Industrial Symbiosis

Towards a design process for eco-industrial clusters by integrating Circular Economy and Industrial Ecology perspectives

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Industrial Symbiosis: towards a design process for eco-industrial clusters by integrating Circular Economy and Industrial Ecology perspectives

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ABSTRACT

Industrial Symbiosis (IS) is a collective approach to competitive advantage in which separate industries create a cooperative network to exchange materials, energy, water and/or by-products. By addressing issues related to resource depletion, waste management and pollution, IS plays an important role in the transition towards sustainable development. In the literature, two conceptual perspectives on IS can be identified: the Industrial Ecology (IE) and the Circular Economy (CE) perspective. Despite the recognition of these two perspectives, their relationship remains unclear and explicit attempts to develop an integrated perspective have not been made yet. Consequently, the goal of this research is to highlight and start addressing this critical gap of knowledge in order to support future research and practice geared towards the design of new IS clusters. We pose the following research question: *How can the IE and CE perspectives on IS be combined in order to support the design of IS clusters?* To this end, we first investigate the two perspectives more in depth and compare them in terms of nature, features and relevance for the study of IS. This is done by applying them as conceptual lenses for the analysis of the same case study, an existing IS cluster. The comparative analysis provides insights into how the two perspectives differ, ultimately demonstrating that they are complimentary and both necessary to fully describe an IS cluster. While the CE perspective is more suitable to explain how a cluster functions from a business standpoint in the operating phase, the IE perspective is more suitable to explain its development over time and its impacts on the environment, the economy and society. Building upon the outcomes of the comparative analysis, we leverage on the discipline of Strategic Design and integrate the two perspectives into a process for designing new IS clusters. We suggest two directions for future research. First, improving our comparative analysis of the two perspectives by looking at a wider and sample of IS clusters of different sizes and in different contexts. Second, focusing with more specificity on the issue of how IS clusters can be designed, potentially by trying to apply the process we propose on a real case aimed at designing a new IS cluster.

KEYWORDS
Industrial symbiosis
Eco-industrial clusters
Circular economy
Industrial ecology
Sustainable business model
Strategic design

1. INTRODUCTION

Industrial Symbiosis, defined as a collective approach to competitive advantage in which separate industries exchange materials, energy, water and/or by-products, plays an important role in the transition towards sustainable development (Chertow, 2000, 2007). Specifically, Industrial Symbiosis addresses issues related to resource depletion, waste management and pollution by using waste streams to generate value more efficiently across networks of industrial actors (Chertow, 2007; Massard, Jacquat, & Zürcher, 2014).

The concept of Industrial Symbiosis (IS) finds its origin in the field of Industrial Ecology (IE), with the industrial park of Kalundborg figuring as a prominent example (Chertow, 2007; Ehrenfeld & Gertler, 1997). Within social science oriented IE literature, IS is typically studied as a dynamic collaborative process evolving over time (Boons, Spekkink, & Jiao, 2014; Boons, Spekkink, & Mouzakitis, 2011). In line with the system perspective of IE, IS is viewed as a process of interacting firms, which over time produces (emergent) outcomes (Boons et al., 2014, 2011). More recently, IS is also studied as an example of a business model for Circular Economy (Bocken, Short, Rana, & Evans, 2014; Forum for the Future, 2016; Short, Bocken, Barlow, & Chertow, 2014).

Circular Economy (CE) is a concept that has recently gained traction in policy, business and academia to advocate a transition from a linear 'take-make-dispose' model, with raw materials one the one end and wastes at the other, towards a circular model, in which waste is a resource that is valorized through recycling and reuse (Gregson, Crang, Fuller, & Holmes, 2015; MacArthur, 2013). The appeal of CE is that it promises to reconcile environmental and economic goals by reducing resource use and stimulating economic growth at the same time. While concepts related to sustainable development come and go, CE has been very successful in gaining policy, business and civic traction (Hobson, Lynch, Lilley, & Smalley, 2018). Since IE can be considered as one of the main roots of CE (Bocken, Olivetti, Cullen, Potting, & Lifset, 2017; Lüdeke-freund, Gold, & Bocken, 2018), a large communality between the CE and IE strands of literature is not surprising. Both IE and CE are based on the idea of closing energy and material loops in order to make economically appealing a reduction of the environmental impact of industries (Ehrenfeld, 2004; MacArthur, 2013).

The IE process perspective on IS and the CE business model perspective on IS both put emphasis on different, but equally relevant aspects of IS. The IE perspective provides good understanding of how IS comes into being, but pays limited attention to the role of economic logic in symbiotic exchange; the CE perspective provides a good understanding of economic logic but does not pay attention to systemic behavior of IE (e.g. the role of path dependencies and lock-in in the development of IS). This suggests that an integration of the two perspectives will result in a richer insight into IS and support a better design of new IS clusters (Bocken et al., 2017; Fraccascia, Magno, & Albino, 2016; Short et al., 2014).

Accordingly, we pose the following research question: *How can the IE and CE perspectives on IS be combined in order to support the design of IS clusters?*

We aim to answer this research question by posing two sequential research objectives. The first objective is investigating the IE and CE perspectives on IS more in depth, by comparing them in terms of nature, features and relevance for the study of IS. Building upon it, the second objective is to show how this comparison can be used to support IS practice by making an initial attempt to combine the CE and IE perspectives into a process for designing new IS clusters. Since both the IE and the CE perspective have no explicit design orientation, within our second objective we leverage upon insights from the field of strategic design (Calabretta, Gemser, & Karpen, 2016). Strategic design is a stream of research and applied discipline based on using design principles and practices for the formulation and implementation of innovation strategies for organizations, including industrial networks (Calabretta et al., 2016).

The remainder of this paper is structured as follows. In section 2 we will draw on the literature review to articulate the research gap in more detail, by elaborating and comparing the IE and CE perspective on IS. Section 2 is divided in four parts: part one puts IS in context across the CE and IE perspectives; part two frames IS from the IE perspective; part three frames IS from the CE perspective; part four elaborates on the research gap reiterates our research objectives. Section 3 discusses the methodology and is divided in two parts: part one describes the research process and methods to address the objectives; part two introduces the case study going over selection criteria and concise background information. Section 4 presents the findings in two parts: part one reports the findings based on the IE perspective on IS; part two reports the findings based on the CE perspective on IS. Section 5 presents our discussion divided into two parts: in part one, a comparative analysis of the two perspectives is presented; in part two we do the initial attempt to combine them into a design process for IS. Section 6 presents our conclusions divided into two parts: the first part lists and describes our contributions; the second part pins down the limitations of our study and suggests directions for future research.

2. LITERATURE REVIEW

2.1 Industrial Symbiosis in context

Industrial Ecology (IE) emerged in the early 1990s due to concerns about the impact of industrial activities on the environment (Frosch & Gallopoulos, 1989). IE is a discipline that takes the ecosystem as an analogy for the design of industrial systems with an eye on reducing their impact on the environment by closing energy and resource loops (Ehrenfeld & Gertler, 1997; Erkman, 1997; Lifset & Graedel, 2015; Massard et al., 2014). The discipline of IE finds practical application in the design, implementation and evaluation of eco-industrial clusters, defined as a physical "communities of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues including energy, water, and materials" (Ehrenfeld, 2004; Ehrenfeld & Gertler, 1997; Massard et al., 2014). Again drawing on the ecosystem analogy, the functioning of eco-industrial clusters is labeled Industrial Symbiosis, already defined as the interaction of separate businesses entities that create a cooperative network to achieve competitive advantage by physical exchange of materials, energy, water, and/or by-products as well as services and infrastructures (Chertow, 2000, 2007; Ehrenfeld, 2004; Ehrenfeld & Gertler, 1997; Massard et al., 2014). From a technical standpoint, Industrial Symbiosis can take place in different ways: process oriented IS refers to a cooperative network around an industrial process; residue oriented IS refers to a cooperative network around a residual flow; place oriented IS refers to a cooperative network bound to a specific location (Boons et al., 2015). Also from an organizational standpoint IS can take place in different ways, namely anchor manufacturer, eco-cluster development, government planning and business incubator (Boons et al., 2011; Chertow, 2000; Mulrow, Derrible, Ashton, & Chopra, 2017; Sun, Spekkink, Cuppen, & Korevaar, 2017). Anchor manufacturer means that there are one or two industries with large production volumes, resources and byproducts seeking economic, strategic and environmental benefits through resource exchange (Sun et al., 2017). These large industries provide the critical mass for IS to develop within an eco-industrial cluster (Chertow, 2000). Eco-cluster development means that IS is initiated by a governmental and/or industrial actors who make a joint strategic plan to create the network (Boons, Chertow, Park, Spekkink, & Shi, 2017). The aim is generally boosting innovation and economic development while gaining competitive advantage. Government planning means that IS is initiated by a public/governmental institution aiming to boost the economy's productivity and resilience while reducing environmental impact (Boons et al., 2017). Business incubator means that the IS is initiated by a private project implementer who is economically interested in attracting or growing industrial or commercial tenants capable of engaging in symbiosis (Mulrow et al., 2017). All of these can be defined as IS dynamics, namely the ways in which an IS is generated and structured from a technical and organizational standpoint.

