IIIEE Theses 2023:12

Sustainability benefits of industrial symbiosis

Building value from stakeholders

Laura E. Redmond

Supervisor

Karolina Södergren

Thesis for the fulfilment of the
Master of Science in Environmental Management and Policy
Lund, Sweden, May 2023

Published in 2023 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

ISSN 1401-9191

Acknowledgements

I am grateful for this experience to write the third (and hopefully final) thesis of my life. It has been a wild ride to quit my job in Canada, change course, and take a whole new perspective- professionally and personally. Firstly, I would like to thank the IIIEE and the researchers and professors who have created such a tremendous and exciting learning experience throughout the EMP Master's Program. Thanks to my thesis supervisor, Karolina Södergren for her support throughout this process, from being an excellent sounding board from my initial ideation to asking all the right questions to keep things on track and relevant.

Thank you to everyone at WA3RM for the opportunity to bring my "research to life". Thanks to Danna Persson, Jack Fraser, Thomas Parker, Niklas Rydberger, and others for help with practitioner interviews, connections to interviewees, and for reviewing my Swedish translations. Your insights were invaluable to understanding how to build my results on practitioner knowledge and create useful practical outcomes. Thanks to Murat Mirata for providing his expertise on industrial symbiosis in Sweden and connecting me with the network.

Thank you to all the interviewees from my case studies, everyone who responded to and distributed my survey to stakeholders. The passion for industrial symbiosis and creating a more sustainable future for industry that I felt from these folks was infectious and something I will take with me throughout my career.

I am so grateful to EMP Batch 28 for a thrilling two years of building new friendships, cooking together, hiking our way through Skåne and learning from each other's diverse backgrounds and expertise. Thanks to my partner, Blaine, for his support and willingness to uproot our lives and move across the world to Sweden. I would like to dedicate this thesis to my late grandfather, Rae MacDonald, an avid activist, a supporter of the little guy, a purveyor and admirer of art, caregiver to animals, and lover of nature. His strong words will live on here- "*No matter what, don't you think trying to save our earth is more important than anything else in our world?*"

Abstract

The circular economy (CE) brings a shift in business operations that could increase societal well-being and reduce environmental costs, making regionalization and circular supply chains crucial to reduce greenhouse gas emissions. Industrial Symbiosis (IS) is a strategy to enhance the circularity of industry by exchanging resources and knowledge sharing between different actors in an industrial system. IS can provide benefits to companies, regions, the environment, and society, but a broader sustainability assessment is needed to realize its impact on sustainable development at a local and regional level. However, stakeholders' integration is still not fully understood, and successful implementation requires knowledge of the local context, stakeholder engagement, and an understanding of the social dynamics. This thesis aims to understand the importance of integrating sustainability benefits and stakeholders into IS business models. It explores eight IS networks in Sweden to identify gaps in co-creating value propositions to align with sustainable business models. The research questions aim to understand how IS networks organize internally and externally with stakeholders to develop value propositions and business models and what benefits are perceived as important by different stakeholder groups. The study found that IS in Sweden is shifting towards facilitated networks of collective knowledge sharing and eco-cluster development, and the success of IS networks is dependent on the active participation of universities, public entities, companies, and community stakeholders. Greater collaboration between these groups can lead to a more aligned value proposition and bring the highest value to the region. Economic benefits, environmental benefits, and social benefits were identified as important value propositions for IS networks in Sweden, but different actors had varying views on their relative importance. The study provides insight into the value proposition of IS networks from the perspective of different stakeholders, paving the way for a more sustainable business model.

Keywords: Industrial symbiosis; stakeholder engagement; sustainable business models; circularity; sustainability benefits

Executive Summary

There is an urgent need for a systems transition to a society with more resource-efficient and low-carbon economies to maintain the earth's safe operating space. The industrial sector is identified as a significant producer of greenhouse gas emissions, and global supply chains are becoming more complex, making regionalization and increased circularity of supply chains critical to reducing vulnerabilities. The circular economy (CE) brings a major shift in how business is done, which has the potential to increase the well-being of society and minimize environmental costs. There is a need for close coordination and reliance on various actors of CE networks at all scales, where relevant stakeholders need to be involved in the design of Circular Business Models (CBMs) to promote shared value. Industrial Symbiosis (IS) is identified as an important action to increase the circularity of industry in the EU action plan for circularity, which involves prolonging the value of underutilized resources through the exchange of materials, energy, water, and knowledge sharing. However, there is a lack of understanding of how stakeholders are being integrated, and while IS can provide many benefits to companies, regions, the environment and society, a broader sustainability assessment is critical to realizing the influence that IS can have on sustainable development at the local and regional level.

Problem Definition

The potential of IS to provide sustainability benefits and integrate stakeholders is hindered by a disconnect between many IS actors. Successful implementation of IS projects requires an understanding of social dynamics, knowledge of the local context, and stakeholder engagement to qualify and understand value proposition expectations and perceptions.

Aim and Research Questions

This thesis highlights the importance of integrating dimensions of sustainability and stakeholders into IS circular business models, by understanding the values and expectations of diverse stakeholder groups. The research aim is to explore eight IS networks across Sweden to develop a strategy to understand the value proposition of these unique projects from the perspective of different stakeholders. The research questions aim to understand **1) how IS networks organize internally and externally with stakeholders to develop value propositions and business models**; and **2) what sustainability benefits are perceived as important by different stakeholder groups**. By identifying gaps in the co-creation of value propositions, a better strategy can be developed to align with sustainable business models.

Methods

The research design followed three main phases, as identified in Figure I. In Phase 1, Step 1 was important to define the research questions by understanding the background literature, existing research gaps, and practitioner pain points. Research questions and methodology were developed next, and case examples from across Sweden were selected for analysis. Phase 2 included the constructing of methodology based on research from Phase 1, including Data Collection. Data collection included conducting interviews with the facilitators of the selected case examples and conducting a survey on the stakeholders of those case examples. A coding framework was used for the qualitative data analysis to develop the major themes of the thesis. Phase 3 involved the incorporation of data into the analysis, writing and presentation of results.

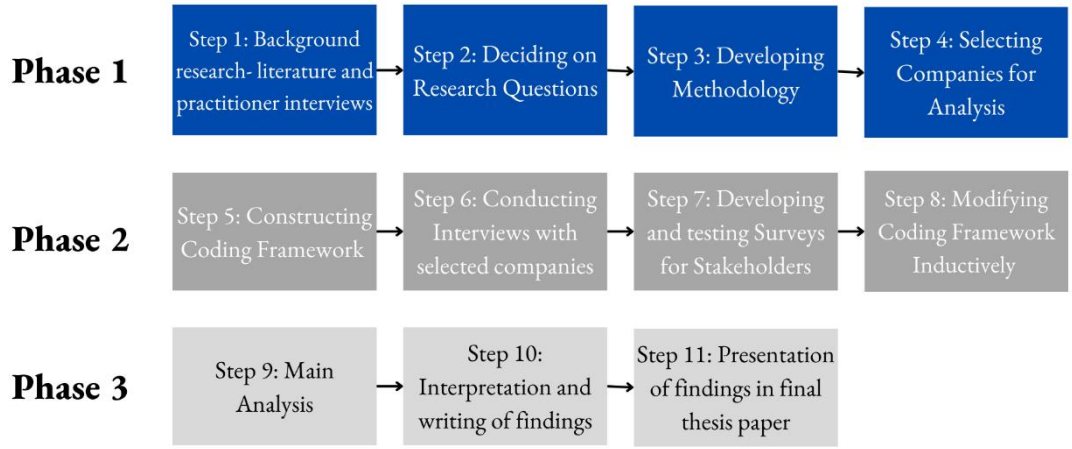

Figure I- Conceptual framework to guide the process of research. Phase 1 is the preparatory steps and involved literature and practitioner research, developing the methods and selecting case studies. Phase 2 includes data collection and Phase 3 data analysis and presentation.

Main Results

RQ1: How are IS networks in Sweden currently organizing internally and externally with stakeholders to develop IS value propositions and business models?

Finding #1: This thesis offers a description of the internal organization of eight IS case examples in Sweden- Paper Province in Karlstad, Sotenäs Symbioscentrum, Händelö Eco-Industrial Park, Malmö, Lidköping, Food Valley of Bjuv, Stenungsund, and High Coast Innovation Park in Örnsköldsvik.

Finding #2: With origins in self-organization, IS in Sweden is shifting towards facilitated networks of collective knowledge sharing and eco-cluster development. Learning and knowledge sharing from successful mature IS networks is leading to the expansion of the IS concept in existing and emerging networks in Sweden.

Finding #3: Pilot projects can create benefits and help overcome many barriers to IS. The benefits of pilot projects include increasing trust and collaboration between network actors, increasing knowledge sharing and connections to external actors like researchers, reducing risk from access to external funding, and creating a common vision for the IS network.

Finding #4: The success of IS networks in Sweden is dependent on the active participation of stakeholders including the four assessed in this study- universities, public entities, companies, and community. Greater collaboration between actor groups can lead to a more aligned value proposition and bring the highest value to the region in which the IS operates.

Finding #5: While IS networks have different approaches to engaging with stakeholders and integrating the four major actor groups, the community and civil society sphere is relatively empty, with efforts to engage the community being minimal.

RQ2: What are the sustainability benefits of IS cases from the perspective of different stakeholder groups?

Finding #6: The perceived value of IS across IS networks in Sweden depends on several factors and different actors have varying views on the most important benefits that IS can offer to themselves and their communities and regions.

Finding #7: Economic benefits. Economic growth, competitive advantage, increased employment, and higher revenues are the most important economic benefits of IS in Sweden, and IS networks attract new companies to the regions based on their capacity and associated benefits.

Finding #8: Environmental benefits. Respondents in Sweden consider the reduction of atmospheric CO_2 or other greenhouse gases to be the most important environmental benefit of IS, while other environmental benefits of IS received mixed results, possibly due to unique IS networks offering unique benefits that did not align more generally across different networks.

Finding #9: Social benefits. The highest aligned important value statements from the survey were for increased jobs and income for the region, which aligns with the literature. Other important social benefits identified by stakeholders included improving knowledge and education, increasing the community's network to work and cooperate, and increasing community engagement and participation. Two other social benefit statements that were ranked as high importance were that IS provides equal opportunity to all genders and for all individuals, but further research is needed to understand how IS networks can create these benefits.

Conclusions

This thesis aimed to explore how Swedish IS networks operate internally and externally and to understand how different actors perceive the value propositions of these projects. Research question 1 aimed to understand the organization of IS networks with regards to stakeholder involvement and found that engaging the four major actor groups of the quadruple helix model (i.e., industrial actors, public actors, researchers, and civil society) is essential to address different needs and develop value propositions. The engagement of the local community is also critical to achieve the social benefits of IS networks, and stakeholders should be recognized as equal negotiation members during IS development. Research question 2 focused on understanding the benefits of IS from different stakeholder perspectives, revealing that stakeholders have differing perceptions of the importance of IS benefits. It is important to communicate the unique value propositions of specific IS networks that align with stakeholder expectations. Social benefits of IS stand out as important, and practitioners need to consider focusing on and reporting the social benefits that IS can bring to communities. To avoid conflicts, practitioners should engage stakeholders early on in value proposition conversations and communicate the unique value propositions of specific IS networks in a meaningful way. To develop shared value across all groups, methods to create value *for* and *with* stakeholders should be employed, and practitioners should focus on local conditions to grow the possibilities for IS in alignment with stakeholder support. Overall, practitioners should aim to strengthen stakeholder involvement in value co-creation with diverse groups to maximize the impact of IS networks.

