aiming at industrial symbiosis emergence* that is currently developing or has been developed, i.e., representing a stage where the mechanisms leading to industrial symbiosis emergence can be uncovered.

Table 2 Overview of the three cases studied (see online version for colours)

Parameters/cases	Malmö Port	Foss-Marseille	Biopark Terneuzen
General overview	The industrial port area is at the heart of the city's energy and waste management. The infrastructure is well developed for logistics, electricity, heat, gas, and wastewater treatment. There are more than 200,000 m ² available land for further development.	The industrial port area accommodates 17 industries. Due to its previous activities, PIICTO is a major hub for energy, chemistry, and material with world-class infrastructure. There are more than 6,000,000 m ² available land for further development.	The industrial port area was initiated in 2007 as part of a larger project—Bio Base Europe—managed by Zeeland Seaport, today the North Sea Port accommodates more than 60 companies in a large variety of industries.
How the industrial area serves as a platform for industrial symbiosis	<ul style="list-style-type: none"> • Large network of actors across sectors. • Focus on building institutional capacity for symbiosis, operationalized by a Symbiosis Function. 	<ul style="list-style-type: none"> • Large networks of actors across sectors. • Focus on innovation and plug & play opportunities to support industrial and environmental transformation. 	<ul style="list-style-type: none"> • Large networks of actors across sectors and a computer-aided platform. • Focus on identifying opportunities for existing and new collaboration.
How industrial symbiosis emerges	Through a number of EU and government funded projects, aimed at developing collaborative visions that eventually have come to comprise the whole city.	Through a system of working groups, each targeting specific themes, the system fosters projects on synergetic relations and establishment of new firms.	Through industrial park promoters that foster symbiotic linkages, building relational, knowledge, and mobilization capacities among actors.
The rationale of industrial symbiosis	<ul style="list-style-type: none"> • Focus on increasing long-term collaboration among companies within the port industrial area, including customers and urban actors (e.g. municipality). • Providing test beds for developing a clean-tech city and contributing to sustainable development. • Attracting new companies and organizations. 	<ul style="list-style-type: none"> • Focus on consolidating the existing industrial ecosystem. • Increase the attractiveness of the territory in order to support regional development in terms of new companies and jobs. • Contribute to sustainable development. 	
Port Authority involved	The Copenhagen Malmö Port actively assumes responsibility for specific working packages, and engages in coordination of activities, including marketing and environmental affairs.	The Fos-Marseille port is an important stakeholder in the PIICTO association, which comprises the system of working groups. The port manages specific projects when relevant.	The former Zeeland Seaport initiated Biopark Terneuzen and coordinated the process. Today, other actors have been engaged, but the North Sea Port still coordinates main part of the initiative.
Other actors involved	<ul style="list-style-type: none"> • Malmö municipality • Research and education institutions • Consultancies • Companies within waste management, water treatment, energy etc. 	<ul style="list-style-type: none"> • Eighteen manufacturers • Two local authorities, one consular chamber, and several government services such as ADEME • Union of Chemical Industries • Four competitiveness clusters 	<ul style="list-style-type: none"> • Businesses in the area • Knowledge institutions • Local, provincial, and national authorities • Innovation institutions • Consultancies • A variety of other national entities

Cases that complied with the selection criteria were listed and the most relevant subsequently contacted, of which three cases were willing to share their experience with industrial symbiosis emergence. These cases were Malmö port industrial area (Sweden), Industrial area of Fos-Marseille under the Plateforme Industrielle et d'Innovation du Caban Tonkin (PIICTO – the industrial platform for innovation of Caban Tonkin) (France), and the industrial area of Biopark Terneuzen within North Sea Port (The

Netherlands). Table 2 presents an overview of the three cases, which represent diverse approaches to management of industrial symbiosis emergence through establishment of partnerships, even though similarities exist regarding co-location and the diversity of companies and organisations present at the port industrial areas. The industrial symbiosis emergence in Malmö port area is at the beginning stage where initial synergies are explored. In the Fos-Marseille industrial area, the industrial symbiosis emergence process is at its extending phase as several symbioses are created and new synergies are explored. The process at Biopark Terneuzen is at a development stage where several synergies are functioning, and new synergies are being explored. The variety of phases meant that we were able to study experiences of industrial symbiosis emergence at varying temporal distance from their point of inception, where the number of stakeholders across the cases varied from 12 to more than 40.