The Circular Economy (CE) is a concept based on ideas that date back decades and refers to an industrial system that is restorative or regenerative by intention and design (MacArthur, 2013). The CE may be defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" (Geissdoerfer, Savaget, Bocken, & Hultink, 2017; Lüdeke-freund et al., 2018). The origins of the concept may be traced back to the 1960s when publications such as Silent Spring (Carson, 1962), the Tragedy of the Commons (Hardin, 1968) and Operating Manual for Spaceship Earth (Fuller, 1969) drew attention to global environmental issues such as finite resources and toxicity (Blomsma & Brennan, 2017). However, the concept has gained momentum more recently in business, policy and academy, not the least catalyzed by the Ellen MacArthur Foundation who created the 'Butterfly Diagram' as a way to visualize a hierarchy of circularity strategies, which combine business and resource perspectives (Bocken et al., 2017; MacArthur, 2013). The foundations of the Circular Economy have been in place for many years and recent developments have put the concept high on the policy and business agenda. Ultimately CE is an umbrella concept based on five principles: design out waste, building resiliency through diversity, rely on renewable energy, waste is food, think in systems (Blomsma & Brennan, 2017; Lewandowski, 2016; MacArthur, 2013). Going a layer deeper, we find that the transition to a Circular Economy can be achieved through a framework based on three strategies, namely narrowing, slowing, closing resource loops and three pillars, namely technical innovation, business model innovation and collaboration (Bocken, de Pauw, Bakker, & van der Grinten, 2016; Kraaijenhagen, van Oppen, & Bocken, 2016; McDonough & Braungart, 2002; Stahel, 1994). Narrowing loops means using less material input for production in order to have less waste output at the end of life. Slowing loops means lengthening the use phase. Closing loops can be understood as recycling. Circular innovations always entail a technical, collaborative and business model aspects, therefore the three pillars should be taken into consideration simultaneously. Zooming in further in the business model innovation niche of CE, we find circular business models, namely business models aiming to drive the sustainability of a business network through the circular strategies. Amongst several archetypes of circular business models we find Industrial Symbiosis, framed as an archetype to create value from waste (Bocken et al., 2014; Forum for the Future, 2016).

Figure 1 locates visually the IS concept within the IE and CE research streams. It is immediately visible that while the CE stream frames IS as a specific type of business model archetype within a much larger context, the IE stream frames IS as a prominent example of how IE principles are applied, and therefore the concept has been studied significantly more in depth.

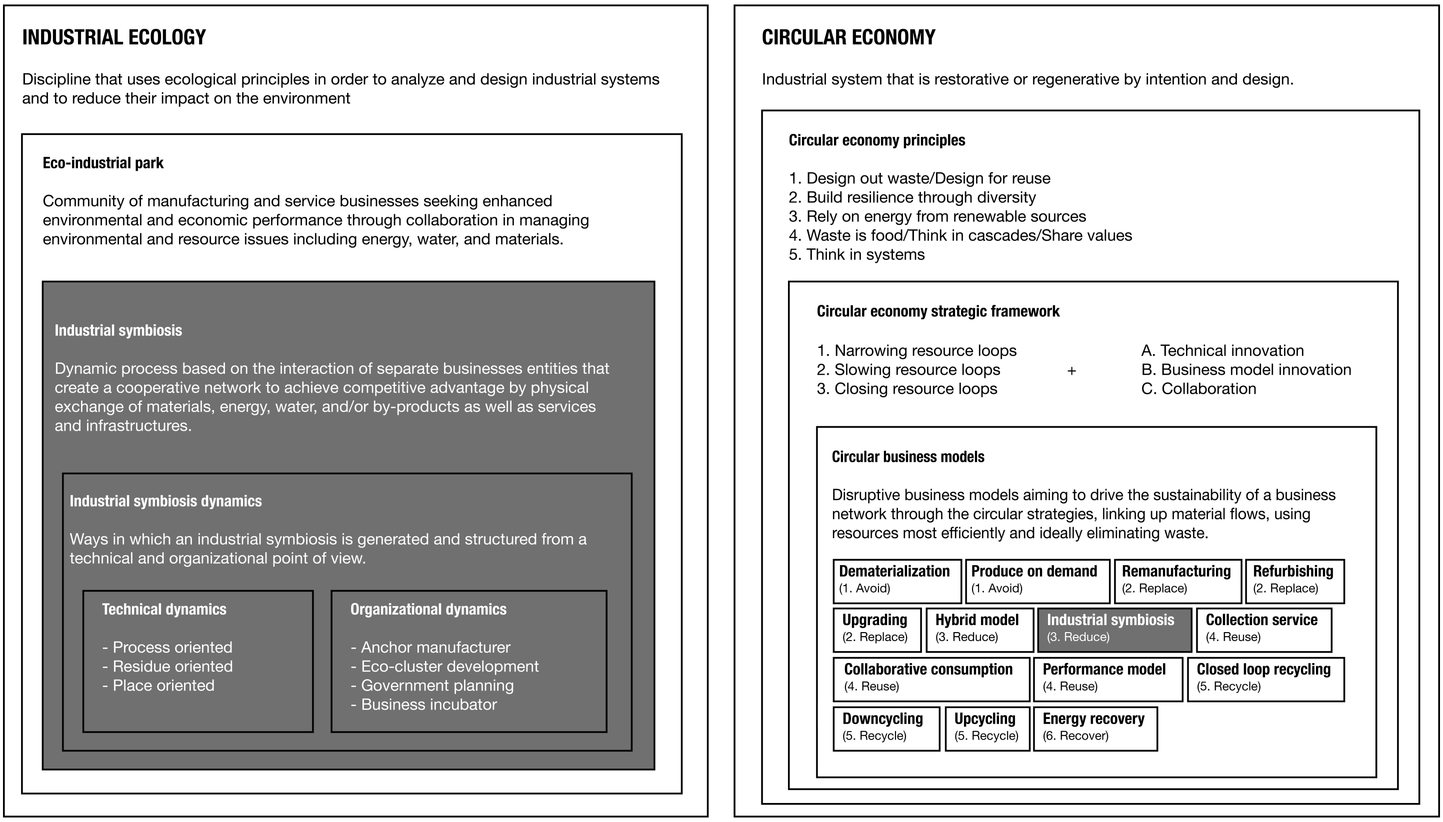

Figure 1. Locating Industrial Symbiosis in the Industrial Ecology and in the Circular Economy research streams.

2.2 Industrial Ecology perspective on Industrial Symbiosis

From the IE perspective, IS is framed as a socio-technical *process* based on the cooperative interaction of separate business entities exchanging materials, energy, water, by-products, services and infrastructures to achieve competitive advantage (Boons et al., 2014, 2011; Chertow, 2007; Massard et al., 2014). The IE perspective often places a major focus on quantitatively assessing the positive environmental impacts of IS though Life Cycle

Assessment (LCA) and Material Flow analysis (MFA) (Massard et al., 2014). Below (figure 3) we visualize this definition into a descriptive framework based on three pillars of the IS process, namely starting conditions, events and outcomes (Boons et al., 2014, 2011). The first pillar, starting conditions, is about the antecedents leading to the establishment of an IS cluster in terms of organizations involved, their business profile and specific features, their previous relationships and triggers to collaborate, their initial ideas concerning the technical system and selection of a potential location for the cluster (Boons et al., 2011; Massard et al., 2014). The second pillar, events, is about the chain of technical, social and policy actions leading from starting conditions to the implementation of the IS cluster (Boons et al., 2011; Sun et al., 2017). The third pillar, outcomes, is about the economic, environmental and social impact related to the implementation and evaluation of the industrial symbiosis cluster (Massard et al., 2014).

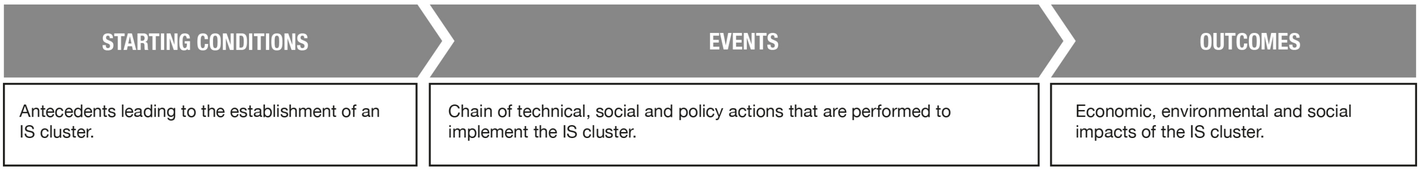

Figure 2. Industrial Symbiosis framed as a socio-technical process. Based on: (Boons et al., 2017, 2014, 2011; Chertow, 2007; Massard et al., 2014; Sun et al., 2017)

2.3 Circular Economy perspective on Industrial Symbiosis

From the CE perspective, IS is framed as business model archetype based on sharing infrastructures and by-products to improve resource efficiency and creating value from waste (Bocken et al., 2014; Forum for the Future, 2016; Kraaijenhagen et al., 2016; Lombardi & Laybourn, 2012; Short et al., 2014). Short et al. (2014) investigate the potential of IS as a business model innovation for sustainability through the case of British Sugar's internal symbiosis. Below (figure 2) we visualize this definition into a descriptive framework based on the three pillars of a circular business, namely technical innovation, collaboration and sustainable business model innovation (Kraaijenhagen et al., 2016). In the case of IS, the first pillar essentially entails a technical innovation based on the exchange of waste, resources and energy across multiple production process (Albino & Fraccascia, 2015; Bocken et al., 2014; Fraccascia et al., 2016; Short et al., 2014). The second pillar, collaboration, is about identifying the stakeholders who need to collaborate in order for the IS cluster to be implemented and operate successfully (Kraaijenhagen et al., 2016; Short et al., 2014). The third pillar, sustainable business model innovation, is about defining a specific value proposition around the elimination of the concept of waste, specific value creation / delivery activities and cross industry partnerships to eliminate life cycle waste, specific value capture mechanisms to turn waste into value and save virgin material and energy (Bocken et al., 2014; Richardson, 2008; Short et al., 2014; Teece, 2010).