Table of Contents

List of Figures

List of Tables

Abbreviations

CBM- Circular Business Model

CE- Circular Economy

CHP- Combined Heat and Power

EIP- Eco-Industrial Park

GHG- greenhouse gas

IS- Industrial Symbiosis

RI.SE- Research Institute of Sweden

SBM- Sustainable Business Model

1 Introduction

There is an urgent need for society to transition to more resource efficient and low-carbon economies in order to reduce the substantial risk of destabilizing the earth's safe operating space (Rockström et al., 2009; Steffen et al., 2015). The planetary boundaries of climate change and biosphere integrity in particular hold the potential to drive us into an entirely new state and influence other boundaries that are critical for earth and societal functioning (Steffen et al., 2015). Industrial sectors are a large producer of greenhouse gas (GHG) emissions worldwide especially when considering indirect emissions from electricity (IPCC, 2022). In Sweden, the industrial sector accounts for over one third of total domestic GHG emissions (Statistikdatabasen, 2021). Global supply chains are also becoming more dynamic, complex, and volatile (Fernández Campos et al., 2019), making regionalization and increased circularity of supply chains critical to reducing vulnerabilities (Hofmann, 2019). Creating a net-zero industrial sector is a global challenge that will require coordination throughout value chains to improve energy and material efficiency, circular material flows and stimulate innovation in new technologies and management processes (IPCC, 2022). Localizing business can also bring positive benefits for communities such as heightened social cohesion, community spirit, and trust building (Raworth, 2012). Building circularity into business models at the local or regional level is one way to reduce the risk of businesses in today's complex and integrated world.

The circular economy (CE) represents a major shift in the way we do business, with the potential to fundamentally transition society to increase the wellbeing of citizens while minimizing environmental costs (Ghisellini et al., 2016). CE involves shifting from the linear economy model of take-make-dispose towards a system that keeps economic value in systems and products for longer and reduces risks associated with waste and dependency on raw materials (Ellen MacArthur Foundation, 2013). Typically, circular solutions are implemented at the local or regional since the benefits of circularity are highest when transportation and transaction costs are low. The concept of circularity stems from keeping the value in products for as long as possible, which is easier to do when distances between uses are minimized. The CE has become a priority solution all over the world, with the European Commission adopting the new circular economy action plan in March 2020 as a major component of the Green New Deal and the industrial transformation towards climate-neutrality and future proof competitiveness (European Commission, 2020).

CE networks of all scales are just that- webs of actors, businesses, even entire industries- and this requires close coordination and reliance on various actors. One of the key principles of integration of a circular economy includes involving relevant stakeholders in the design of the business model. Reciprocal interactions between all the actors within the diverse value creation network is important to fill the needs of all stakeholders and preserve the long-term sustainability of the synergy (Hofmann, 2019). When executed well, circular business models (CBM) have a chance to be regenerative- they reuse materials more carefully and collectively to repair the degradation of the living world (Raworth, 2012). To implement CBMs, important factors include involving relevant stakeholders in the CBM design through reciprocal interactions and promoting "shared value" which emphasizes the importance of compatible and harmonized value creation (Hofmann, 2019). It is important to emphasize the local context and reframing of sustainable value propositions in different places when a company decides to expand a tested business model to a new location (Han et al., 2022). When circular businesses are created with the local context in mind, they can also be more distributive- where they enhance shared value and opportunity for all instead of directing value to the hands of only a few (Raworth, 2012). The local aspect and understanding of different stakeholder group contexts are therefore critical in the successful implementation of sustainable circular solutions that are both regenerative and distributive.

One important action to increase the circularity of industry in the EU action plan for circularity includes facilitating Industrial Symbiosis (IS) with reporting and certification to enable greater implementation of IS in Europe (European Commission, 2020). IS is a collective approach by two or more actors to prolong resource value which typically involves the exchange of materials, energy, water, and/or other by-products (Chertow, 2000). The definition has been enhanced overtime, but IS brings together different actors and sectors to increase the long-term value of underutilized resources (i.e., by-products, waste streams) by creating synergies for resource use as well as (more recently) knowledge sharing (Kosmol et al., 2021). The most well-known and well-studied example of IS is the Kalundborg Industrial Park in Denmark (Chertow, 2000), but cases of IS have grown immensely stemming from the reporting and demonstration of this successful site (Neves et al., 2020). IS projects can provide many benefits to companies, regions, the environment, and society. The assessment of IS systems through the lens of environmental impacts is common, but reviews of the economic and social sustainability pillars are less frequent (e.g., Martin & Harris, 2018). However, a broader sustainability assessment is critical to realizing the influence that IS can have in sustainable development at the local and regional level. The dissemination of benefits of IS is important because it can act as a lever to encourage the development of IS synergies for companies and for municipalities to integrate IS into local planning practices (Neves et al., 2020).

1.1 Problem Definition

The potential of Industrial Symbiosis (IS) to provide sustainability benefits and integrate stakeholders is hindered by a disconnect between many IS actors. The successful implementation of IS projects requires an understanding of social dynamics, knowledge of the local context, and stakeholder engagement to qualify and understand value proposition expectations and perceptions.

The potential of IS lies in its ability to integrate stakeholders and provide sustainability benefits to those stakeholders. Despite this potential, there is a disconnect in many IS entities where stakeholders are not being integrated to the extent they desire. One significant barrier to the successful implementation of IS projects is understanding the social dynamics (Harris et al., 2018), and more extensive knowledge of the local context. In many cases, IS parks are created organically, while many pre-meditated industrial parks largely fail to overcome the barrier of generating intercompany cooperation (Chertow, 2007). However, there have been many successful IS parks, planned and unplanned, that have had positive benefits for surrounding communities (Neves et al., 2020). The context-dependent understanding of potential IS projects must therefore be prioritized before the project can be successfully implemented (Jensen et al., 2011). The stakeholder engagement for an IS project involves many diverse actors including municipalities, industries, and the local community. Each stakeholder group has a unique perspective on what value the projects can offer them. Therefore, it is essential to qualify and understand the value proposition expectations and perceptions of IS project stakeholders to translate regenerative business models across different stakeholders, contexts, and locations.

IS networks have potential to contribute to regions through improving environmental performance of local industries and providing socio-economic benefits (Harris et al., 2018; Martin & Harris, 2018). Various regenerative industries have identified several use cases for business models for firms both producing and using waste as a resource (Fraccascia et al., 2019). Business opportunities exist to create regenerative and distributive practices where IS can be used to reuse materials more carefully and the local context can be used to create shared value for many (Raworth, 2012). However, a broader sustainability assessment of IS is critical to realizing the influence that IS can have in sustainable development. It is evident that the economic and environmental benefits of IS are well known, but the social aspects are less studied or simply grouped with economic aspects like jobs (Domenech et al., 2019; Wadström

et al., 2021). The dissemination of all benefits of IS is critical to encouraging the development of IS through policy and planning practices (Neves et al., 2020).

1.2 Aim and Research Questions

To ensure sustainability is integrated into circular business models such as IS projects, it is critical that companies are aware of strategies to integrate different groups of stakeholders into their value propositions. If we do not understand the values of the diverse actor network of stakeholders, there are missed opportunities to meaningfully engage in co-creation of value. Studying how companies can better understand the value proposition expectations and perceptions of different stakeholders in different localities can allow a greater integration of actors into circular practices and align with a sustainable business model design and innovation.

There are many Industrial and Urban Symbiosis networks in operation in Sweden today. The aim of this thesis will be to explore industrial symbiosis networks in Sweden to understand the value proposition of these locally unique projects from the perspective of the diverse actor network of different stakeholders. To focus on the overall sustainability of IS, the different dimensions of sustainability will be assessed including economic, environmental, and social.

This research aim will be addressed by answering the following two research questions that will guide this research:

RQ1: How are industrial symbiosis networks in Sweden currently organizing internally and externally with stakeholders to develop IS value propositions and business models?

RQ2: What are the sustainability benefits of industrial symbiosis cases from the perspective of different stakeholder groups?

The concept of co-creation is central to addressing these research questions and developing a better strategy for value proposition co-creation. By understanding how IS projects are currently interacting with stakeholders to develop value propositions and business models, gaps can be identified in this important process. By understanding which benefits of IS different stakeholder groups perceive as important, a better strategy for co-creation of value propositions can be developed.

1.3 Scope and Delimitations

This study explored the stakeholder interaction strategies and benefits from the perspective of different stakeholder of eight IS networks cases in Sweden. The geographical scope of this study is industrial symbiosis networks that have been established in the country of Sweden. There have been over twenty IS networks identified and researched in Sweden, many of which emerged organically to create mutually beneficial sharing of resources (Harris et al., 2018; Mirata, 2018). Many Swedish IS networks have incorporated different industrial and urban activities with many of them built with dependencies around traditional industries in the forestry and manufacturing industries (Harris et al., 2018). Many IS networks in Scandinavia focus on reuse of waste energy and heat with many centered around combined heat and power (CHP) systems and district heating networks due in part to promotion through policy incentives and infrastructure development (Domenech et al., 2019). Low-grade heat waste from industry can be used for heating purposes with substantial environmental benefits when low-grade heat recycling can replace the burning of fossil fuels, and there are abundant cases in Sweden with potential to use such waste heat and waste nutrient streams (Parker & Kiessling, 2016).

The IS networks assessed in this thesis range in their date of establishment of IS practices and projects from as early as 1965 before the more modern concept of IS was conceived. The geographical range of the cases is concentrated in the southern third of Sweden apart from Örnsköldsvik in the north and with Malmö being the furthest south. The IS networks that were included are from all three categories of symbiosis- Energy; Material, by-products and waste; and Water (Wadström et al., 2021), with many IS projects integrating multiple types of symbioses into their networks.

Limitations to defining this scope to Sweden include an inability to drastically generalize findings to other locations. IS networks are built up over many decades and are by virtue very embedded in society and norms of the location in which they exist. Sweden is unique in the sense that there is a high focus on innovation, sustainability, and a high level of trust embedded into Swedish society (Baas, 2011). The long history of IS in Sweden makes it difficult to generalize findings from Swedish IS case studies to other places in the world.

1.4 Ethical Considerations

This thesis is funded by WA3RM AB, which is a company that will gain a benefit from this research. I also work part-time for the company as a Sustainability Analyst, which has created a deeper understanding of the barriers and enablers within the IS environment and built a relevant thesis outcome. However, this connection did not influence the nature of research direction or conclusions, and researcher integrity was maintained through the research process. This was done by maintaining connection to the IIIEE throughout the research process and by including external stakeholders in the research development process to preserve my ability to ensure integrity of the research results. The results were presented in an unbiased way that objectively represents the participants and conclusions of the study. If there are company-specific recommendations that come out of the research, that will be kept separate from the thesis research which has broader reach.