3.1 Data collection

Data collection took place in three steps. First, data were collected through extensive desk research in order to

- 1 create a thorough overview of each case
- 2 collect details on each industrial symbiosis emergence process, and lastly
- 3 identify representative interviewees for subsequent explorative and validating semi-structured interviewing.

The data extracted functioned as primary sources for the subsequent analyses. Therefore, a variety of kinds of archival and documentary data were examined, as presented in Table 3.

Second, data were collected through interviews with port environmental managers, researchers, and private actors. The purpose of the interviews was to further explore the industrial symbiosis emergence and validate the data collected through archival sources. The interviews were conducted by one member of the research team, recorded, and subsequently fully transcribed.

Third, a last round of data collection was implemented that aimed at complementing the previously collected data and providing deeper insights into the cases. The types of archival data differed from case to case and was in accordance with the process' status. That is, the process of industrial symbiosis emergence was at its incipient phase in Malmö and no academic papers on it are yet to be found. Therefore, the main archival sources were websites and online media papers presenting the case. In the case of Fos-Marseille the process was ongoing with few academic papers presenting it, so that the data were collected from various sources. In the case of Biopark Terneuzen, the process was terminated and a variety of academic papers were published. These were the main source of data collection for this case while the websites and informational leaflets complemented these.

The data collection was developed and structured based on the conceptual framework presented in Section 2. A series of questions, presented in Table 4, were developed to assist the data collection and assure a systematic procedure for collecting data through archival sources, document analysis and interviews.

Table 3 Overview on data collection sources

<i>Case</i>	<i>Data type</i>	<i>Data format</i>	<i>Sources</i>
Malmö Port	Websites	Archival data and document analysis	City of Malmö and Malmö Industrial Park (n.d.) City of Malmö (n.d.) Epic 2020 Consortium (2014)
	Online papers		City of Malmö (2018) Fraser (2017) CMP (2012)
	Semi-structured interviews with: Environmental manager, Copenhagen Malmö Port	Digital sound recordings (length 1 [1:12:38]; length 2: [1:20:36]) Full transcriptions (length 1: 16 pages; length 2: 14 pages)	Environmental manager (2018) Climate Strategist (2018)
	Climate Strategist at Malmö municipality		
Fos-Marseille	Websites	Archival data and document analysis	PIICTO (2018a)
	Informational leaflet		PIICTO (2018b)
	Academic papers		Cerceau et al. (2014) and Mat et al. (2016)
	Semi-structured interview with: General Secretary, Project manager, PIICTO Association	Digital sound recordings (length [0:41:42]) Full transcriptions (length: 6 pages)	General Secretary and Researcher (2018)
	Researcher, Post-doc in industrial ecology in port industrial areas		
Biopark Terneuzen	Websites	Archival data	Biopark Terneuzen (2018)
	Informational leaflet		Biopark Terneuzen (n.d.a) Biopark Terneuzen (n.d.b)
	Online papers		Flanders Bio-based Valley (2018) Särnblom and Maaskant (2016a) Särnblom and Maaskant (2016b) Särnblom and Maaskant (2017) Spekkink (2013, 2015, 2016)
	Academic papers		
	Semi-structured interview with: Director of Project development and innovation at North Sea Port	Digital sound recordings (length [0:53:06]) Full transcriptions (length: 10 pages)	Director of Project development and innovation and Director of one company (2018)
	Director of one company within industrial symbiosis		

Table 4 Guiding questions for data collection developed according to the analytical framework

<i>Conceptual framework elements</i>	<i>Specific aspects</i>	<i>Questions addressed</i>
<i>Actors</i>	Specific actors	<ul style="list-style-type: none"> • What were the actors involved? • How did you identify the actors to be involved?
	Actors' roles	<ul style="list-style-type: none"> • What functions and roles did the involved actors played? • How did the roles change during the process? • Was there a coordination body? Who was it? And what specific functions it had?
<i>Activities</i>	Type	<ul style="list-style-type: none"> • What kind of activities were organised? • What was the aim of the activities?
	Activated capacities	<ul style="list-style-type: none"> • What capacities did the activities address? • What capacities did the activities necessitate?
<i>Partnerships</i>	Types of relationships	<ul style="list-style-type: none"> • Which kind of relationships were present among actors in the process? • To which extent where informal relationships played a role vis á vis the formal ones? • Were there any platform to accommodate the partnerships for industrial symbiosis?
	Development	<ul style="list-style-type: none"> • How did the relationships within partnerships evolved? • Were some actors joining the process and others leaving or the same actors collaborated along the process?
	Rationale	<ul style="list-style-type: none"> • Why did actors involve in the process? • Why partnerships for industrial symbiosis?
<i>Context</i>	Port industrial areas as context	<ul style="list-style-type: none"> • Why industrial symbiosis in port industrial areas? • What capacities do these areas have to support industrial symbiosis emergence? • What role did colocation have?
	Organisation of the process	<ul style="list-style-type: none"> • Within what frameworks did the process develop? • How did the process management unfold? • How was funding secured? • How and who organised activities?
	Timeframe	<ul style="list-style-type: none"> • How long was the process on? • What was the timeframe of the process?