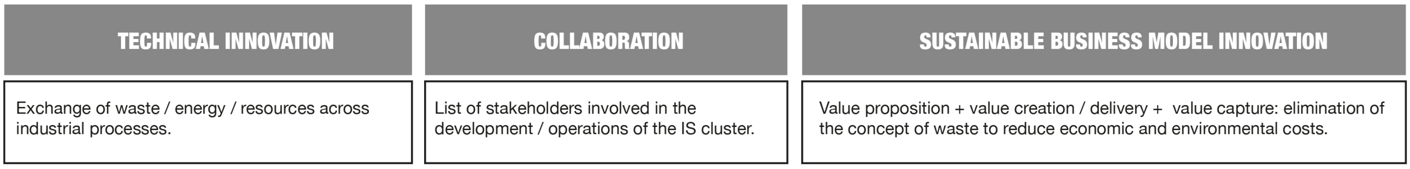

Figure 3. Industrial Symbiosis framed as a circular business model. Based on: (Albino & Fraccascia, 2015; Bocken et al., 2014; Fraccascia et al., 2016; Kraaijenhagen et al., 2016; Short et al., 2014)

2.4 Research gap and objectives

In section 2.1 we showed that IS is studied from two perspectives: IE and CE. In section 2.2 and 2.3 we reviewed how these two perspectives frame IS. The IE perspective frames IS as a socio-technical process unfolding through a set of events from starting conditions towards outcomes, with a strong focus on environmental impact assessment. The salient quality of the IE perspective is providing the study of IS with a dynamic process dimension emerging from events and collaborative interactions of multiple stakeholders; its drawback is being theoretical and complex in language, hence difficult to act upon for practitioners (Boons et al., 2017, 2014, 2011; Chertow, 2007; Massard et al., 2014).The CE perspective frames IS as a sustainable business model in which several stakeholders collaborate on a technical innovation, with a strong focus on business viability. The salient quality of the CE perspective is bringing business model thinking and language into the study of IS; its drawback is not being able to completely break free from the static and firm centric approach typically entailed with business model thinking itself (Albino & Fraccascia, 2015; Bocken et al., 2014; Fraccascia et al., 2016; Kraaijenhagen et al., 2016; Richardson, 2008; Short et al., 2014; Teece, 2010).

Recent articles about IS have recognized the existence of this twofold perspective and have started to cross-pollinate them in order to combine the qualities and address the drawbacks of the separate perspectives (Albino & Fraccascia, 2015; Bocken et al., 2017; Fraccascia et al., 2016; Lange, Korevaar, Oskam, & Herder, 2017; Lombardi &

Laybourn, 2012; Mulrow et al., 2017; Paquin, Busch, & Tilleman, 2015; Short et al., 2014; Walls & Paquin, 2015). This is essential to advance both IS research and practice. In fact, an integrated perspective would provide researchers with an improved theoretical understating of IS, which is necessary to support practitioners aiming to design new IS clusters more effectively (Albino & Fraccascia, 2015; Fraccascia et al., 2016; Lange et al., 2017; Lombardi & Laybourn, 2012; Mulrow et al., 2017; Paquin et al., 2015; Short et al., 2014). Additional rationale in favor of an integrated perspective is that IE researchers have been studying IS more extensively and for a longer time, therefore CE researchers should look into their work in order to gain insights on the technical side and environmental assessment aspects of IS (Bocken et al., 2017; Lüdeke-freund et al., 2018).

However, even though the existence of these two perspectives is recognized and the relevance of an integration is acknowledged by IS researchers, their relationship remains unclear and explicit attempts to develop an integrated perspective have not been made yet. Consequently, this paper addresses two sequential objectives: first, comparing the two perspectives in terms of nature, features and relevance; second, using the outcome of the comparison into an initial attempt to combine the two perspectives into a design process for new IS clusters.

3. METHODOLOGY

In order to assess to what extent the combination of an IE and CE perspective can lead to deeper insight in IS, we applied both perspectives as conceptual lenses in a case study (Yin, 2017). Case study research is the preferred strategy to investigate contemporary issues and related “how questions” (Yin, 2017). We apply the IE and CE perspectives as two conceptual lenses to investigate the same case. This allows us gain insight into how the two perspectives differ theoretically and empirically. In order to combine the IE and CE perspectives into a process for designing new IS clusters we conducted a Strategic Design co-creation workshop (Calabretta et al., 2016; Sanders & Stappers, 2012). Recently, Strategic Design has influenced sustainable business model innovation research and practice: co-creation workshops have been used to support multiple industrial stakeholders to collectively synthesize the outcomes of an analysis into a tangible business model output (Baldassarre, Calabretta, Bocken, & Jaskiewicz, 2017; Bocken, Schuit, & Kraaijenhagen, 2018; Calabretta et al., 2016; Geissdoerfer, Bocken, & Hultink, 2016; Sanders & Stappers, 2012; Schuit, Baldassarre, & Bocken, 2017). Thus, together with four academic experts we apply Strategic Design as a conceptual lens to frame the results of the comparative analysis. This allows us to condense them into a process to design IS clusters. The following parts of this section provide more information on the selected case study (section 3.1) and on the steps performed to execute the methodology (section 3.2).

3.1 Case study selection and background information

The selection of our case study is based on the following criteria. First, in order to be recognized as an IS, the IS cluster must be based on the collaboration of multiple stakeholders of different kind, exchanging waste and / or energy, materials, infrastructure (Chertow, 2007). Second, the IS cluster must have explicit environmental and social objectives next to economic ones. Third, the IS cluster must be in the operating phase since without this requirement it would not be possible to investigate how the IS cluster was developed and what was the impact of its formation. Fourth, enough documentation on the IS cluster should be available in order to be able to conduct background research on it. Fourth, the IS cluster should be located in Europe in order to obtain a European perspective on IS (see limitations in section 6). The case that we select according to these criteria is an IS cluster located in the south of the Netherlands. Before starting our own investigation, we perform a background research online, on project reports and through academic publications in order to collect more information on the IS cluster (Boons et al., 2015, 2017, 2014; Makkink, 2016; W. Spekkink, 2015).

In the IS cluster selected as a case study, waste heat and CO_2 of a large industrial company are collected and used as resource inputs for sustainable greenhouse farming in nearby areas. The IS cluster is based on the collaboration of several stakeholders including the local government (Local province / Local Municipality / Local Port Authority), the industrial company, local horticulture entrepreneurs and WarmCO$_2$. The goal of the local government is to promote sustainable development: boosting the economy of the region by using waste as a resource, reducing the footprint of the industrial company on the local environment, creating jobs and improving quality of life in the area. The goal of the industrial company is to gain competitive advantage by better managing its waste streams of heat and CO_2, improving its environmental performance and reducing its footprint. The goal of the local horticulture entrepreneurs is to receive CO_2 and thermal energy as inputs for their greenhouses in a way that is financially convenient and environmentally sustainable. This convergence of intents resulted in the creation of WarmCO$_2$ in 2009. WarmCO$_2$ is a small spinoff company started by the local government and the industrial company specifically to manage all the work related to the development and operations of the IS cluster. The IS cluster is currently in the operating phase. WarmCO$_2$ owns and operates the infrastructure for collecting and distributing residual CO_2 and waste heat from the industrial company into the greenhouses. During the development phase of the IS cluster also a large commercial bank and a construction company were involved. The role of the commercial bank was to provide a financial loan to WarmCO_2 for building the infrastructure while the role of the construction company was to actually build it.

This IS cluster represents a simple yet paradigmatic example of how several stakeholders of different type can engage in a long term collaboration aimed at generating economic, environmental and social value at the same time. Further in the paper, the details of this collaboration are critically analyzed from a CE perspective (section 4.1) and from a IE perspective (section 4.2).

3.2 Methodology steps

Recent articles on IS have argued that an integration of IE and CE perspectives on IS is needed to support the design of IS clusters (Albino & Fraccascia, 2015; Bocken et al., 2017; Fraccascia et al., 2016; Karpen, Gemser, & Calabretta, 2017; Short et al., 2014) This gap in IS research is substantiated through a literature review of IS within the CE and IE literature streams. The literature review identifies key elements from both perspectives and crystallizes them visually into two separate descriptive frameworks (Corbin & Strauss, 2008). Such frameworks represent two different conceptual lenses for the study of IS (figure 2 and 3). This is the starting point of a research process in which two objectives aiming to contribute in filling the gap are posed and addressed sequentially through three research steps. The first two steps are functional to address the first research objective, namely making a comparative analysis of the IE and CE perspectives on IS in order to advance towards an integrated perspective. The third step builds on the previous ones to address the second research objective, namely combining the CE and IE perspectives into an initial attempt of defining a process for designing IS clusters. Within each step several qualitative research methods for data collection and analysis are used. An overview of the research process is provided in figure 4.

The first step is to use a case study of an IS cluster to enrich the two theory-driven conceptual lenses with empirical data. This step begins with case study selection and background research on it (see section 3.3). After identifying an IS cluster suitable for our research purpose, we interview its operating and financial managers. The two managers are interviewed separately for three times in total with a conversation approach (Patton, 2002).