The principles of informed consent were followed, and all interview and survey participants were notified of the aim of the research and consented to being included. Minimal personal data was collected in the survey process (i.e., email addresses) but were handled according to Article 5 of the EU's General Data Protection Regulation (GDPR) and deleted when no longer needed. Participation in the study was voluntary and participants willingly agreed to answering questions and being recorded when feasible. Names of respondents are not used in this thesis and this study is not expected to have a negative impact on any participants or their personal privacy or business reputation. No questions were asked about anything that would jeopardize a company's competitive advantage or confidential information. The interview design was created with the intention of reducing bias by not asking leading questions. All respondent data records are stored in files on a protected personal computer. The research design stated here has been reviewed against the criteria for research requiring an ethics board review at Lund University and has been found to not require a statement from the ethics committee.

1.5 Audience

The main target audience of this thesis is IS practitioners. This will mainly consist of facilitators and coordinators of IS synergies (i.e., municipalities, industry associations, championing companies). The outcomes of this research will also be relevant beyond IS applications for other circular businesses that are trying to better understand how to integrate actor networks and stakeholders into their business model design and innovation. This can be useful for companies that are trying to scale to different locations and may not be familiar with the social, environmental, and economic benefits and perspectives of the local stakeholders. Through better integration of stakeholders and shared value, this research will help circular businesses

become more sustainable and consider a wider breadth of benefits their business can offer. This research will also be interesting from an academic perspective since stakeholder theory and business model theory will be integrated to interpret results. It will also focus on the understudied social and environmental benefits that IS can provide to regions and communities. Recommendations for how to integrate different stakeholders into business practices will be useful to increase the value gained by all actors. The methodology used to consider the different sustainable business model benefits could be used as a framework for future research.

1.6 Disposition

Chapter 1 presents the research problem, aims and research questions, ethical considerations, and the intended audience of the thesis. Chapter 2 provides a literature review with a background of the most relevant literature within the field. This will provide insights on research gaps that have been identified in the literature to be addressed in this thesis. It will follow a conceptual framework built by the author and explore the literature around Industrial Symbiosis, Sustainable Business Models, and Stakeholder theory. Chapter 3 will focus on the research design, data collection, selection of actors, and data analysis. Chapter 4 will reveal the results and major findings from the data. The discussion will make up Chapter 5 where the results will be discussed in greater detail and in relation to previous literature and research. Chapter 6 will provide main conclusions and recommendations to practitioners and ideas for future research.

2 Literature Review

This chapter will summarize the major literature that is relevant to this study. It will cover current background knowledge relevant to the IS literature as well as concepts from the sustainable business model, circular economy literature and stakeholder theory literature. It will use a conceptual framework to guide the development of ideas. Section 2.1 will develop the conceptual framework and briefly describe the major concepts that are important to this study. Sections 2.2-2.5 will describe the major concepts of industrial symbiosis, sustainable business models including circular economy concepts, and stakeholder interactions, individually.

2.1 Conceptual Framework

The conceptual framework used to develop this literature review was developed based on background knowledge required to answer the research questions. At the forefront, the IS concept was researched to provide background on the academic IS literature and identify research gaps and gain an operational understanding. Literature from perspectives of sustainable business models and stakeholder theory were used to build a case for the benefit of integrating stakeholders into IS systems (Figure 1). The following sections will describe the IS concept- what is it, how does it work, and what are the context specific details important to this study? The next section will dive into sustainable business models and understand how IS can be connected to the SBM concept and the three pillars of sustainability. Lastly, this literature review will review the stakeholder perspective of IS to provide background for the research on who is benefiting and engaging in the development of IS.

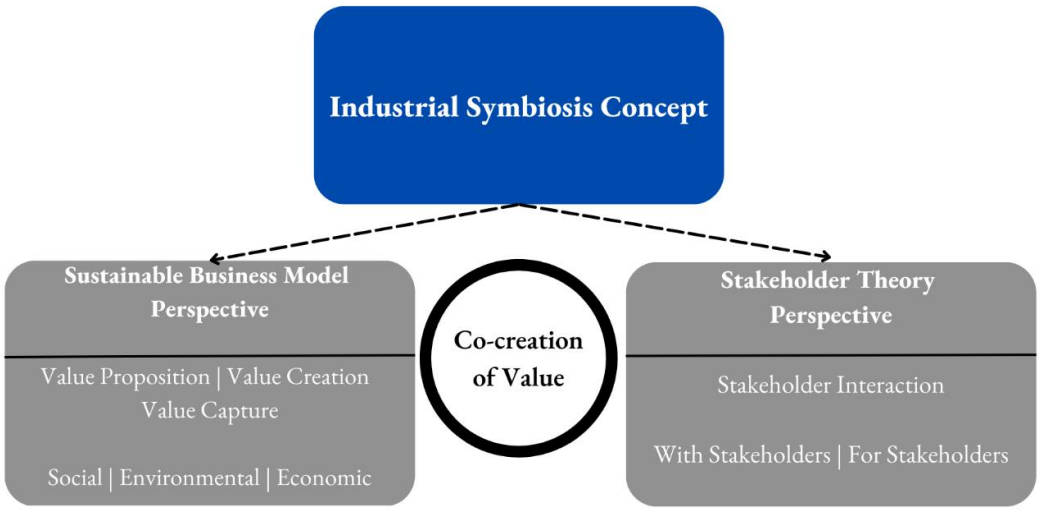

Figure 1- Conceptual Framework used in the development of the literature review.

Source: Author's own conception

2.2 Industrial Symbiosis Concept

Industrial symbiosis (IS) is a collective approach by two or more actors towards resource value prolongment. The most cited definition of industrial symbiosis is below:

Industrial Symbiosis (IS) "engages traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by- products" (Chertow, 2000).

Lombardi & Laybourn (2012) further refined the definition of IS as engaging diverse organizations in more innovative practices that foster long-term culture change. This focus on

innovation and the collaboration of diverse organizations brought to light the mutual value that can be achieved from IS to improve business and knowledge sharing within networks. The definition has been enhanced overtime, but IS brings together different actors and sectors to increase the long-term value of underutilized resources (e.g., by-products, waste streams) by creating synergies for resource use as well as (more recently) knowledge sharing (Kosmol et al., 2021). The most well-known and well-studied example of IS is the Kalundborg Industrial Park in Denmark (Chertow, 2000). Kalundborg is recognized as a system that built on existing scarcities, opportunities, geographic co-location of industries at a port, as well as policy incentives which led to its success (Chertow, 2007). Since this case, other cases of IS have grown immensely stemming from the reporting and demonstration of this successful site in Denmark (Neves et al., 2020).

IS has been classified in many ways over the years (e.g., Boons et al., 2017; Chertow, 2007; Domenech et al., 2019) with the literature generally evaluating the two models of symbiosis as a planned eco-industrial park model or a self-organized model. The planned model is an IS that has made a conscious effort to co-locate industries together for the purpose of sharing resources (e.g., through government planning or external stakeholder group engagement; Chertow, 2007). The self-organized model of IS emerges organically and from the motivations of individual businesses who see a value from exchanging resources (Chertow, 2007). Kalundborg is an example of a self-organized model where companies spontaneously saw the benefit of symbiosis and formed contracts together and eventually developed an industrial park. The ways in which IS networks operate and establish is a complex and dynamic process, and several other models have been developed in more recent years. For example, Boons et al. (2017) developed seven types of IS dynamics that can exist which are characterized by the actors involved in and motivations of the initial establishment, as well as a typical storyline for each type. The seven different IS dynamics include self-organization, organizational boundary change, facilitation through brokerage, facilitation through collective learning, pilot facilitation, government planning, and eco-cluster development (Boons et al., 2017).

In Sweden, many IS linkages have been established historically through the industrial activities in the forest industry, with common practices of connecting to district heating systems (Wolf, 2007). The economic policies of the early 20th century encouraged efficient and diversified production of forest products which led to a number of IS linkages between companies based solely on business cases (Baas, 2011). The well-established district heating systems across Sweden also provided infrastructure to build synergies from early years, only to be called IS once the academic literature "uncovered" these pre-existing partnerships (Chertow, 2007). The structure of industry in Sweden is predominated by small and medium enterprises (SME), which makes unplanned IS more manageable. For example, low population areas in Sweden, where many industries are located, provide a close proximity and interaction between stakeholders and representatives of industry, government, and academia so meetings can be held frequently and trust can be built between partners (Baas, 2011). The uncovering of existing linkages, the creation of new partnerships, and the co-creation of solutions is made further viable by the high level of trust and innovative attitudes that are embedded into Swedish society (Baas, 2011).

The success of IS systems depend on a number of conditions including techno-spatial conditions, knowledge availability, economic and market conditions, political conditions, and organizational and social dynamics (Harris et al., 2018). Other success factors of IS projects include active participation of the companies in the project development, including investment of time, finances and resources (Heeres et al., 2004). One major barrier to IS development is understanding the social dynamics (Harris et al., 2018), and more extensive knowledge of the local context to bring these ideas to fruition in more than one location. In many cases, IS parks are created organically, with many pre-meditated industrial parks struggling to generate the cooperation required for success (Chertow, 2007). The understanding of the local context of

potential IS projects must therefore be prioritized to successfully implement the project (Jensen et al., 2011). This includes the engagement of diverse stakeholders that each hold their own perceptions and expectations of IS in their community.

2.3 Sustainable Business Model Perspective

The three-pillar definition of sustainability includes the economic, environmental, and social dimensions. Sustainable Business Models (SBMs) are designed to take into account this triple bottom line, and broadens the focus away from the individual firm and towards a wide network of stakeholders to transform the traditional business model (Bocken et al., 2014). The traditional business model is a representation of how an organization creates, delivers, and captures value through value proposition, value creation, and value capture (Teece, 2010), without much focus on extending the idea of the organization. SBMs can create a competitive advantage through contributions to sustainable development of not just the company but also society, generating a greater overall customer value (Lüdeke-Freund, 2010). The value proposition provides environmental and social value, in addition to economic value (Bocken et al., 2014). SBMs can be categorized into eight archetypes: maximize material and energy efficiency; create value from 'waste'; substitute with renewables and natural processes; deliver functionality rather than ownership; adopt a stewardship role; encourage sufficiency; re-purpose the business for society/environment; and develop scale-up solutions (Bocken et al., 2014). The business model archetype titled *create value from 'waste'* are those that turn waste streams into valuable inputs for other production to increase efficiency and prolong utilization, for example, IS (Bocken et al., 2014). There are many other ways SBMs can be classified including a Taxonomy from (Lüdeke-Freund et al., 2018) which lays out 45 patterns of SBMs. The *Closing the Loop* patterns includes IS, co-product generation, product recycling, and reuse. These patterns help integrate circular material and energy flows into collaborations, and key business activities and are expected to contribute to ecologic–economic value creation, with less focus on social value creation (Lüdeke-Freund et al., 2018).