3.2 Data analysis

Data analysis was based on a reproductive approach to exploring the mechanisms that affect the empirical phenomenon in question (Bryman, 2012; Frederiksen and Kringelum, 2020). Nvivo11 software was used to manage the data collected through archival sources and document analysis, and the interviews' transcriptions. As the structure of the data collection and the interviews was guided by our analytical framework, a few initial provisional codes (Miles et al., 2014) were identified deductively *á priori* to data analysis. The structure of the interview guide functioned as initial codes: actors, activities, partnerships, and context. Based on the conceptual framework and the subsequent specific questions presented in Table 4, two members of the research team undertook independent first-order coding of all interviews. Data processing was characterised by inductive coding that emerged progressively. The computer-aided qualitative software then enabled the comparison of codes (Saldāna, 2015) through several rounds of discussion among members of the research team with the aim of developing second-order coding. The discussions resulted in a process of cross-case second-order coding in terms of a thematic analysis to identify common themes across the data. The result was a visual mind map that served as an organising principle for the analysis presented in the next section. This included few other codes such as organisation of industrial symbiosis, and its process. A subsequent iteration of discussions and revisiting data (Eisenhardt, 1989) resulted in an overall graphic representation of the findings (see Figure 2 in the next section). By interchanging independent and joint coding, researcher triangulation was enhanced in order to ensure the validity of the qualitative data analysis.

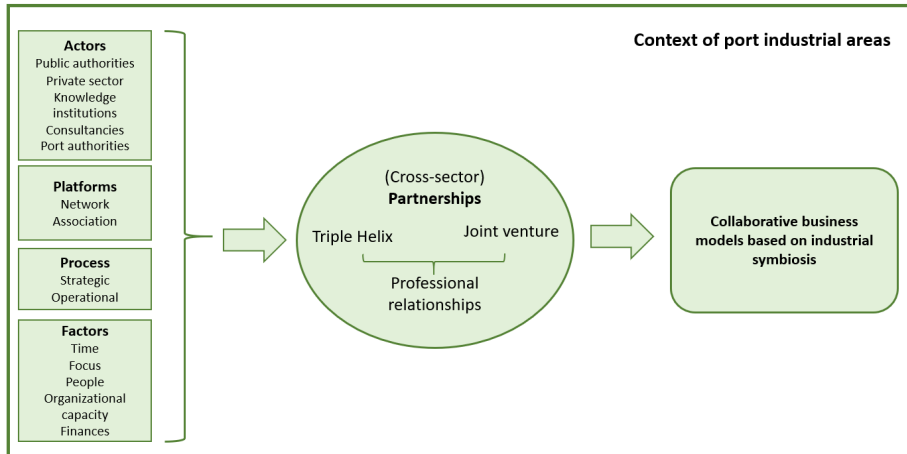
4 Findings

The overall findings are summarised in Figure 2. As the figure shows, the partnerships for industrial symbiosis are found to develop with the aim of achieving commercially viable results at strategic and operational levels of industrial symbiosis. Five groups of actors are predominantly participating in collaboration by contributing their specific organisational capacities to the development of partnership. The processes by which partnering develops are characterised by strategic and operational activities that are nested in particular forms of platforms that comprise various networks and associations.