Two of the interviews take place face to face; one of them takes place over Skype. All interviews are digitally recorded. During the interviews, respondents are asked to provide a comprehensive overview of the IS cluster twice: first using the IE framework as a guideline to describe it as a socio-technical process and then using the CE framework as a guideline to describe it as business model. While one researcher leads the interview, a second one takes notes directly on the frameworks using them as guiding templates for structuring the collected data. Throughout the interviews, next to collecting data the interviewers collaborate with the respondents in the analysis of such data. The templates with raw data noted upon them are progressively adjusted and improved by adding new key elements according to the practice-based inputs provided from the interviewees. This approach is in line with qualitative research procedures for visually analyzing data and conceptualizing findings (Corbin & Strauss, 2008; Miles, Huberman, & Saldaña, 2013). In parallel, the researchers use the recordings of the interviews to support additional literature searches aiming to partially corroborate new framework elements from a theoretical standpoint. This results in two improved descriptive frameworks for the IE and CE perspectives on IS, based on literature as well as on empirical data (figure 5 and 6).

The second step is comparing the IE and CE conceptual lenses on IS. In this step, the two lead researchers set up three brainstorming sessions with five academic experts within the CE and IE fields. The brainstorming sessions focus on visually analyzing the frameworks produced in the previous step by looking at their differences in of nature, features and relevance (Corbin & Strauss, 2008; Miles et al., 2013). After the brainstorming sessions, the two researchers condense the outcomes of the analysis in table 1 and distill guiding principles to design IS clusters (Corbin & Strauss, 2008; Miles et al., 2013). Table 1, related reflections and guiding principles represent out outcome for the first research objective.

The third step aims at addressing the second objective of the article, namely combining the two lenses into a process for designing new IS clusters. For this purpose, two academic experts in the strategic design domain are involved in a research workshop together with one academic expert on CE and one academic expert on IE, in order to combine the two frameworks. Strategic design refers to the use of design principles and practices for the co-creation of business strategies and processes (Calabretta, Gemser, and Karpen, 2016). Thus, strategic design principles, can guide the development of a process for designing new IS clusters. Previous IE literature has already called upon a design lens in order to derive prescriptive knowledge for the development of IS (Lange et al., 2017). Additionally and more broadly, previous research has provided evidence for the effectiveness of design practices to improve sustainable innovation (Baldassarre et al., 2017; Manzini, 1999; Manzini & Vezzoli, 2003; Schuit et al., 2017). During this workshop, the IE and CE frameworks, the table with the comparative analysis and guiding principles are posted on the wall to trigger a discussion: the different expert views are combined through a Strategic Design lens into rough sketches of the process to design IS clusters. Consequently, the sketches are refined into a final version by the lead researchers (Corbin & Strauss, 2008; Miles et al., 2013). The Industrial Symbiosis Design Process represents an initial attempt to address the second research objective.

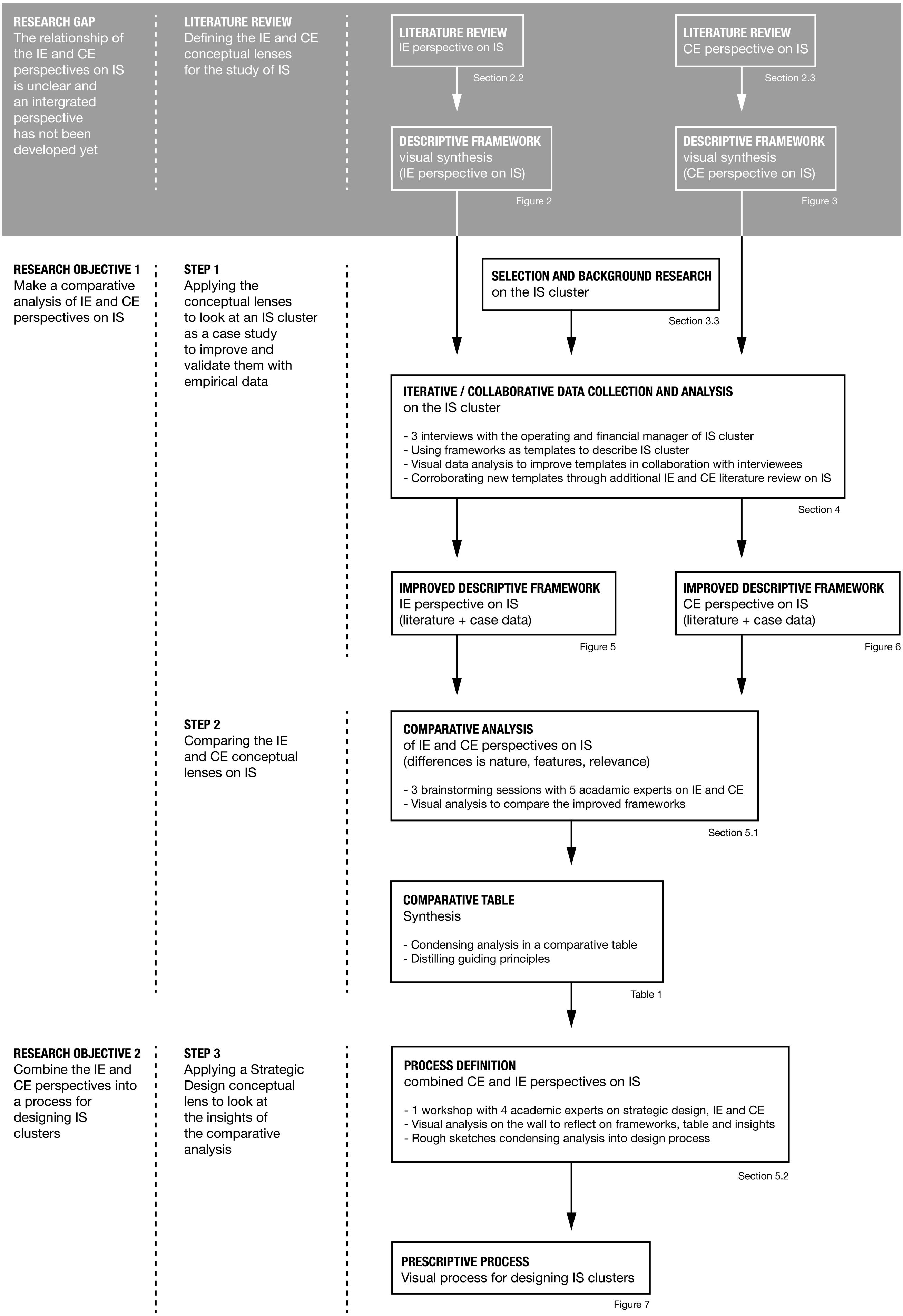

Figure 4. Research process to compare the CE and IE perspectives on IS and combining them into a process for designing IS clusters

4. FINDINGS

This section reports the findings that emerged from the analysis of the case study on the IS cluster performed from the IE and CE perspective.

An overarching finding is that both frameworks were very useful for interviewees describing the IS cluster. We found that while the IE framework is more suitable to explain its development over time and impacts, the CE framework is more suitable to explain how the IS cluster functions from a business standpoint in the operating phase. This finding, grounded into a concrete case, supports the necessity to combine the IE and CE perspectives in order to get a full and clear picture of how to set up and manage IS.

The rest of this section is divided in two parts, each explaining how findings related to the IE or CE perspective on IS are condensed into key elements to be added to the related framework. An improved framework filled in with the data from the case is presented at the end of each part, explaining its implications and applicability.

4.1 Improved Industrial Ecology framework for Industrial Symbiosis

The framework about the IE perspective on IS based on literature (developed in this research) is grounded on three pillars: starting conditions, events and outcomes. During the iterative process of collecting and analyzing data in collaboration with the interviewees, we uncovered the following findings.

First, the case study suggests that starting conditions of IS could be framed through five key questions: who is the initiator of IS, why did he initiate the IS, how did the IS process start, where is the IS located, what type of technical system underlies the IS. In our case study the initiator of IS is the local government, represented by a coalition between the Local Province and Local Municipality commission execution to the Local Port Authority. Initially, their objective was to create space for new greenhouses, an endeavor pushed top down through government planning. However eventually, thanks to synergies stemming from geographical proximity and bottom up convergence of intents, this objective evolved into the creation of an innovative IS cluster that would contribute to the sustainable development of the region by creating new jobs through farming and by reducing emissions into the air and local waterways from the chemical company's side. Concerning lS location and its scale, those were fixed constraints determined by the chemical company's location and by the place for the greenhouses selected by the local government. Concerning the type of technical system, centered on a waste recovery process, pipes would have to be built in order to channel CO_2 emissions and residual heat from the chemical company as inputs into the greenhouses. The nature of the system was determined by the type of waste emissions available, which were aligned with the inputs needed by greenhouses. According to the interviewees, it is essential to get a clear picture of what starting conditions of IS are and this can be achieved by categorizing factors leading to it. Such finding is corroborated by literature talking about different industrial symbiosis dynamics, contingencies leading to the emergence of an IS cluster (Boons et al., 2015, 2017, 2011; Mulrow et al., 2017). However, the interviewees pointed put that such categorization and related naming is rather complex and therefore we opted for a simpler alternative based on the five key who, why, how, where, what questions. Consequently, we improve the framework by making this explicit, adding to the starting conditions pillar five key elements related to the five key questions. By answering to those, the framework provides a clear yet simple picture of the starting conditions of IS.