2.3.1 A Circular Economy

SBMs that 'close the loop' or 'create value from waste' can also be related to the circular economy, with a key example of a circular business model being IS. The traditional linear economy assumes a take-make-dispose model of consumption which requires a high usage of raw materials, energy, and cheap waste disposal (Ellen MacArthur Foundation, 2013). There are limits to this type of economy with an unsustainable dependency on resource extraction as supply chains become more complex and risks to business becomes more pronounced (Fernández Campos et al., 2019). The circular economy (CE) is a holistic alternative approach that has the potential to radically transition society into a more sustainable model that increases the wellbeing of citizens while minimizing environmental costs (Ghisellini et al., 2016). The main objectives of circular business models (CBM) are functions of decoupling for more sustainable economic growth, and for resilience for greater autonomy and reduced risk of volatile markets and resource scarcity (Hofmann, 2019). When executed well, CBMs have a chance to be regenerative- they reuse materials more carefully and collectively to repair the degradation of the living world (Raworth, 2012). Criticisms of the CE argue that the connection between CE and sustainability is not clear, questioning the decoupling of economic growth from environmental impact and its ability to encompass complex networks of flows in the area it operates (Corvellec et al., 2022). From a sustainability perspective, there is a lack of understanding of the holistic impacts and benefits of the CE in different contexts.

Although the economic benefits of increased circularity are clear (Ellen MacArthur Foundation, 2013), there has been an increased interest in recent years on the social and environmental aspects of increased circularity (Ghisellini et al., 2016; Hofmann, 2019; Padilla-Rivera et al.,

2020). However, the social and environmental benefits of the circular economy are unclear, lacking an understanding of how the CE will contribute to these two pillars of sustainability (Corvellec et al., 2022). Under the Lüdeke-Freund et al. (2018) classification of SBMs, models that focus on closing the loop can be expected to contribute to ecologic–economic value creation. The social dimension which includes concepts about transparency and social justice in value creation networks and reducing social disparities are issues that are rarely addressed in the CBM concept (Hofmann, 2019). The social angles that are most frequently addressed include employment, education and awareness, health and safety, and government involvement (Mies & Gold, 2021). This means that one cannot simply classify all circular economy solutions as sustainable, given that the definition of a SBM must include environmental and/or social aspects in its value proposition.

2.3.2 Sustainability Benefits of Industrial Symbiosis

The link between IS and sustainability is less refined in the literature, however, IS is generally considered a SBM because it promotes the efficient use of resources, reduces waste, and creates economic, social, and environmental benefits. IS and more broadly the CE has been connected to Sustainable Development Goals (SDGs) including those related to food security, wellbeing, water and sanitation, sustainable energy, sustainable economic growth, resilient infrastructure, and sustainable consumption and production (Cecchin et al., 2020). Business opportunities exist to take waste streams, use a designated technology or process, facilitate business model design and financial procurement, to create regenerative businesses. Many regenerative industries have identified several use cases for waste-to-x type business models to help facilitate IS projects, for example using heat recycling to enable food production (Parker & Kiessling, 2016).

Throughout this thesis, the word 'value' is defined as any identified desired effect originating from an IS synergy and may be used interchangeably with benefit, gain or desired effect (as defined in Wadström et al., 2021). IS networks have potential to contribute to regions through improved environmental performance of local industries and socio-economic benefits (Harris et al., 2018; Martin & Harris, 2018). However, a broader sustainability assessment is critical to realizing the influence that IS can have in sustainable development at the local and regional level. In (Wadström et al., 2021), a review of 56 IS research articles identified that economic and environmental benefits are central to the IS concept and are well studied when compared to the social aspects. Studies that focused on meso level circular economy social benefits (i.e., IS) focused on the local community, but typically this was done in a passive manner (Mies & Gold, 2021). In many cases the social aspects of IS are grouped with the economic aspects, with indicators of success consisting of number of jobs created (Domenech et al., 2019). The dissemination of all benefits of IS is critical to informing policy decisions around IS synergies in companies and municipalities (Neves et al., 2020).

Economic Benefits

Economic benefits that are measured across projects can include revenue and number of jobs, but early on in IS development it is typical to have a lot of unknowns about quantifiable economic benefits (Heeres et al., 2004). Economic values are frequently assessed in the literature, including impacts of lower input costs, increased revenue, decreased costs, avoided taxes, lower production cost, reduction of waste disposal costs, and increased profit, however few studies have actually quantified these benefits (Wadström et al., 2021). Reduced input costs, waste management costs and new revenues from by-products with a higher value have also been mentioned as economic benefits of IS (Mirata & Emtairah, 2005).

Environmental Benefits

Environmental benefits are the most often quantified of sustainability impacts in the IS literature (Heeres et al., 2004; Neves et al., 2020). The most common environmental benefits reported on

are those related to climate-change- for example, quantified GHG reductions, landfill and methane reductions, and freshwater use reductions (Domenech et al., 2019; Neves et al., 2020; Wadström et al., 2021). The reduction in use of resources that are non-renewable and overall resource use efficiency is also highlighted as a benefit from an environmental perspective (Mirata & Emtairah, 2005).

Social Benefits

The close collaboration of diverse actors is essential for the functioning of IS. Consequently, the components identified for social sustainability are associated with various interrelated groups of actors. Economic and environmental impacts of IS are relatively well studied when compared to social impacts, a finding that has been found in much of the IS literature (Wadström et al., 2021). The social outcomes that are typically reported on are related to network outcomes, followed by increased income from jobs- which could arguably be classified as economic benefits since they are focused solely on the market producer (Wadström et al., 2021). Other social benefits mentioned in the literature include increases in not just job numbers but job quality as well as improved work environments (Mirata & Emtairah, 2005).

IS networks have the potential to positively contribute to environmental and social benefits of a region (Martin & Harris, 2018). In Martin & Harris (2018), the environmental, social and economic impacts of an emerging IS network called Sotenäs Symbioscentrum. The Symbioscentrum offers value-added products and processes including fish processing, recycling plastic wastes, algae production, and plans for biogas production in the future. The assessment found that the IS network was able to contribute positively to the environment (e.g., reduced eutrophication, GHG reductions) and regional socio-economic situation (e.g., job retention, local innovation, community engagement). The social impacts of the gained local prosperity were evident, and the industrial production gained longer-term sustainability to be maintained in the region (Martin & Harris, 2018).

Firms that use and sell waste apply different business models (Fraccascia et al., 2019) that can integrate social factors and community in novel and exciting ways. IS principles can be closely linked to SBMs since they both offer innovative ideas to create environmental and economic benefits. The two concepts can complement each other as well with IS focusing on waste use benefits and the SBM perspective looking closely at value creation (Short et al., 2014). IS networks can bring intersectoral organizations together to collaborate in new ways that stimulate the reorganization of traditional systems and build regional innovation capacity (Mirata & Emtairah, 2005).

2.4 Stakeholder Interactions

A stakeholder, according to Freeman (1984), is "any group or individual who can affect or is affected by the achievement of the organization's objectives". Stakeholder engagement is an important part of business design and innovation, especially in sustainable business models. The following sections will review how stakeholders are a necessary part of sustainable businesses, and then more specifically, IS.

2.4.1 Stakeholders in Sustainable Business Models

The development and operation of a sustainable business model demands the engagement of and creation of value for stakeholders- through partnership, participation, communication, and consultation (Goni et al., 2021). Preconditions for stakeholder interaction in sustainable business models have been identified by Fobbe & Hilltofth (2021) and include to build capabilities, establish high-quality relationships, align sustainability values, and value perceptions, recognize influence on stakeholders, and recognize stakeholder influence. These

preconditions are only established through meaningful stakeholder interaction and reciprocal relationships (Fobbe & Hilletofth, 2021). Although the requirement of stakeholder interaction for integrating sustainability into business models is well understood (Goni et al., 2021; Preghenella & Battistella, 2021), the specific role of stakeholder interaction in SBM development and innovation and particularly of certain stakeholder groups is not fully understood.

Stakeholder interaction can play different roles in SBM elements and can contribute to sustainable value propositions, creation, and capture (Fobbe & Hilletofth, 2021). Value propositions can be developed *for* stakeholders (considering their needs, costs, and benefits) but can also be developed through interactions *with* stakeholders (partnerships, direct communication, feedback, testing) (Fobbe & Hilletofth, 2021). When value propositions are developed for stakeholders, the organization needs to identify which stakeholders they propose value, and how it can satisfy the needs or be detrimental to or miss other stakeholder groups (Bocken et al., 2019). They must ensure that all stakeholders, not only customers, are considered in value proposition, in particular the costs and benefits for each actor group, including ones that were previously ignored (Baldassarre et al., 2017; Geissdoerfer et al., 2016). A shift is occurring from the creation of value for stakeholders to the creation of value with stakeholders for sustainable business cases (Freudenreich et al., 2020). Value creation with stakeholders can take the perspective of establishing a joint purpose with stakeholders, not just for stakeholders, including reciprocal flows and overall value creation with mutual stakeholder relationships (Freudenreich et al., 2020). Stakeholders can be recipients of value but in addition can be creators or co-creators in joint processes (Freudenreich et al., 2020).

It is clear that early and continuous stakeholder engagement is essential to bring business models towards sustainability, with different stakeholders playing different roles (Fobbe & Hilletofth, 2021). It is therefore critical to understand the values that are held by each stakeholder group to best integrate them into the business model development process. To develop value propositions through interactions with stakeholders is a difficult task with potential conflict and dissonance from some groups. Further, there is a gap in understanding of the role of stakeholder interaction in more collaborative circular business models (Fobbe & Hilletofth, 2021).

2.4.2 Stakeholders in Industrial Symbiosis

The development and operation of sustainable IS projects is dependent on several actors, and different actors have higher relative power among the stakeholders (Hein et al., 2017). There are symbiosis partners that are involved in the exchange of resources, but there are also other stakeholders that are critical for the success of the network. Successful IS projects requires active participants from various stakeholders, including the public sector government agencies; representatives from local companies and potential tenants; financial and industry leaders; local chamber of commerce; labour representatives; academia; practitioners for the building phase; and community and environmental organizations (Heeres et al., 2004). For example, in a case study in France, it was found that the stakeholder that finances the symbiosis through way of a contract and those stakeholders providing critical resources held the highest relative power (Hein et al., 2017). Since trust is such a salient part of IS partnerships, it is important to understand the stakeholder dynamics to ensure the success of a project (Hein et al., 2017).

Different models to describe arrangements of stakeholders in the innovation landscape have evolved over time. The triple helix model introduced in the 1990s describes the relations between three spheres- university, industry, and government (Etzkowitz & Leydesdorff, 2000). This was the first model that introduced the enhanced role of academia into innovation in increasingly knowledge-based societies, and away from the model where industry was the firm leader in innovation (Etzkowitz & Leydesdorff, 2000). The triple helix model has been used to understand the conceptualization of the CE by these different institutional spheres, and to understand the overlap, or consensus space, where there exists the best opportunity for

innovation and advancement (Anttonen et al., 2018). Through this model, the consensus space for the circular economy between the triple helix institutional spheres focuses on how the CE can use waste to create new resources, business and products (Anttonen et al., 2018). This clearly relates to IS as an opportunity for advancement of the CE that is supported by multiple institutional spheres. The triple helix system is important because it allows for systemic innovations that transcend individual spheres and combines and enhances the competencies of all three (Ranga & Etzkowitz, 2013). Cooperation between spheres can help advance knowledge flows and lead to integrated innovation for the CE (Arsova et al., 2021). The triple helix model has been used by IS networks and projects in Sweden and elsewhere in the EU (Svendsen Lander et al., 2021) and the quadruple helix has also emerged in recent years to describe the key stakeholders that contribute to funding, knowledge, and partnerships in IS projects (Moodie et al., 2019; Transition ApS, 2021). The quadruple helix has further widened the reach to include the active role of citizens as part of the innovation system (Arsova et al., 2020). This opens up space for social innovation and innovation beyond science and technology-based innovation (Arsova et al., 2021), which is particularly relevant to the CE and by extension IS. Further, a CE-centric quintuple helix was developed to capture the spatial dimension with the natural environment at the centre of the model, creating an aim at conservation of the environment suitable for socio-ecological transitions (Arsova et al., 2021).