The *partnerships* are dynamic. Often, they evolve from existing relationships, projects, or other types of collaboration, but during the process, new actors, mostly embedded in existing networks, enter, while some of the original actors depart. The partnerships are characterised by a small core of leading actors who, in most cases, remain core figures throughout the process. Storytelling often plays an important role in attracting new actors. The relationships are often informal and based on verbal agreements, common interests, and mutual trust; rather than contractual agreements, the economic and strategic interests of actors are the glue that keep the partnership together. In general, the relationships are of a professional nature, anchored in joint operational and strategic activities, and to an important extent reinforced by project applications, joint mission statements, and mutual letters of intent. The relations that carry partnerships are purely professional and occur mainly in terms of joint venturing (i.e., a joint business enterprise which is distinct from the existing business of the organisations) and triple helix formation (i.e., a cross-sector collaboration among private, public and research

organisations). Joint ventures mostly occur as business-to-business collaborations aiming at achieving specific operational goals and inter-organisational synergies, while triple helix formations are characterised by private companies, public bodies, and knowledge institutions pursuing long-term and strategic goals, albeit sometimes with operational activities as drivers.

Figure 2 The overall findings (see online version for colours)



Source: Developed by authors

The *platforms* supporting partnerships vary from case to case, which was reflected in the fact that the interviewees used the term “platform” ambiguously. While some referred to a technical way of organising data for industrial symbiosis flows, others referred to the way in which activities supporting partnerships were organised. Two kinds of organisations appeared to function as particularly significant platforms: networks and associations. Networking was extensively used in the case of Malmö, especially in the form of workshops, study visits, breakfast meetings, and conferences with the purpose of aligning visions and interests, and shaping practices of working together. Networking was also formalised in the form of a Symbiosis Function, i.e., an arrangement by which collective decision-making on establishing synergies could be made. The composition of the Symbiosis Function varied from case to case as only the actors engaged in the specific case entered the decision-making body. Networking was also the platform used in creating Biopark Terneuzen, in this case connecting companies within chemical process industry with those in the agricultural sector (Spekkink, 2013, 2015), and as in the case of Malmö, a coordination body assures alignment of visions, missions, and strategies. The dominant form in Fos-Marseille was association, where a specific multi-actor association (PIICTO) had been created with the purpose of improving competitiveness and synergies among the participants. The association represents a specific juridical entity focused on a collective approach to industrial symbiosis facilitation carried out by a coordinating body. The association is endowed with a board that makes strategic decisions on area development, while thematic working groups engage in creating synergies at the operational level.

Among the *actors within partnerships*, port authorities play an especially important part in staging industrial symbiosis emergence. The agglomeration of multiple companies

and other organisations, comprising manufacturing, system operators, services, consultancies, and public bodies within a diverse set of industrial activities opens up potential synergies that are supported by port authorities in various ways. In all cases, port authorities dispose of plots of available land for industrial development, and take initiatives for developing, supporting, and coordinating synergies. They provide financial resources and infrastructure for synergistic relations, and facilitate connections between existing or new companies. They link logistic activities and transmissions between the port area and the local, regional, and national/transnational surroundings. They work on attracting new companies or participants in specific projects and participate in knowledge dissemination. Finally, they often bridge public authorities and private companies, because they play dual roles as both part of the public sector and the private market.

The main role of public authorities, besides functioning as regulators and gatekeepers of legalisation of activities, is to provide public and political support to initiatives for industrial symbiosis. The support covers a range of phenomena, including financing projects, coordinating activities, disseminating knowledge, and anchoring industrial symbiosis in different departments of the municipality. The role of knowledge institutions is mainly to support the coordinators of industrial symbiosis in terms of knowledge generation (e.g., feasibility studies), project dissemination, raising awareness of the potentials of industrial symbiosis (e.g., through workshops), and assuming an advisory capacity in relevant activities. In performing these activities, knowledge institutions often facilitate the connection of actors across sectors. Consultancies are especially important as administrators and managers of project timelines, knowledge disseminators, and knowledge generators (e.g., feasibility studies). Finally, the role of private actors depends on whether or not they are core in the activities going on. Depending on the centrality of their position in the partnerships, they may be supporting the coordinator, contributing with knowledge and resources, or taking the lead during the process. In almost any case, they will be applying industrial symbiosis.

In general, the partnerships for industrial symbiosis emergence seem to be driven by the desire to produce economic, environmental, and social impact in the region where industrial symbiosis takes place. Actors share the idea that industrial symbiosis can contribute to competitiveness and cost efficiency, and open up new business opportunities that can be exploited collaboratively. Furthermore, there seems to be a sense of ‘obligation’ to sustainable development that informs the decisions within the partnerships. How these motivations affect partnering depends on the development of relational, knowledge, and mobilisation capacities. In all three cases, the ability of actors to combine intra- and inter-organisational structures was important. Furthermore, the actors leading the partnering process were characterised by a proactive approach, strong communication culture, and the ability to align strategic and operational goals within and across organisational boundaries.