Second, events related to IS are based on a chain of different types of actions taking place in different phases. In our case study we see first a preparation phase followed by a development and operation phases through which chains of institutional, financial, technical, commercial and social actions occur. On the institutional level we see, in the preparation phase, the action of establishing a partnership between the local government and the chemical company giving birth to a venture called WarmCO_2. The financial chain of actions begins in preparation with the local government providing a guarantee of 65M € needed to implement the project. In development, WarmCO_2 takes the loan from the bank and starts paying for infrastructure development, while in operation WarmCO_2 gradually pays back the loan by buying waste streams from the chemical company and reselling them to farmers in the form of a 15 years contract. The technical chain of actions begins with a feasibility study in the preparation phase followed by the construction company building the infrastructure in development and by WarmCO_2 taking care of continuous process optimization in operation. At this stage the chemical company also works on system maintenance and the construction company abandons the endeavor. Commercial actions start only in the operation phase, which sees WarmCO_2 continuously comparing the price of its offering with energy market prices in order to support the IS cluster business case. The chain of social actions is about stakeholder engagement and conflict management and takes place all through preparation, development and operation. According to the interviewees is important to distinguish between different types of actions and phases to fully understand the process of how an IS cluster comes to being. Such finding is corroborated by literature. Concerning the nature of actions, literature mentions social, institutional and technical / physical actions (Boons et al., 2011; Sun et al., 2017). Concerning process phases, literature mentions all phases of preparation, development and operations reported from interviewees, although with slightly different terms (Massard et al., 2014). Consequently, we improve the framework by making this explicit, adding several key elements to the event pillar: the three phases, namely preparation, development, operation and the five action categories, namely technical, institutional, financial, commercial and social actions. In the framework each IS related action can be associated to a phase and to a category.

Third, outcomes of IS include environmental, social and economic impacts taking place in parallel on a micro firm / local level and on a macro national / global level. In our case study, environmental impact on the micro level is related to a reduction in CO_2 and heat emissions from the chemical company's side into the air and local waterways: these emissions are channeled into pipes and used as input for greenhouse farming. On the macro level, environmental impact is related to avoided greenhouse emissions and avoided use of natural gas as thermal energy source to heat the greenhouses. Social impact is related to job creation through the IS cluster, which is a positive gain on the local as well as national scale. In addition, reduced emissions also bring a positive impact on the wellbeing of local population. Economic impact on the micro scale is mostly represented by gains for the chemical company: small profits in the short term, derived by selling the waste streams to WarmCO_2; competitive advantage in the long run, derived by the acquisition of know how into waste management in view of more stringent future policies. On the macro scale, economic impact is related to sustainable economic development of the Netherlands and Europe through the implementation of an innovative IS cluster. According to the interviewees, impact should be defined and quantified not only in terms of categories but also in terms of scale. This is relevant to have a more clear and precise picture of the impact that could eventually be used strategically to inform future developments. Such finding is corroborated by literature on CE impact assessment, reporting on the importance to have impact indicators on different scales of magnitude (McDowall et al., 2017). Consequently, we improve the framework by making this explicit, adding new key elements to the outcomes pillar impact: impact categories, namely environmental, social, economic, and impact scale, namely micro and macro. In the framework each outcome can be reported in terms of category and scale.

Fourth, IS as socio-technical process is not linear but iterative in nature. Starting conditions determine events, which determine outcomes, which in turn impact the starting conditions, meaning that new collaboration may arise in the same context and / or amongst the same actors. Moreover, events are iterative in nature themselves, meaning that preparatory activities determine development activities, which determine operational activities, which in turn determine a new cycle of activities. In our case study, project outcomes provide important lessons learned for all stakeholders and increased collaborative capacity, which laid the foundation for the implementation of future projects. For example, the operating manager of WarmCO$_2$ was recently hired by the industrial company to work on IS related tasks in another country. Concerning the iterative nature of events, WarmCO$_2$ continuously takes care of optimizing the IS process, which requires new preparation and development activities over time. According to the interviewees, it is essential to stress the iterative nature of the IS cluster development and implementation process in order to make sure that all stakeholders involved have realistic expectations and embrace the endeavor with a "trial and error" mindset towards success. Consequently, we improve the framework by making this explicit, adding two loops in the top part showing the iterative nature of the whole process and events.

The final framework of the IE perspective on IS is visualized in Figure 5. The framework is based on literature and on case study data, which complement and corroborate each other providing a comprehensive view on how IS is framed from a IE perspective. This comprehensive view provided by the framework can be applied by IS research and practice. IS researchers can apply it to better investigate and discuss all the elements entailed with the process of developing an IS clusters over time. IS practitioners can apply it as well to map all the details related to the development of an IS cluster. The interviewees explicitly stated that "this frameworks is a very helpful tool to map how the IS cluster was developed over time and to explain its impacts to the other stakeholders and third parties". This aspect is particularly relevant to understand how IS clusters can be created and what impact they bring.

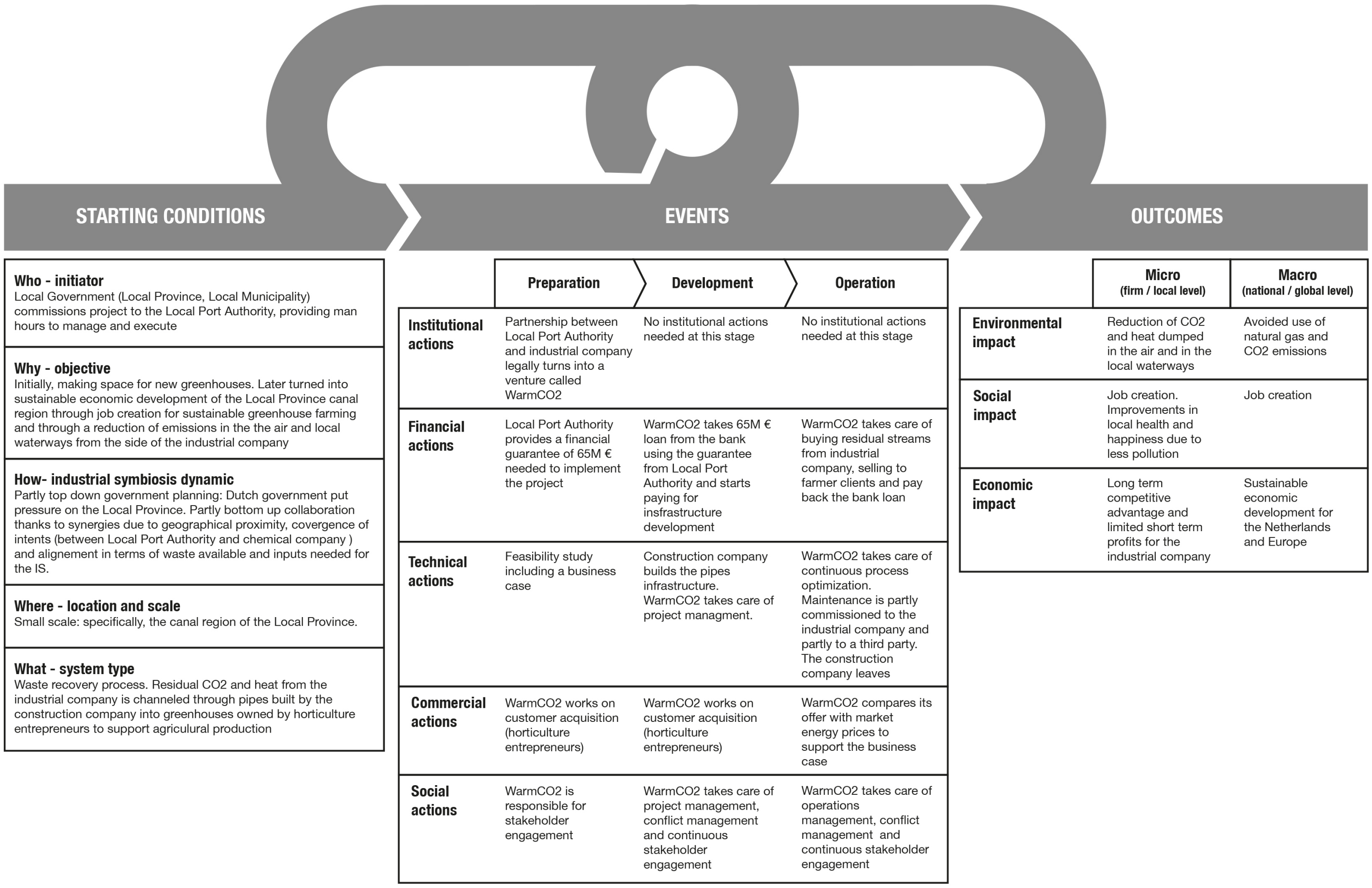

Figure 5. Socio-technical process to develop the Industrial Symbiosis cluster. Based on case study data and adapted from: (Boons et al., 2015, 2017, 2014, 2011; Chertow, 2007; Massard et al., 2014; McDowall et al., 2017; Mulrow et al., 2017; Sun et al., 2017)

4.2 Improved Circular Economy framework for Industrial Symbiosis

The original framework about the CE perspective on IS based on literature (developed in this research) is grounded on three pillars: technical innovation, collaboration and business model innovation. During the iterative process of collecting and analyzing data in collaboration with the interviewees, we uncovered the following findings.

First, IS technical innovation entails a specific system type. In our case study, such system is centered on waste exchange: residual heat and CO_2 from the chemical company is channeled into nearby greenhouses to support sustainable tomato farming. According to both interviewees, a system type description is crucial to understand how the cluster functions. Such finding is corroborated by IE literature describing different system types (Albino & Fraccascia, 2015; Boons et al., 2015; Fraccascia et al., 2016). Consequently, we improve the framework by making this explicit, adding a new key element to the technical innovation pillar: a "system type label", where the technical system based on waste exchange may be described.