The four stakeholder groups that will be investigated throughout this study are based on the quadruple helix model, with the environmental context of the quintuple helix driving the aim more indirectly. The quadruple helix of these four actor groups will be used to assess the level of stakeholder engagement occurring in IS networks across Sweden:

1. Industrial actors, businesses
2. Public actors, including all levels of governments
3. Research institutes, universities
4. Communities, civil society

2.4.3 Co-Creation of Value

Stakeholder interaction is important for two perspectives of value capture including creating value for stakeholder, and interacting with stakeholders to create value (Fobbe & Hilletofth, 2021). Co-creation of value is a cooperative process where companies collaborate with their stakeholders to create mutual value that meets the needs and expectations of all parties (Prahalad & Ramaswamy, 2004). This process involves understanding and integrating perspectives, insights, and expertise of different stakeholders into the design and development of business models and products. Co-creation of value can lead to increased innovation, and improved sustainability outcomes. A study on circular businesses conducted in Italy revealed that co-creation processes can prove advantageous not only for firms by enhancing their offerings, increasing customer loyalty, and acquiring new customers but also for participants, who gain empowerment, economic benefits, and a sense of satisfaction for contributing towards an environmental cause (Re et al., 2021). The idea of co-creation of value can be woven into stakeholder interactions in IS to increase innovation and provide a greater sustainable value overall.

3 Research Design & Methods

This section will describe the rationale for research design choices and the methodology which was followed to collect and analyze data.

3.1 Research Design

Since the main aim for this thesis is pragmatic in nature, it was important to use multiple methods to gain insights into real life applications. To answer the proposed research questions, a mixed methods research approach was used (Figure 2). A mixed method research approach uses multiple lines of inquiry and integrates both qualitative and quantitative data to extend the insights of the research (Creswell & Creswell, 2018). By using qualitative methods first, the researcher could explore and interpret the meaning building from more specific understanding of processes or groups at a given time to more general themes (Creswell & Creswell, 2018). The basis of qualitative research is open-ended questions and responses through a variety of methods. Multiple case studies were used in this research design because it allows a line of inquiry where an in-depth analysis of a case can be conducted in a structured way. Case studies are most valuable when the main question of the research is explanatory and descriptive, which aligns with the real-life applications of this thesis (Yin, 2014). In this research, specific successful cases of IS synergies across Sweden were assessed to make greater generalizations to other IS cases within and outside of Sweden. The open-ended qualitative methods helped build closed-ended survey questions to converge results in a way that provided greater insights. This can be described as an exploratory sequential design, where the qualitative data collection and analysis builds to the design of the quantitative analysis (i.e., the survey) (Creswell & Creswell, 2018).

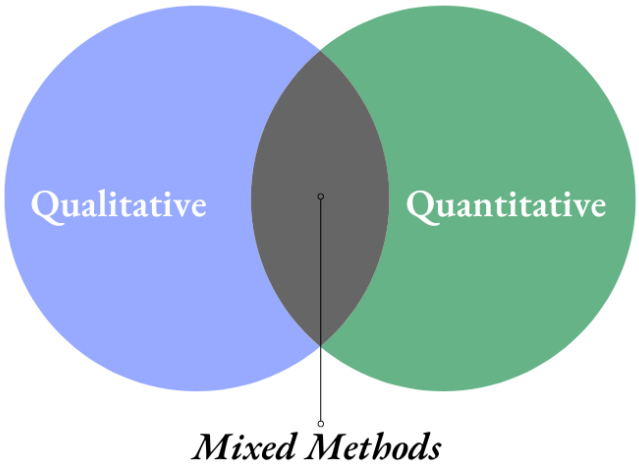

Figure 2- The research design followed a mixed method approach which combines insights from both qualitative and quantitative data.

The research process consisted of three primary stages, as depicted in Figure 3. The first step played a crucial role in formulating the research inquiries by examining the relevant literature, identifying existing gaps in previous studies, and understanding the challenges faced by practitioners. Subsequently, research questions and the appropriate methodology were devised, and a collection of IS case studies from various locations in Sweden were chosen for analysis. Phase 2 involved the development of the methodology, building upon the findings from Phase 1, which included the collection of data (Section 3.2). Phase 3 involved the incorporation of data into the analysis, writing and presentation of results (Section 3.4).

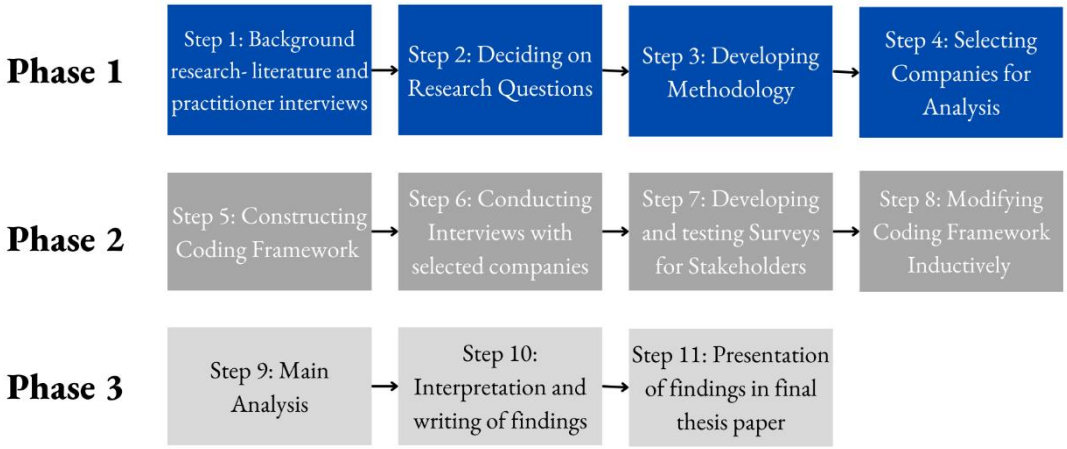

Figure 3- Conceptual framework to guide the process of research. Phase 1 is the preparatory steps and involved literature and practitioner research, developing the methods and selecting case studies. Phase 2 included data collection and Phase 3 data analysis.

3.2 Data Collection

The data collection phase will include two main methods: semi-structured interviews (Section 3.2.1) and surveys (Section 3.2.2) (Figure 3; Step 6 and 7).

3.2.1 Semi-structured Interviews

In the interview stage, facilitators, developers and/or coordinators of various IS networks from across Sweden were questioned. Eight interviews were conducted with nine individuals from eight IS networks. The average time of each interview was 30 minutes. Interviews were conducted on online platforms of the interviewee's preference, either Zoom or Microsoft Teams. Each interview was conducted one-on-one with one exception where two individuals were interviewed together. All interviews were consented to and recorded with permission from the interviewee.

The overall purpose of the interviews was to investigate how these synergies are working with stakeholders during the conceptualization and operation phases of the projects. The goals of the interviews were firstly to gain more information about what the IS facilitators believe are the main value propositions of the IS synergy they are involved with. Secondly, it was important to better understand the stakeholder interactions that were held during the development and operational phases of each specific IS. These two goals were connected because it was important to know which stakeholders were involved, and how their value propositions were integrated into the business model development and future innovation within the IS. Semi-structured interviews were used to guide discussion but allow for the addition of new information where the interviewee prioritised conversation. Interviews were intended to gain insights from different cases to get a holistic account of stakeholder processes as well as the perceived value the practitioners see from the synergies that they coordinate.

A basic interview guide with consistent questions for each interviewee can be found in Appendix A. Each IS case was researched and reviewed before the interview took place to develop a case-specific interview guide, and questions were aimed at the following categories:

- Description of the IS project; role of the interviewee
- Major value proposition from the perspective of the interviewee. Perceptions of different value propositions of different actors.

- Description of IS project conceptualization process
- Stakeholder involvement in the development of the IS project
- Stakeholder involvement in the operation of the IS project
- Contact information for stakeholders was requested

Some limitations of interviews include the filtering of information by the participant through their own worldview, a bias in results based on the researcher presence and having questions or responses misinterpreted (Creswell & Creswell, 2018). In addition, respondents offered different levels of detail, offering unique and sometimes difficult to compare perceptions of situations. To verify and build on the results of interviews, surveys offered triangulation by providing an additional data source to seek convergence and complementarity on results from the selected case studies (Greene et al., 1989). In addition, and where necessary, validation procedures such as member checking was completed to ensure that interviewees agree with the interpreted findings and to reduce researcher bias.

3.2.2 Stakeholders Survey

The survey was conducted after interviews were completed. The primary purpose of the survey was to provide a more numeric description of the stakeholders of the case studies by getting the opinions from a sample population from each case. Surveys can provide a quantitative description of opinions of a given population by way of a sample population (Creswell & Creswell, 2018). The survey method was chosen because it was a way to scan a large number of stakeholders and their perceptions of the benefits of the IS network that they are connected to. The survey was designed with close-ended questions but also included open-ended qualitative questions to gain further insights on specific views from respondents. The survey instrument used was Google Forms for its accessibility and ease of use. The survey was field-tested by practitioners in the IS field in Sweden, and translated into Swedish to give respondents the option to respond in their native language. Translation was completed using DeepL software (DeepL Translator, 2023), and the Swedish survey was validated by three Swedish speakers. The survey was active between 24 February and 15 March 2023. The English version of the survey can be found in Appendix B.

The survey utilized a conceptual framework developed originally to coordinate between different actors and business models to realise the benefits of Nature Based Solutions (Naturvation, 2022). The Naturvation Business Model Puzzle is built in collaboration with different stakeholders to understand the values of a given nature based solution project, and who receives these benefits. The puzzle has been adapted to suit the aim of this thesis, mainly to address the value proposition of IS projects to relevant stakeholders in the actor network including economic, environmental, and social benefits (Table 1). The intent is to understand how different actor groups evaluate and prioritize the value of the IS project in which they are connected to. The survey used multiple choice questions to direct respondents towards the pre-established framework. The framework chosen was based on Wadström et al. (2021) which established three benefit categories for IS taken from the three pillars of sustainability-economic, environmental, and social. For each benefit category, specific benefits were based on the following frameworks: Economic benefits were based on basic market valuations; ecological benefits were based on the planetary boundaries framework (Rockström et al., 2009); social benefits were based on doughnut economics (Raworth, 2012). For each type of benefit category a selection of benefits was listed, and respondents were asked to assign a level of importance for each. Respondents were also asked to indicate which actor group they were associated with in order to generalise benefits that are prioritized for each actor group.

Table 1- Framework used to develop the survey design which included respondents from several different actor groups and asked respondents to assign a level of importance to different benefits offered by the IS project that they are connected to.