Important were, of course, the kind of people that drive the process. In the cases of Fos-Marseille and Biopark Terneuzen, especially people with decision-making power, e.g., CEOs, were important drivers for industrial symbiosis emergence. In Malmö, this was the case to a smaller degree as the composition of people important to an ongoing initiative tended to shift as processes went along. However, keeping a sustained focus on the aims and outcomes of activities were important in all three cases. The need to sustain focus may reflect that industrial symbiosis emergence takes a lot of time. Time appeared to be a key element in the process of partnership formation for identifying potential, achieving strategic alignment, building operational consensus, and establishing actual

activities. This also pertains to setting up the overall structure of the platform for the industrial symbiosis emergence (four years in Fos-Marseille, seven years in Malmö, and eleven years for Biopark Terneuzen).

5 Discussion and conclusion

This paper contributes to filling the gap of how industrial symbiosis emergence unfolds within port industrial areas and contributes to sustainable development. It shows that within port industrial areas, industrial symbiosis emerges through collaborative stakeholder processes (thus complementing the existing literature – see e.g., Boons et al. (2017)) – that take the form of collaborative business models. Port authorities of modern ports exert a range of organisational roles, spanning the traditional port roles of operator and landlord, to the modern roles of community manager, facilitator and coordinator of innovative activities (Gjerding and Kringelum, 2018).

Our study exemplifies that the diversity of these roles, in combination with the agglomeration effects of developing port industrial areas, make ports a natural habitat for industrial symbiosis. The way that life proceeds in these habitats are characterised by collective efforts that bridge economic, environmental, and social objectives across private and public sectors, in effect blurring the organisational borders between private companies and bodies of public and semi-public activities. The decision-making processes and the activity systems of the actors involved become intertwined by partnerships that lead to sustainable business models. This supports the body of research concerned with the effect of partnerships on sustainable business models (see e.g., von Malmborg, 2004; Rohrbeck et al., 2013; Park et al., 2016; Costa and Ferrão, 2010; van Beers et al., 2009; van Berkel et al., 2009; Heeres et al., 2004).

The present study does not pretend to have created a generalised understanding of industrial symbiosis emergence. We have purposefully selected three cases, which can create bias, of course, especially since a process of coding interviews is inevitably based on the researchers' frame of reference. We have tried to mitigate the sources of bias by presenting the case selection process in detail, emphasising variety in case selection, and applying researcher triangulation to the interpretation of data.

There are three important lessons to be learned from this paper. First, industrial symbiosis emergence is a cross-sector phenomenon that will take the form of collaborative business models when strategic aspirations and organisational goals are aligned. Alignment requires strong coordinative leadership that is facilitated by one or more platforms for collaboration. It is based on commitment to something more than operational and economic goals, i.e., the desire for contributing to the combination of economic, environmental, and social goals. Second, modern ports are arenas for collaborative efforts across organisational boundaries and sectors that contribute to economic and social development within both the private and public spheres. Industrial symbiosis appears as a promising pathway for how port industrial areas can develop in the future, and certainly must invoke the strategic interest of actors involved in creating and developing port industrial areas. Third, the importance of geographical proximity, which is frequently mentioned in the literature, on industrial symbiosis is, in particular, present in port industrial areas in terms of economies of scale and scope, the spanning of sectoral boundaries, and stakeholder processes conducive to industrial symbiosis.

These lessons may give rise to interesting lines of future research. First, while the present study has indicated that actors in industrial symbiosis often are motivated by something more than economic objectives, there has been no reference to the issue of corporate social responsibility. Recent research suggests that corporate social responsibility is increasingly applied to the issue of sustainability with an emphasis on collaborative efforts and the development of shared visions (Hens et al., 2018; Porter and Reischer, 2018). Second, the relationship of partnerships in industrial symbiosis may imply that activities across organisational boundaries will become integrated to an increasingly larger degree. In the case of industrial symbiosis, a larger degree of integration will blur the distinction between manufacturing and servicing activities. In consequence, the emerging scientific field of servitisation (Bustinza et al., 2017; Wang et al., 2015; Droge et al., 2009) may become a fruitful line of inspiration for future research on industrial symbiosis emergence.

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