Second, IS collaboration encompasses different stakeholders in terms of type, size and role. In our case study there are six stakeholders. The Local Province / Local Municipality / Local Port Authority collaborate as one stakeholder representing the local government at the large, medium and small scale. Their role was to provide the initial IS idea along with a guarantee on the initial investment needed to implement it. The chemical company is a large private enterprise producing chemicals including fertilizers. The company is based in the Local Municipality and its role is providing waste as input within the IS cluster. WarmCO_2 is a small enterprise started in order to have an entity that could embody the partnership between the local government and the chemical company. The role of WarmCO_2 is taking care of the implementation, coordination and technical maintenance of the IS cluster during the operating phase. The commercial bank is a large private company that provided the financial resources needed to start the IS cluster. The construction company is a medium size enterprise that built the piping system to channel the chemical company's waste streams into the greenhouses. Local famers as a stakeholder consist in a multitude of small private enterprises, which use the chemical company's waste streams as key resource input for their business. According to the interviewees, stakeholder type, size and role play a crucial role in the implementation and operations of an IS cluster because they are often the root of converging or diverging priorities, objectives and expectations. Therefore, it is essential taking into account these stakeholder features when developing an IS cluster. Consequently, we improve the framework by making this explicit, adding a new key element to the collaboration pillar: a "stakeholder label", which allows to go beyond simply listing stakeholders towards mapping their collaboration by defining type, size and role for each one of them.

Third, sustainable business model innovation for IS entails various value proposition, creation / delivery and capture mechanisms that take place in parallel at the level of each stakeholder. In our case, the Local Province / Local Municipality / Local Port Authority aims to promote economic development and job creation in the region through the sustainable farming of tomatoes, which is a key aspect of the IS cluster value proposition. In terms of value creation and delivery they contribute by providing the land on which the cluster is built and a guarantee for the bank loan. On the value capture side they make a financial investment in the form of working man-hours and, being public sector, do not expect to have any revenue from it. The chemical company produces chemicals and fertilizer, which is a key aspect of the IS cluster value proposition. In terms of value creation and delivery, it provides the residual heat and CO_2 as waste inputs for the system and takes care of technical maintenance. In terms of value capture, it has costs on the personnel working on maintenance, small revenues by selling the waste streams to WarmCO_2 and long term competitive advantage by exploring alternative possibilities for waste disposal in view of more stringent future policies. WarmCO_2 embodies the IS cluster by providing a legal and commercial entity for collaborating partners, an essential aspect for the very existence of the IS cluster value proposition. On the value creation and delivery side, WarmCO_2 takes care of managing development, operations and stakeholder engagement. In terms of value capture, it has costs for the salaries of three employees and revenues by reselling the waste streams from the chemical company to the farmers. These revenues are entirely used for covering the salaries and paying back the bank loan needed as initial investment. Up to date, WarmCO_2 does not make profit. Farmers contribute to the overall value proposition of the IS cluster by growing tomatoes more sustainably and selling them to people. In terms of value creation and delivery, they build the greenhouses themselves, which are necessary system infrastructure. In terms of value capture, their costs lay in the investment for building the greenhouses, buying waste as input from WarmCO_2, paying a fee for land use to the Province and their revenues are associated to selling their products. The bank and the construction company are not involved during operations but only during the development of the IS cluster. Therefore, they do not contribute to its value proposition but only to value creation in the initial stages by providing respectively the financial loan to build the system and the actual piping infrastructure. In terms of value capture their costs and revenues lay respectively in the giving the loan and getting back the interest for the first, and in paying the salaries of workers to build the infrastructure and getting a commission fee for that by WarmCO_2. According to the interviewees each stakeholder, given its own individual objectives and role, contributes to the overall business model of the IS cluster by bringing different components of the value proposition, creation, delivery and capture mechanisms. In other words, the overall business model emerges by combining these components in such a way that stakeholder incentives are aligned and the performance of their current processes is not altered negatively. Furthermore, next to the other business model dimensions, it emerged that in order to fully capture how the IS cluster operates, a value missed and destroyed dimension should be incorporated. For example, a malfunctioning in the system would create serious damages to the industrial company's plant and a decrease in productivity for horticulture entrepreneurs. Such finding is corroborated by literature, which refers to value missed and destroyed next to the other dimensions (Bocken, Short, Rana, & Evans, 2013). Consequently, we improve the framework by making all of this explicit, adding to the business model pillar new key elements: "value proposition, value creation / delivery, value capture, value missed / destroyed labels". In the framework, each stakeholder can be associated to all the business model dimensions in order to map how it contributes to the overall IS cluster business model.

The final framework of the CE perspective on IS is visualized in Figure 6. The framework is based on literature and on case study data, which complement and corroborate each other providing a comprehensive view on how IS is framed from a CE perspective. This comprehensive view provided by the framework can be applied by IS research and practice. IS researchers can apply it to better investigate and discuss all the elements entailed with the business operations of an IS clusters. IS practitioners can apply it as well to map all the details related to the business operations of an IS cluster. The figure shows how this has been done for the IS cluster we examined as a case study. The interviewees explicitly stated that "this frameworks is a very helpful tool to map how the IS cluster functions as a business and can be used to plan and manage operations with the stakeholders involved". This aspect is very important align stakeholders before and during the operating phase by making explicit their roles, contributions and incentives within the IS business model.

TECHNICAL INNOVATION	COLLABORATION	SUSTAINABLE BUSINESS MODEL INNOVATION			
System type	Stakeholders	Value proposition	Value creation / delivery	Value capture	Value missed / destroyed
Waste exchange Residual CO2 and heat from the industrial company is channeled through pipes into greenhouses to support agricular production	**Name** Local Province, Local Municipality / Local Port Authority **Type** Local Government / commercial authority **Size** Large, small / medium **Role** Provider of initial idea and investment guarantee	Sustainable economic development and job creation in the Local Province	Ownership of the land to build the system and guarantee for the bank loan	Costs: Time of people involved in the project. Revenues: land fees fom horticluture entrepreneurs. Does not make profit	Space used for greenhouses could have been used for something else
	Name Commercial bank **Type** Private enterprise **Size** Large **Role** Loan provider		Provide money to WarmCO2 as a loan. Financial transaction	Costs: initial investment. Revenues: get back money from investment	Could have invested in something else
	Name Industrial company **Type** Private enterprise **Size** Large **Role** Provider of waste streams / technical maintenance	Produce chemicals and fertilizer	Supplies waste streams (CO2 + heat) to the system. Maintenance of the technical system (heat exchanger + CO2 pipes) employees are working on it.	Costs: employees working on maintenance. Revenues: long term competitive advantage, limited short term profit by selling waste stream to WarmCO2	If the system malfunctions loses money
	Name Construction company **Type** Private enterprise **Size** Medium **Role** Construction of physical infrastructure		Know how about infrastructure building. Building pipes infrastructure	Costs: building pipes infrastructure. Revenues: selling the work	
	Name WarmCO2 **Type** New venture / spinoff **Size** Small **Role** Legally needed for the three above to partner	Embody the IS cluster by providing a legal and commercial entity to collaborating partners	Project management, operations management, conflict management, stakeholder engagement	Costs: salaries the employees (project coordinators), buying waste from the industrial company; pay back investment to banks / Local Port Authority. Revenues: 15 year contract with farmers, does not make profit	
	Name Horticulture entrepreneurs **Type** Many small private enterprises **Size** - **Role** End users / customers	Grow and sell sustainable vegetables to people	Build the greenhouses necessary for the system to work	Costs: investment to build the greenhouses, buy waste heat from WarmCO2, buy land from the Local Port Authority. Revenues: sell vegetables.	If the system malfunctions are less productive

Figure 6. Business model of the Industrial Symbiosis cluster. Based on case study data and adapted from: (Albino & Fraccascia, 2015; Bocken et al., 2013, 2014; Boons et al., 2015; Fraccascia et al., 2016; Kraaijenhagen et al., 2016)

5. DISCUSSION

This research aims to investigate the IE and CE perspectives on IS and to advance towards their integration for the design of IS clusters. Accordingly, this discussion section is divided in two parts. The first part critically analyzes and compares the two perspectives by looking at how they differ in terms of nature, features and relevance. The second part, uses the analysis in an initial attempt to combine the two perspectives into a process to design IS clusters.

5.1 Comparative analysis of the IE and CE perspectives on IS

The comparative analysis of the IE and CE perspectives on IS is based on the comparison of the two frameworks presented in the findings section (figure 5 and 6), which represent the result of our effort to crystallize the two perspectives using both literature and case study data. Consequently, we compare the two frameworks and related perspectives in terms of their nature, features and relevance. Our comparative analysis is summarized in Table 1.