Who Values What?	Economic Benefits	Ecological Benefits	Social Benefits
Conceptual Frameworks Used	Market valuations	Planetary Boundaries	Doughnut economics or SDGs
Industrial Actors, Businesses			
Public Actors, Governments			
Research Institutes, Universities			
Communities, Civil Society			

3.3 Selection of Actors

IS case examples that were assessed in this study were selected based on specific criteria. Firstly, the IS project had to follow the definition for IS that aims for the exchange of heat, water, waste and/or other residuals between industrial and/or urban facilities. Secondly, given the short time constraints of the research, existing information on the IS network needed to be easily accessible. Case studies were first selected based on existing information as summarized in Linköping University (2021) and Mirata (2018). There have been over 20 IS networks identified in Sweden (Mirata, 2018), but the IS case examples chosen for this study were those that had a large enough scale that it contributes significantly to the local economy, in order to identify local and regional benefits, thus allowing the scales to be comparable between cases. In addition, it was important that the case examples each contained a key person, or initiator, that was available to speak in an interview on behalf of the IS network. Interview participants were chosen based on their focal roles as facilitators or coordinators of IS synergies. It was important that this contact was connected to the organization that initiated the IS project(s) or network and had a helicopter view of its history and operations. Contacts were collected from and verified with practitioners who have extensive experience with IS in Sweden. In addition, snowball sampling was used to gain new contacts from the selected interviewees. The eight case examples and corresponding interviewee roles are summarized in Table 2.

Table 2- Case Examples chosen for this study including the location and role of the individual who was interviewed.

Case Example	Location	Interviewee Role
Paper Province	Karlstad, SE	Innovation Advisor and Project Manager
Sotenäs Symbioscentrum	Sotenäs Municipality, SE	Developer
Händelö Eco-Industrial Park	Norrköping, SE	Senior Project Manager
City of Malmö	Malmö, SE	Climate Strategist and Project Manager
Lidköping Municipality	Lidköping, SE	Environmental Strategist
Food Valley of Bjuv	Bjuv, SE	Business Coordinator
Stenungsund Chemical Cluster	Stenungsund, SE	Former Managing Director
High Coast Innovation Park	Örnsköldsvik, SE	Former Communications Manager

Survey contacts were compiled from requests to interview participants as well as distributed widely on key LinkedIn accounts within the IS industry in Sweden. Each interviewee was asked to send contact information for stakeholders of the IS synergy that they were involved in from a variety of actor groups including from public, private, and external organizations. The hope with this request was to get an array of stakeholder types that are relevant for IS (e.g., Heeres et al., 2004). By requesting contacts from IS coordinators and leaders, stakeholders could be asked which IS they were interacting with to get a sense of how values differed across IS synergy locations as well as actor groups.

Given the time constraints of this study, convenience sampling was used to select survey respondants and was based on the contacts that the interviewees were willing to send it to (Creswell & Creswell, 2018). Although less desirable, a nonprobability sample was chosen because encapsulating the entire stakeholder network and selecting a random sample was unreasonable given much of this network is still unknown.

3.4 Qualitative Data Analysis

Following each interview, the recorded audio was transcribed using a free artificial intelligence subtitles program (freesubtitles.ai, accessed 2023). Each transcript was manually audited immediately after completion of the interview to review for any mistakes and remove redundant words. Qualitative data analysis for this study was conducted using NVivo 12 software for PC. NVivo software provides the opportunity to code interviews and qualitative data using different 'nodes'.

Coding was used to assign labels to develop overall themes that organized the qualitative results in a systematic way. Coding is the process of taking chunks of text or paragraphs and labeling them with a specific term, or code (Creswell & Creswell, 2018). These codes help to categorize the qualitative data into themes that will make up the major results of the thesis. To assess the data, deductive analysis of transcribed interviews was used. The framework for content analysis was determined before the data was collected and based on the research questions; thereby utilizing structured coding and themes to develop the interview guidelines (Step 5 of Figure 3). The coding framework was modified when interesting new information was collected from interviews so that it could be included in the results. NVivo was used to code the transcripts using different 'nodes' for each code. The initial coding was broader to break up the transcripts into smaller pieces that could then be analysed with more focused coding. The focused codes were able to gain more insights into the details of the initial codes. The theoretical themes were then determined by comparing the focused code to the theory that was found in the background literature review of the study (see Table 3).

Table 3- Coding structure used in qualitative data analysis to lead from the research questions to the theoretical themes that make up the results of this study.

Research Question	Initial Code	Focused Code	Theoretical Themes
RQ1: How are industrial symbiosis networks in Sweden currently organizing internally and externally with stakeholders to develop IS value propositions and business models?	Anything referring to how the IS network was first established Anything referring to how the IS network is currently operating	What was the initial motivation and who were the actors involved? How does the IS network organize itself internally?	7 dynamics of IS networks: Self-organization Organizational boundary change Facilitation (brokerage) Facilitation (collective learning)

	Anything referring to how the IS network is engaging with external stakeholders	How is the IS network engaging with external actors? How often are groups meeting? Who are the main stakeholders involved?	Pilot facilitation Government planning Eco-cluster development Changes or shifts in the above dynamics Stakeholder engagement
RQ2: What are the sustainability benefits of industrial symbiosis cases from the perspective of different stakeholder groups?	Any description of the main benefit that the IS network brings Any mention of how the value proposition differs between different stakeholders	Which stakeholders focus on which values?	Economic value propositions Environmental value propositions Social value propositions

3.5 Quantitative Data Analysis

Survey data was analysed using Google forms. A total of 12 responses were used in analysis, ten answered in Swedish and two answered in English. Since the survey was sent out to stakeholders by the interviewees, the response rate is unknown. The results were downloaded into an excel file where data were further assessed and results from the two languages were combined and translated. Each of the benefits from the three categories (economic, environmental, and social) were ranked based on how much alignment there was on the importance of the benefit. For example, benefits that had more than 50% of respondents indicating that it was of high or very high importance were categorized as Aligned High Importance. For benefits had more than 50% of respondents indicating no importance, low importance, or this benefit is not present, they were categorized as Aligned Low Importance. Benefits that fell into neither of these categories and had mixed results between actors, were categorized as Mixed Results. Basic comparisons were made across different actor groups, different IS projects, and different types of benefits. This analysis was meant to answer questions about which benefits were the most important to whom, and where?

4 Results

4.1 Overview of Case Examples

This section will cover a brief overview of each case example in this study. It will provide a brief description of the location, timeline, history, and main industries involved in each IS case. These details were established in the interview stage of the data collection from interviews with facilitators of each IS network case example. It is important to provide a description of each case example to understand the context behind the rest of the results and analysis.

4.1.1 Paper Province in Karlstad

The Paper Province is a forest industry cluster based in Karlstad municipality which started in 1999, with IS coming into focus in 2015. The member-based cluster organization Paper Province started with seven companies and at the time of writing has 130 member companies. Originally the cluster was quite geographically narrow, but it has expanded to a larger region. The Paper Province acts as a facilitator to the whole value sharing network of the forestry sector in the region. One of the main focuses of Paper Province is innovation, with an established incubator focusing on the bioeconomy.

4.1.2 Sotenäs Symbioscentrum

The Symbioscentrum in Sotenäs municipality is located on the west coast of Sweden, north of Gothenburg. The municipality has been actively engaged in developing a network of IS since 2013, and the Sotenäs Symbioscentrum opened in 2015. The Symbioscentrum aims to facilitate both industrial and social symbiosis in the marine sector. The current network contains eight businesses working with two sides of the symbiosis network- the marine food industry and bioeconomy from ocean plastics. The Symbioscentrum was developed with an ambition to create green development in the municipality.

4.1.3 Händelö Eco-Industrial Park

Händelö Eco-Industrial Park (EIP) has a long history stemming from the CHP moving out of Norrköping city in the 1980s to a small island with an active harbour where industries have gathered, called Händelö. In 2000, a major ethanol company was established as a bioethanol company in Händelö. Händelö EIP was developed in 2019 and is facilitated by an external actor, Cleantech Östergötland. Cleantech Östergötland is a membership organization financed through EU-level projects. The EIP considers themselves to be a "world-leading symbiosis between industry and city with a bio-based and circular economy" (Händelö Eco-Industrial Park, 2023).

4.1.4 Malmö

Symbiotic partnerships have been active in Malmö since the 1990s mainly between energy and waste management, and the city's district heating network. More focused work on industrial and urban symbiosis has been active in the city since 2012 to try to expand and facilitate collaborations around all kinds of resource flows. The Norra Hamnen industrial area has been a testbed for new companies to work collectively on solutions to transport, energy, and waste management. Today, industrial and urban symbiosis is becoming integrated into new and existing areas of operation, and the geographic scope is expanding to areas outside of the harbour like Fosie and Fortuna Hemgården. IS is also becoming an important tool for broader urban development. The city of Malmö has been the facilitator and manager of several externally funded projects that are striving for a circular vision of the area.

4.1.5 Lidköping

Many examples of IS in Lidköping have been uncovered in recent years, starting with the district heating system in 1985, expanding to more symbiotic relationships with the biogas plant being built in 2012. The spontaneous development of symbiosis in the region has been focused on energy production and agriculture. IS in Lidköping contains only a few companies, including food production and a biogas company. A recent externally funded project led in 2018 by Lidköping municipality identified 26 symbiosis possibilities and the network is working to arrange the allocation of responsibilities to work towards bringing these possibilities to fruition.

4.1.6 Food Valley of Bjuv

The IS in Bjuv municipality started around 2007 with the connection between a biogas plant with an industrial food production plant to process residuals into biofertilizer and biogas. The businesses connected to the network have expanded to build what is known today as the Food Valley of Bjuv which is a large cluster of food companies working with IS. Central to the symbiotic activity in Bjuv is sustainable food production and using excess heat as a resource. Bjuv municipality is a facilitator of the symbiotic collaborations, and it aims to make connections and support circular production in the region.

4.1.7 Stenungsund

Stenungsund is Sweden's largest chemical cluster, located on the west coast north of Gothenburg. IS activities in Stenungsund have developed gradually starting in 1965. The symbiosis network is centred around a polyethylene producer. The collection of chemical companies in Stenungsund have found many opportunities to share resources and by-products and have developed new product streams based entirely off the availability of by-products. The actors collaborate on joint endeavors and have developed trust while aiming for ambitions towards bio-based chemistry in Sweden.

4.1.8 High Coast Innovation Park

In Örnsköldsvik municipality there has been a long history of IS in the forest industry. Many companies originated from a major pulp mill company, which split up in the end of 1990. From there, the Domsjö industrial area has been a place to attract innovation for collaborations in symbiosis in the biorefinery sector. In 2003, Processum AB was formed, and has acted as the engine of symbiosis in the Domsjö area. Processum is a member-based facilitator of IS and other innovative bio-based research. Domsjö has recently been renamed to the High Coast Innovation Park to reflect its geographic location.

4.2 Case Example Operations

The case examples operate independently of one another and have developed unique strategies for ongoing operations and stakeholder involvement. Throughout interviews with the facilitators, it was clear that many IS networks were utilizing projects to develop IS in their regions and build their actor networks. This section will discuss the cases in two main ways that the IS networks are operating internally: project-based cases, and opportunity-based cases.