	INDUSTRIAL SYMBIOSIS	
	INDUSTRIAL ECOLOGY PERSPECTIVE	**CIRCULAR ECONOMY PERSPECTIVE**
Nature	**Definition of Industrial Symbiosis** Socio-technical process **Focus** Process understanding and environmental impact assessment **Language** Scientific language of technical and social sciences	**Definition of Industrial Symbiosis** Sustainable business model **Focus** Business viability and operations **Language** Operative business language
Features	**Pillars** Starting conditions > events > outcomes **Key elements** - Initiator (who) - Objective (why) - Industrial symbiosis dynamic (how) - Location and scale (where) - System type (what) - Event phases (preparation, development, operation) - Action categories (institutional, financial, technical, commercial, social) - Impact scale (micro, macro) - Impact categories (environmental, social, economic) **Time dimension** Dynamic and iterative process of the IS cluster developed over time **Point of view** IS collaborative project as unit of analysis and design (cross-organizational) **Overall complexity** High	**Pillars** Technical innovation + collaboration + business model innovation **Key elements** - System type - Stakeholders (name, type, size, role) - Value proposition - Value creation / delivery - Value capture - Value missed / destroyed **Time dimension** Still snapshot of a moment in time during the operating phase of an IS cluster **Point of view** Based on separate stakeholder roles (firm-centric) **Overall complexity** Low
Relevance	**Function** Understand the starting conditions, development dynamics and impact of the IS cluster **Use** Describe the development process and impact of an IS cluster over time	**Function** Understand how an IS cluster operates in terms of value proposition, creation / delivery, capture, missed / destroyed **Use** Prescribe how to define and manage the business operations of an IS cluster

Table 1. Comparative analysis of the CE and IE perspectives on IS

In terms of nature, our comparison takes into consideration the differences of the IE and CE perspectives in the following aspects: definition of Industrial Symbiosis, focus and language. According to literature, the IE and CE perspectives define IS differently: the first defines it as a socio-technical process (Boons et al., 2011; Chertow, 2007; Massard et al., 2014) while the second defines it as a sustainable business model (Bocken et al., 2014; Forum for the Future, 2016; Short et al., 2014). Building upon the literature, our case study and improved frameworks (figure 5 and 6) show that these different definitions have repercussions on the focus that each perspective brings. The CE perspective focuses on the business the operations underlying an IS cluster. (Albino & Fraccascia, 2015; Short et al., 2014). This business focus is very important to "align stakeholders, ensure financial viability and survival of the IS cluster" (IS cluster manager interviewee). The IE perspective focuses on understanding the process and the impact related to the creation of an IS cluster (Boons et al., 2011; Massard et al., 2014). This focus on process and assessment is very important to "understand the context around the IS cluster and its stakeholders and to keep track of the environmental and social impacts" next to the economic side (IS cluster manager interviewee). Furthermore, the different focuses are also reflected in different languages used to talk about IS. The CE perspective uses the language of business innovation practitioners and researchers (Bocken et al., 2014). "When operating an IS cluster, using a business language that is direct and simple is essential to plan, communicate and execute effectively" (IS cluster manager interviewee). On the other hand, the IE perspective uses a more scientific and technical language at the boundary across engineering and social sciences (Chertow, 2000; Massard et al., 2014).

In terms of features, our comparison takes into consideration the following aspects: pillars, key elements, time dimension, point of view and overall complexity. According to literature, both perspectives are based on three main pillars: starting conditions events and outcomes for the IE perspective (Boons et al., 2014); technical innovation, collaboration, business model innovation for the CE perspective (Kraaijenhagen et al., 2016). Building upon the literature, our case study and improved frameworks (figure 5 and 6) show that these pillars are characterized by several key elements (see table 1 for the complete list). However, we observe that the IE perspective is characterized by more key elements than the CE perspective, and therefore it can be used to analyze an IS cluster more in detail. This difference is also related to another crucial feature, which is the time dimension. The CE perspective provides a still snapshot of how ad IS cluster functions businesswise in the operating phase and as such it does not take the time dimension into consideration (Albino & Fraccascia, 2015; Bocken et al., 2014; Fraccascia et al., 2016). The IE perspective on the other hand, does take the time dimension into consideration by framing IS as an iterative process that takes place over time, as indicated by the arrows in our framework and in those found in IE literature (Boons et al., 2014, 2011; Massard et al., 2014). Acknowledging this iterative time dimension is very important because "an IS cluster is never finished: its processes are constantly improved to increase positive impact over time" (IS cluster manager interviewee). Another feature that sets the IE and CE perspectives apart is their different point of view. The CE perspective distinguishes stakeholders according to their role but, in line with traditional business modeling perspectives, it is still anchored to a firm-centric point of view and therefore it does not easily support the definition of a collective point of view (Albino & Fraccascia, 2015; Bocken et al., 2014; Fraccascia et al., 2016; Osterwalder & Pigneur, 2010; Richardson, 2008; Short et al., 2014; Teece, 2010). On the other hand the IE perspective, by defining IS as a collaborative innovation process, fosters a cross-organizational point of view in which the IS cluster is joint project, unit of analysis and design (Boons et al., 2014; Massard et al., 2014; Mulrow et al., 2017). "Adopting a collective point of view is the most difficult yet important thing to do: developments should be constantly discussed and agreed with all stakeholders over time for the benefit of the project otherwise the IS cluster fails" (IS cluster manager interviewee). Due to a higher number of key elements, a cross-organizational point of view and the presence of a time dimension, we note that the IE perspective, presents a higher overall complexity when compared to the CE perspective.

Finally, in terms of relevance, our comparison takes into consideration the function and use of the two perspectives. According to literature and to our case study, the two perspectives have different functions and uses. The IE perspective is functional to understand the starting conditions, development dynamics and impact of the IS cluster (Boons et al., 2014; Massard et al., 2014; Sun et al., 2017). Therefore it can be used to retrospectively describe the development and impact of an IS cluster over time, as explained by the managers we interviewed within our case study when commenting on the final IE framework (see the last paragraph of section 4.1). The CE perspective is functional to understand how an IS cluster operates in terms of value proposition, creation / delivery, capture, missed / destroyed (Bocken et al., 2014; Short et al., 2014). Therefore, it can be used descriptively but also prescriptively for the definition and management of the business operations of an IS cluster, as explained by the managers we interviewed within our case study when commenting on the final CE framework (see the last paragraph of section 4.1).

The main insight of our comparative analysis is that the IE and CE perspectives on IS are complimentary. We argue that their differences in nature, features and relevance should be leveraged in combination to get a more thorough understanding IS clusters and to better design them accordingly. This insight is supported by former literature on IS which has already attempted cross-pollinate the two perspectives in order to combine their qualities and address their drawbacks (Bocken et al., 2017; Lange et al., 2017; Lombardi & Laybourn, 2012; Mulrow et al., 2017; Paquin et al., 2015; Short et al., 2014; Walls & Paquin, 2015). Our empirical case study confirms the relevance of this insight. For example, by using both perspectives it is possible to get a full picture about the role and aims of the local government with in the IS cluster development and operations. The IE perspective tells us that that the original intent of the local government was not creating an IS cluster but rather using a piece of land for greenhouse farming to support job creation and eventually that job creation was used as a measure to determine project success; the CE perspective tells us that the local government owns the land on which the IS cluster is built. This type of complimentary information is needed in order to better understand existing IS clusters and to design new ones accordingly. This insight clarifies the relationship between the two perspectives, addressing a knowledge gap in current IS research and reinforcing the argument that future research should move beyond the current state of cross-pollination and attempt an explicit integration.

5.2 Industrial Symbiosis Design Process

We use the comparative analysis as a starting point to explicitly combine the two complementary perspectives. The integration of the perspectives is an initial attempt and it is done through a strategic design lens.

Strategic design is a stream of research and applied discipline based on using design principles and practices for the formulation and implementation of innovation strategies for organizations, including industrial networks (Calabretta et al., 2016). A typical strategic design project entails supporting companies in formulating an innovation vision and in identifying business opportunities consistent with the vision. Strategic design has recently been leveraged in sustainable business model innovation research and practice in order to support collaborative innovation process across multiple stakeholders (Baldassarre et al., 2017; Geissdoerfer et al., 2016). Thus, strategic design is suitable to address the challenge of setting up and growing an IS cluster. The core principles of strategic design include an iterative and collaborative approach for the generation of new ideas, through a set of specific design practices, methods and tools such as creative sessions and (early) prototyping of concepts (Brown, 2008; Calabretta et al., 2016; Dorst, 2010). Consequently, strategic design offers a good lens to address the IS design process as collaborative innovation project. Finally, strategic design integrates design principles with a business mindset, combining long-term strategic directions with short-term tactical decision and implementation actions in order to hit both long term and short term performance goals (Calabretta et al., 2016; Grant, 2016; Hultink, 1997). Ultimately, strategic design is about defining the strategic vision for an innovation, designing a concept and the business around it and finally assessing results before moving into a new iteration (Baldassarre et al., 2017; Calabretta et al., 2016). Applying this strategic design lens allows us combining notions from the IE perspective (the iterative dimension and focus on impact assessment) with notions from the CE perspective (the simplicity, business model focus and prescriptive thinking) into a process for designing IS clusters.

The Industrial Symbiosis Design Process (figure 7) is the result of our attempt to integrate the IE and CE perspectives on IS through a strategic design lens. Leveraging on the IE perspective, the process takes the “collaborative innovation project” as unit of design (Massard et al., 2014; Mulrow et al., 2017). In line with the IE perspective, the context box indicates that the process does not take place in the vacuum place within a specific historical, geographical, political, and organizational setting while the time arrow at the bottom indicates that each iteration should take place in a definite timeframe (Boons et al., 2014, 2011; Massard et al., 2014). Again, building onto the IE perspective, each iterative cycle takes places in three steps (Boons et al., 2014). However, leveraging the CE perspective, these steps are framed prescriptively and using a simple business language (Fraccascia et al., 2016; Kraaijenhagen et al., 2016). Through the strategic design lens, the three steps of the process are defined as strategy definition, business design and impact assessment (Calabretta et al., 2016). In order to support practice, we specify objectives, methods & tools and type of decisions for each step. The first step is defining the strategic vision. The objective of this step is developing a joint shared vision and related strategic goals for the IS innovation project (Calabretta et al., 2016). The definition of the vision and of the strategic objectives can be supported by design methods and tools, namely stakeholder analysis, system mapping and vision creation (Calabretta et al., 2016; Stickdorn, Schneider, Andrews, & Lawrence, 2011). The second step is business design. Borrowing from the CE perspective, the objective of this step is developing a business model for the IS cluster (Fraccascia et al., 2016; Kraaijenhagen et al., 2016; Short et al., 2014). Business design can be supported by the value mapping tool and sustainable business model canvas (Bocken et al., 2018, 2013). As stressed by the strategic design lens, this step is iterative in nature; short-medium term tactical decisions to involve stakeholders and reach consensus on the business model are repeatedly taken here (Calabretta et al., 2016; Hultink, 1997). The third step is impact assessment. In line with the IE perspective, the objective of this step is assessing the sustainability impact of the IS cluster (Boons et al., 2014; Massard et al., 2014). In line with Strategic Design, this is done according to the criteria developed in step 1 (Calabretta et al., 2016). Again borrowing from the IE perspective and triple bottom line thinking, such criteria need to relate to environmental, social and economic impact (Elkington, 1998; Hall, 2011; Massard et al., 2014). According to the IE perspective, impact assessment of IS can be supported by life cycle assessment tools: traditional Life Cycle Assessment (LCA) for environmental impact, Social Life Cycle Assessment (S-LCA) for social impact and Life Cycle Cost (LCC) for economic impact (Dreyer, Hauschild, & Schierbeck, 2006; Massard et al., 2014; Norris, 2001; Sala, Vasta, Mancini, Dewulf, & Rosenbaum, 2015). A final mention on this process concerns the starting point of the process, which may not necessarily be the definition of a strategic vision. As the IE body of literature mentions, IS projects are often the result of previous collaborations of stakeholders in relation to different and disparate objectives, therefore an IS collaborative project may as well begin by assessing existing realities or by introducing incremental improvements into existing business models (Boons et al., 2014, 2011; W. A. H. Spekkink & Boons, 2016).