4.2.1 Project-based Cases

These types of IS networks focus on organizing stakeholders around projects with specified timelines and goals. In the current state of operations of IS in Sweden, pilot projects with external financing are driving development in many areas. Many of the IS networks have ongoing or recently completed projects that utilize funding from national innovation funds and/or European level funds. These projects are led by diverse actors in Sweden, with the most common project leaders being external organizations or institutions. For example, at Händelö

EIP, Cleantech Östergötland is the project leader on a three-year project (2020-2023) which received funding from the European Union. Cleantech Östergötland is a leader of the project but not one of the six project actors. The use of an external facilitator has eased the operations of such a largescale project and taken this responsibility off the actors involved in the symbiosis. In addition, when actors are not certain about the benefits of such a project, they might not be eager to finance it independently. So having an external organizer and external funding can drive this type of work in innovation.

"Our experience is that when you have an external facilitator or organizer, it is much easier to do a project like this"- Interviewee from Cleantech Östergötland

In the case of Händelö EIP, the EU funded project has a steering committee which contains representatives from all six project actors as well as working groups that are responsible for six different work packages. The steering committee meets multiple times a year and has developed over the course of the project. In the beginning, the focus was on roundtable updates and the agenda, but towards the end, the value of continuous meetings became clear, and the discussions became easier since the actors were more familiar with each other and the projects. Although the focused project goals such as creating a vision for the team was an important way to bring the actors together, it was the continuous meetings and building of relationships that has been the strongest value to Händelö EIP. This familiarity has also increased the discussion around new IS synergies. When an actor has an idea about a new side stream or symbiosis partnership, the steering group has become a convivial place for these ideas to be discussed with the group.

"In the beginning it was very quiet and then as you become more accustomed to each other and you become more familiarized with each other, then it's easier to actually bring it up." – Cleantech Östergötland Interviewee regarding new symbiosis ideas from companies

After numerous meetings, the true potential for collective value creation becomes clear and internally the partners can work together more effortlessly. The project design and goals also bring potential for IS networks to collaborate with external stakeholders. For example, the project at Händelö EIP includes actors from Linköping University and public services like waste and water. Having researchers as a key player in such projects offers knowledge sharing and inspiration on the potential for IS and strengthens the understanding about why it is valuable for industry to participate. One work package was focused on creating a seminar about energy that is not optimized and how it could be utilized. The work targeted industries as well as green farming ventures in the region. This offered the opportunity for the IS network to learn from each other, attract new companies to Händelö, and collaborate with new actors.

Based on interviews completed by Cleantech Östergötland with the six project actors, the three main value propositions of this project are 1) Meeting continuously and creating a positive atmosphere between actors; 2) facilitation of study visits at Händelö; and 3) the establishment of a new entity at Händelö. The first three-year project at Händelö EIP focused on communicating history, what had been done there in the last 20 years, but the next project will strive to look into the future and how Händelö EIP can fit into the green transition and position the region in a more positive way. The actors are excited to be a part of this work, and the project organization makes it manageable for companies for which IS is not part of their core business.

In some cases, municipalities will apply to external funds with a diverse group of stakeholders but then act as the project managers (e.g., Malmö and Lidköping). The presence of external funds reduces the risk to participants and increases engagement from more actors. In Malmö, the most recent externally funded project was completed in 2020, and the focus has since shifted

internally to climate transition planning. The benefit of the projects comes from the connection that it brings between the industrial actors and the municipality. The first project initiated in 2012 focused on the harbour area in Malmö which houses most of the city's energy production, waste incineration and wastewater treatment. The project was initiated by a large energy actor who approached the municipality to help find funds to find ways to use their residual heat. The IS projects led by the City of Malmö grew from there. The projects led by Malmö include diverse actors including universities and business innovation hubs. Malmö has also been involved in international projects and EU level projects where partnerships have been created through official projects. The projects involve collaborating with different actors towards specific goals, but along the way new opportunities are identified.

"It gains momentum over time once you get the right people in the room" – City of Malmö Interviewee

Outside of project work, Malmö representatives are not involved directly with the ongoing operations of IS, however conversations around rekindling the municipal role in IS are in progress. When IS projects are managed by municipalities, it brings in an important stakeholder group that would otherwise not be included in internal dialogue about private actor agreements. The City of Malmö is trying to create a foundation for long-term cooperation that can be supported and scaled through external funding to reduce the risk. Lidköping municipality has also led two IS projects. The projects have created a network for communication between industrial actors, and involved university actors which has increased the network's overall knowledge of IS. However, it is clear from these discussions that taking the lead in IS and allocating long-term responsibilities become difficult once projects come to an end.

The challenges associated with municipalities leading IS projects have been recognized in the literature (e.g., Södergren & Palm, 2021a) and revolve around prioritizing such work above other sometimes urgent work of the public service and finding the right expertise and competencies. Different department goals that can be conflicting, and trying to gain political support to include IS in municipal budgeting can be challenging. Therefore, the continuity of municipal actors can be limited to specific projects that eventually end. It is also dependent on having long-term champions of IS in municipal departments that will focus on keeping IS on the agenda.

4.2.2 Opportunity-based Cases

These types of IS networks are formed around opportunity-based symbiosis. IS networks that are opportunity-based tend to have a longer history of industry collaboration. The focus of IS in these cases tend to be business cases and internal engagement with industry. IS partnerships are formed either through a facilitator or "match-maker", or just through the industrial actors independently.

Municipalities can also be more opportunity-based than the project-based examples of Malmö and Lidköping in the previous section. In the case of Bjuv Municipality, there is no formal network or meetings, only informal meetings that bring together key actors to work on a specific case. The municipality acts as a facilitator to identify and organize key actors when needs arise. This is often done through sharing a cup of coffee, where actors can build trust in an informal setting. As an external actor with a broad view of the IS network, the municipality in this case, can connect the right private stakeholders and identify the best solutions with the highest benefit for the highest number of actors.

In the IS in Stenungsund, the industrial actors are quite connected internally, with management directors from each of the companies meeting regularly. Trust is created by these meetings, and opportunities arise from these regular discussions. Stenungsund is a chemical cluster, and the symbiosis connections between companies are quite technical in nature. The meetings with

management directors can create a higher level of knowledge of the technical aspects of the connections and create business opportunities for sharing highly specific chemical resources.

For example, one of the chemical companies uses hydrogen in their production as one of their major raw materials. They needed more hydrogen in their production about 20 years ago and were considering investing in equipment that would reform natural gas into hydrogen. Another company had a chlorine plant which produced hydrogen as a by-product. However, they were using the hydrogen for their own steam production unit. One other company had another fuel gas as a by-product which could be used in steam production for the chloride plant. Between these three companies, an IS opportunity emerged that ended up being an economic solution for all. These three companies cooperated internally to increase transparency of processes, develop contracts and build these synergies into their business models.

The opportunity-based cases can lead to successful IS partnerships between industrial actors. However, important factors that bring success in these cases include a common and understood history of IS within the network, and strong trust between actors. The importance of meeting, even in informal settings is also evident. Bringing actors together to discuss the potential opportunities for sharing resources can lead to new symbiosis partnerships and innovation across industries.

4.3 Characterization of Cases

Characterizing each case example was completed using Boons et al. (2017)'s seven types of IS dynamics based on the actor motivations, establishment and storyline described by interviewees (Table 4).

Self Organization. The first dynamic is called Self-Organization, and it can be described as an IS that is initiated by industrial actors who see the economic/environmental value in symbiosis and therefore form partnerships and develop contracts for the sharing of resources (Boons et al., 2017). In Sweden, Stenungsund Chemical Cluster is a clear example of self-organization. With the polyethylene manufacturer as an anchor tenant, the Chemical Cluster in Stenungsund has developed organically around sharing resources and taking advantage of valuable side streams. This has been done in an entirely self-organized way, with little input from external organizations, researchers, or government funding. In Norrköping, with the active harbour on Händelö where many large industries gathered over the years, a similar dynamic of self-organization emerged in the early years of symbiosis. Companies saw the value in symbiosis, and many IS partnerships developed informally and organically on Händelö.

Organizational Boundary Change. This IS dynamic is unique to a situation where a firm integrates vertically and then breaks into subsidiary or separate companies where linkages remain after the split (Boons et al., 2017). The initial motivations inside the firm are eco-efficiency and finding value in waste as part of an internal business strategy. In Sweden, High Coast Innovation Park in the early years is an example of this dynamic. Most of the process companies in the Domsjö industrial area originated from the company Mo and Domsjö AB. This company broke into independent firms bought by different investors, but they saw the value in continuing to work together and collaborate despite being separate entities. The technology park began development with a focus on processing industry to attract investors and entrepreneurs to develop projects that were not necessarily the core business for any of the companies. It is not uncommon for people employed by one of the companies in the High Coast Innovation Park to move to another company which contributes to the strengthening of the bond between them. The companies are tied together through the original Mo and Domsjö AB, for practical resource sharing from the central pulp mill, but also through resourcing and collaboration that developed around the former company. This enables high success of resource sharing and examples of IS at what is known today as the High Coast Innovation Park.

Facilitation- brokerage. Facilitation through brokerage occurs when a third-party (e.g., public or private entity) establishes a market for IS development and actively engages industrial actors to develop symbiosis partnerships through the market system (Boons et al., 2017). In Sweden, the Paper Province forest industry cluster in Karlstad is an example of this type of brokerage facilitation. The Paper Province is a member-based third-party organization of 130 member companies. The Paper Province acts as a facilitator to the forestry sector in the region for the whole value sharing network. Only recently has the term IS been used in The Paper Province to describe resource sharing practices that were already present in the area. The Paper Province facilitates the collaboration of industry and researchers to discuss and investigate side streams that could be used in the region. In some cases, the mapping of possibilities is done and discussed with expert groups and companies with the side streams to develop suggestions for implementation. It also happens when a company will come to Paper Province with an idea about a particular side stream, and the Paper Province will help to facilitate and develop this idea. In this way, the Paper Province acts as a broker between and among industrial actors and researchers.

Another example of facilitation in Sweden is the Food Valley of Bjuv. The third-party in this case is a public government actor, the municipality of Bjuv. The municipality in this case has created a market for IS in Bjuv and acts as a broker with no stocks or ownership in any of the companies. They are working with companies to create connections and attract new business to the municipality. The municipality works as a matchmaker of IS, trying to create win-win situations between actors. In this way Bjuv facilitates stakeholders to create and build symbiosis based on a strong knowledge and relationships of the existing businesses.

I connect them with the right private stakeholders which I think they would gain for both of them a win-win- Interviewee Bjuv Municipality

Cleantech Östergötland can also be seen as a facilitator or broker of IS at Händelö. Since 2008, Cleantech Östergötland has been promoting the region's IS practices, driving development and defining it as a business practice (Baas, 2011).

Facilitation- collective learning. In this facilitation dynamic, a main facilitator learns about the IS concept and translates it to the local context to develop a collective learning processes (Boons et al., 2017). The initiator is a third-party organization who enables knowledge exchange and learning between the firms. Sotenäs Symbioscentrum is an example of facilitation of collective learning in Sweden. The Symbioscentrum was developed after the municipality learned about the IS concept through a study visit to Kalundborg Industrial Park in Denmark. Learnings were shared and all actors in the region were encouraged to be a part of the creation of the Symbioscentrum. In this case, the facilitator was a public actor, the municipality. The Symbioscentrum shares findings and results in yearly annual reports and tries to achieve active participation by all actors and stakeholders to strive for continuous improvement of the symbiosis based on learnings.