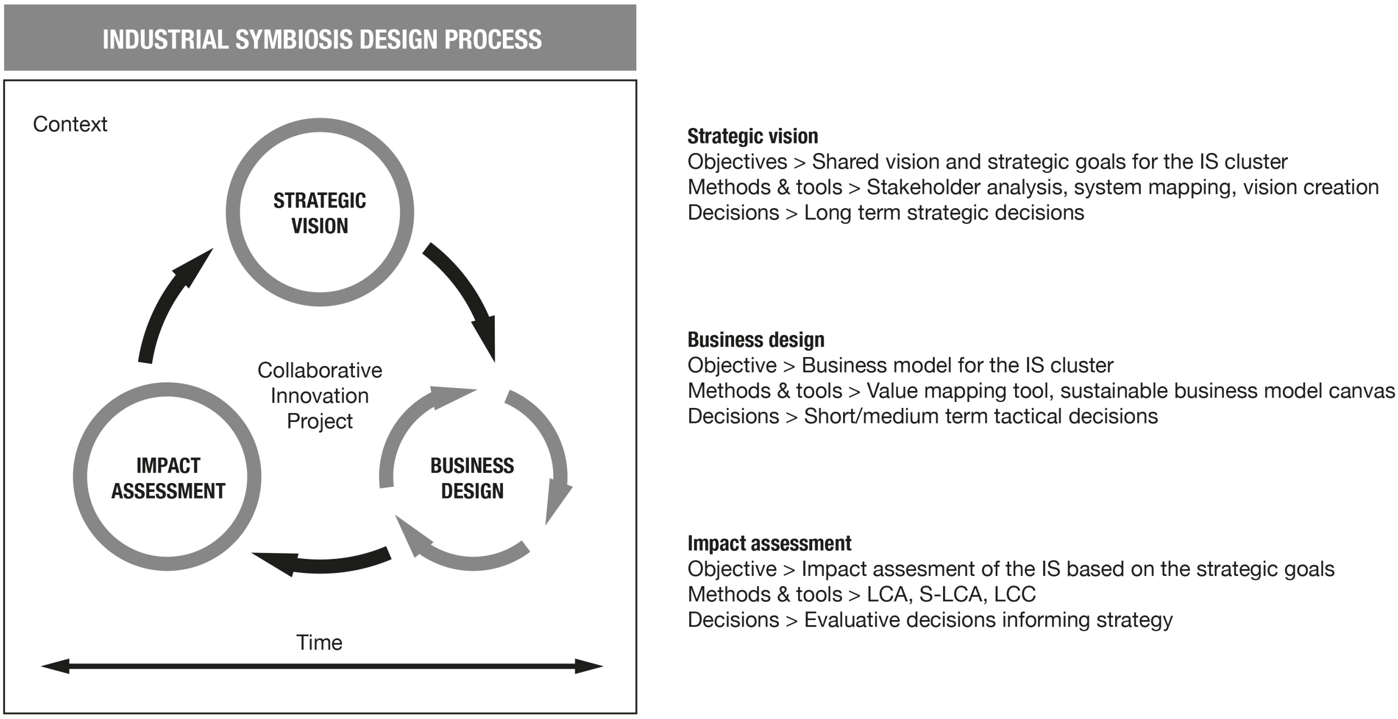

Figure 7. A process for designing IS clusters. Based and adapted from: (Bocken et al., 2018; Boons et al., 2014; Calabretta et al., 2016; Massard et al., 2014)

6. CONCLUSION

This paper addressed the question of how the IE and CE perspectives on IS can be combined in order to support the design of IS clusters. In order to answer this question we first made a comparative analysis of the two perspectives by looking more in depth at how they differ in terms of nature, features and relevance for the study of IS, based on literature study and a case study. Secondly, we used the comparative analysis in an initial attempt to combine the two perspectives into a process for designing new IS clusters.

6.1 Contributions

This paper contributes to IS research and practice. The contributions to IS research are four. First, clearly positioning IS as a research subject within and across the IE and CE research streams (table 1). Second, crystallizing the IE and CE perspectives on IS into two frameworks based on literature and case study data (figure 5 and 6). Third, making a structured comparison of the IE and CE perspectives on IS, explaining how they differ in terms of nature, features and relevance, ultimately showing that they are complimentary (table 1). Fourth, making an initial attempt to combine the two perspectives in an integrated process (figure 7). These contributions are relevant to IS research because they build on previous attempts to cross-pollinate IE and CE work on the subject, reinforcing the arguments calling for an integrated perspective and advancing the theoretical understanding of the phenomenon of IS (Albino & Fraccascia, 2015; Bocken et al., 2017; Fraccascia et al., 2016; Lange et al., 2017; Lombardi & Laybourn, 2012; Mulrow et al., 2017; Paquin et al., 2015; Short et al., 2014; Walls & Paquin, 2015). In doing so, these contributions also touch upon a broader issue that has been recently mentioned explicitly: the need of creating a bridge between IE and CE, allowing researchers in both streams to learn from each other (Bocken et al., 2017).

The contributions to IS practice are three. First, the IE framework that we defined based on literature and on case study data, can be used by practitioners to map the development of IS clusters over time and to describe their impacts (figure 5). Second, the CE framework that we defined based on literature and on case study data, can be used by practitioners map how an IS clusters functions businesswise and to manage operations accordingly (figure 6). The third and main contribution to practice is the process to design new IS clusters (figure 7). This process combines the most relevant qualities of the IE and CE perspectives and frames them with an explicit design orientation derived from the discipline of Strategic Design (Calabretta et al., 2016). The goal is not only to provide practitioners with a more comprehensive understanding of the challenges and aspects that have to be considered when setting up a new IS cluster (e.g. iterative developments, stakeholder collaboration, business incentives, etc.), but also to provide them with knowledge that is actionable. To this end, for each step of the process, it is clearly stated what is the purpose and which methods and tools can be used by practitioners to move forward.

6.2 Limitations and future research

The first limitation of this research is that our findings and contributions are based on a combination of IE and CE literature with empirical data from a single case, a small IS cluster located in the Netherlands. Therefore, we acknowledge that our findings and contributions may provide an incomplete view, influenced by the characteristics and context (e.g. geographical, historical, political, etc.) of the case at hand. As such, they may only be representative for small European clusters, which are mostly based on bottom up collaborative approaches in contrast with structured top down approaches driven entirely by government planning, as for instance in the Chinese context (Bocken et al., 2017; Ghisellini, Cialani, & Ulgiati, 2016; Massard et al., 2014; McDowall et al., 2017; Sun et al., 2017). We suggest that future research on IS should apply the IE and CE perspectives in combination as we did in this study, but instead of focusing on a single case, it should extend the range of the analysis by looking at a wider sample of IS clusters of different sizes and in different contexts. We believe that this analysis would contribute to a better and more holistic understanding of IS as a phenomenon, which is essential to improve future IS practice, which ultimately plays a role in the transformation of industry in the transition towards sustainable development (Chertow, 2000, 2007).

The second limitation of this research is that the Industrial Symbiosis Design Process that we propose is, for the time being, only a concept. This means that it has not yet been validated in practice. This opens up a broader discussion that we consider particularly critical and relevant. According to a strand of IS research rooted in the IE field, to this day many IS clusters (especially in Europe) have "emerged" rather than being "intentionally designed" (Chertow, 2007; Ehrenfeld & Gertler, 1997; W. Spekkink, 2015; W. A. H. Spekkink & Boons, 2016). This raises a question on to what extent IS can, at all, be designed, which is what some of the research with a CE business model focus seem to suggest (Bocken et al., 2014; Fraccascia et al., 2016). In fact, the idea of "intentionally designing" an IS cluster presumes that somebody has to play the role of designer, something that in a context that requires the collaboration of multiple stakeholders (who in most cases have different incentives and motivations) can be quite challenging. The Industrial Symbiosis Design Process that we propose only scratches the surface of this issue by suggesting that the unit of design of new IS clusters should be a "collaborative innovation project" based on the iteration of three steps over time. However, it does not elaborate further on who should play the designer's role and how, and if there can be multiple designers involved over time. We suggest that future research on IS should draw both on CE and IE literature and focus with more specificity on the issue of how IS clusters can be designed. A possible way to start doing this, can be leveraging on our work by interviewing IS practitioners about the process we proposed and by trying to apply such process on a real case aimed at designing a new IS cluster.

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