Pilot facilitation and dissemination. Pilot projects can also be used as a key IS dynamic. A facilitator will translate the IS concept to the local context and then select collocated industrial actors as an experimental site to learn from (Boons et al., 2017). In Malmö and Lidköping municipalities, pilot projects are used extensively partly due to the need for external funding. For example, IS in Malmö grew from the first projects that began back in 2012 that focused on the harbour area since there is a high density of industry, waste treatment, and energy production there. Originally, a large energy producer had a supply of residual heat that they were seeking external funding to find an efficient use for in the harbour. In this case, the harbour in Malmö became an experimental site to learn from and develop best practices and opportunities to

showcase and grow IS in the city. In Lidköping municipality, a small network of companies has rallied around projects related to IS. During the first pilot project in the region, 26 symbiosis possibilities were found in Lidköping, and the municipality is taking this results to develop strategic plans for symbiosis in the region.

Government planning. Public actors can also take the IS concept and include it into policies. Governments can develop IS linkages through policy instruments that stimulate or enforce IS (Boons et al., 2017). In Sweden, this type of dynamic has not yet been fully realized. For example, in the City of Malmö, Vision 2040 states their ambitions for increased circularity and bio-based industry at the port in Malmö by 2040. The idea here is to implement symbiosis to market Malmö as a site to expand urban and industrial symbiosis. The City of Malmö also has envisioned plans to use urban planning for promoting IS but has not yet pursued this outside of strategic documents. In Lidköping, the findings from previous pilot projects are envisioned to be included in different government priorities and portfolios such as energy planning.

Eco-cluster development. A more focused dynamic of IS is through eco-cluster development where local governments and/or industrial actors strategize to develop an eco-cluster. This is a participatory process which includes multiple stakeholders to develop symbiotic linkages to try to enable economic development in the region (Boons et al., 2017). Recent efforts have worked towards developing eco-clusters in Sweden. Sotenäs Symbioscentrum, Händelö Eco-Industrial Park, and High Coast Innovation Park are all examples of concerted efforts towards a common IS goal. However, each of these examples have developed in different ways. It can be argued that Sotenäs Symbioscentrum was always working within the eco-cluster dynamic of IS, however it began as more of a collective learning exercise, facilitated by the municipality. Over time- albeit quickly- the Symbioscentrum developed into an eco-cluster focused on innovation, research, and economic development for Sotenäs municipality. For the examples of both Händelö Eco-Industrial Park and High Coast Innovation Park, the shift towards eco-cluster development has happened over a longer period. Both networks have been long established, and mostly in a self-organized manner. Over time as more connections with external stakeholders and research organizations emerged, these networks have become more established in their self-created IS markets. The eco-clusters that have developed are being more widely communicated to attract and maintain economic development in the regions.

4.3.1 Shifting Dynamics

It is common for IS dynamics to evolve and shift overtime (Boons et al., 2017). One interesting shift that is displayed in Sweden is from self-organization towards facilitated collective learning since the learning can build off existing successful exchanges that have already matured (Boons et al., 2017). Broadly speaking, this implies that learning from mature IS can be an advantage for the further development and growth of IS in Sweden. This could mean a greater need and higher importance of collaboration, collective action, and facilitation of IS networks. For example, Händelö EIP has transformed from a self-organized conglomeration of industry near Norrköping to a facilitation model to more recently developing themselves as an establishing eco-cluster. The active harbour at Händelö offered industries a port for transport and a natural gathering point for developing an industrial area. The CHP plant that served Norrköping and surrounding areas acted as an anchor for the development of IS, and the bioethanol plant that moved onto the island in 2000 confirmed IS as a practice in Händelö. The bioethanol company positioned themselves there since it was geographically located near their raw material, a transport hub, and an energy source. This circular logic has continued at Händelö over the years while the paradigm has evolved. The next major step for Händelö was when Cleantech Östergötland established as a major facilitator to IS in 2008 (Baas, 2011). Out of this cooperation emerged the facilitation dynamic of IS. The two types of facilitation- brokerage and collective learning- can also shift back and forth where positive feedback mechanisms enhance learning

and brings forth more IS exchanges (Boons et al., 2017). Cleantech Östergötland is an external facilitator that works for the industrial actors on Händelö, creating a market for IS and building it into business practices. The next major dynamic transition occurred with the beginning of an EU level funded project in 2020. Cleantech Östergötland was the project leader and financed the 3-year project through European funds, membership fees from the actors, and some regional financing. The backing of financing allowed industrial actors to participate with minimal financial risk. The industrial actors involved in the project are the bioethanol factory, the CHP plant, who drive the IS as part of their core business. The public entities gathered in Händelö are Norrköping municipality, Norrköping port, and Nodra which covers water and waste. The sixth actor involved in the project is Linköping University. Connections to academia actors can increase the knowledge sharing within and across IS networks and has been responsible for initiating and actioning the growth potential of IS in many places. Händelö Eco-Industrial Park has since emerged as a new marketing of well-established practices, developing a motto as a "World-leading symbiosis between industry and city within bio-based and circular economy" (Händelö Eco-Industrial Park, 2023).

Table 4- The seven types of industrial symbiosis dynamics that can exist as characterized by the initial actors, motivations, storyline (adapted from Boons et al. 2017) with examples from Swedish IS cases.

Dynamic	**Initiators**	**Initial Motivations**	**The Typical Storyline**	**Examples from Sweden**
Self-organization	Industrial actor(s)	Economic and/or environmental benefits	Industrial actors see a benefit from symbiosis, find partners, and develop contracts	Stenungsund Chemical Cluster Händelö (early years)
Organizational boundary change	Industrial actor(s)	Eco-efficiency and business strategy	A firm integrates vertically in one location and then splits into separate entities with linkages and symbiosis remaining	Domsjö Industrial area (later the High Coast Innovation Park)
Facilitation-brokerage	Public or private third-party organization	Establish/increase transparency of market for IS development	A third-party sets up a brokerage system where they establish a market for IS development and actively engage industrial actors to develop symbiotic exchanges through the market system	Paper Province Food Valley of Bjuv
Facilitation-collective learning	Public or private third-party organization	Enable knowledge and experience exchanges between firms	A facilitator develops a collective learning process after learning about the IS concept, it is translated to the local context and learnings are fed back into future symbiotic exchanges	Sotenäs Symbioscentrum
Pilot facilitation and dissemination	Public or private third-party organization	Experiment from learnings of existing IS cases in a local context	A facilitator takes the IS concept and translates it into the regional context and then selects collocated industrial actors as an example case with learnings and best practices developed for uses elsewhere	Malmö Lidköping
Government planning	Government actor (s)	Learn from existing cases and implement in new context	A government actor takes the IS concept and includes it in policies and translated to the local/regional context, plans are made to develop linkages through stimulating or enforcing those policy instruments and progress of policy implementation is monitored and evaluated	Malmö (envisioned) Lidköping (envisioned)
Eco-cluster development	Governmental and/or industrial actors	Innovation and economic development	Local governments and/or industrial actors develop a strategy to create an eco-cluster and participatory processes among multiple stakeholders are used to develop symbiotic linkages as part of a broader agenda for economic development	Sotenäs Symbioscentrum High Coast Innovation Park (recently)

4.4 Interaction with External Actors

This section will summarize how each IS network within the study are interacting with external actors. External actors are described as stakeholders who are not directly involved in the IS (i.e., they are not tenants of the IS network). The aim is to understand better which external actors are involved, which perspectives are prioritized, and how these interactions are occurring. The key external stakeholder group for each case example is displayed in bold to indicate their key position in the stakeholder network.

4.4.1 Paper Province in Karlstad

External Stakeholder Involvement from: **industry**, universities

Paper Province connects private actors well through membership as a forest industry cluster network. There have been partnerships with universities to work on trying to connect more consciously to municipal actors. They recognize the need to work cross-sector in the field of IS and bioeconomy innovation but are mainly forestry based. When it comes to interacting with the local community level, Paper Province recognizes the need to engage more. Public engagement is an area that has not been as advanced in the cluster network. Recent EU-level funded research has found that working with civil society is an important part of responsible research and innovation that Paper Province can improve on. When Paper Province is trying to develop a new project, they will typically engage private actors and researchers in workshops and then engage with municipalities only in later stages of the projects. Bringing together actors with side streams and experts is an important part of how Paper Province develops IS partnerships with stakeholders.

4.4.2 Sotenäs Symbioscentrum

External Stakeholder Involvement from: industry, universities, **government**

Sotenäs is a unique example of an IS network that actively tries to engage many groups of stakeholders. For example, during the development stage of a new IS synergy, the municipality uses the multi-helix model to attempt to bring together businesses, doers, regulators, and researchers. This all starts with the industry actors, who Sotenäs engages through joint meetings with different companies, study visits, and project collaborations. The companies are also interacting with each other, not just the municipality as the facilitator. Study visits and seminars are sometimes planned to connect companies to learn from each other and build strategic partnerships.

The knowledge actors like universities and academia are a key component to development at Sotenäs because the municipality acknowledges the limits to their capacity and resources. Knowledge symbiosis becomes an exceptional way that the Symbioscentrum brings IS into the 21st century. Several universities are involved in ongoing projects and actively involved in the network at the Symbioscentrum. According to the municipality, collaborating with multiple actors can increase the complexity of a project, but the outcome becomes more valuable. The municipality also engages with other levels of government for collaborative projects and networking, with some authorities acting as financers in the IS network.

"It's really a value to have different actors in the project with different perspectives on the challenges and opportunities"- Interviewee from Sotenäs Symbioscentrum

Bringing in community stakeholders into the industrial symbiosis development at Sotenäs has proven to be difficult in the beginning, with members of the public not understanding their

role in the process. However, political support of the project has led to a better understanding of the value of the project. The benefits of the Symbioscentrum are reported yearly to justify the value it has for the region and that, among other benefits, it provides green jobs, inspires innovation, and puts the municipality on the map. The report summarizes what value the Symbioscentrum created each year, and why it is important to continue working with IS. Although it takes time to collate and summarize this information from the diverse group of actors, having the internal tracking and external communication has proven important to the success of Sotenäs Symbioscentrum. The public is also invited to many presentations held at the Symbioscentrum, and Sotenäs as the municipality is always trying to better understand how they can create value for the general public as a strong stakeholder and beneficiary.

4.4.3 Händelö Eco-Industrial Park

External Stakeholder Involvement from: **industry**, universities, government

Since Händelö EIP began to develop as a more organized IS network, it has been of high importance to communicate and showcase the benefits of collaboration between industries. This is done through opening up Händelö EIP for visitors and tours to anyone from anywhere who wants to learn more about the innovation that is happening. This has gained interest from ministers, EU ambassadors, and other international visitors. The international interest in Händelö EIP comes from its innovative resource use, renewable energies and unique end products that are created there. In this way, Händelö has been a leader in communicating the benefits of IS to many external groups from inside and outside of Sweden. Händelö has also engaged directly with researchers at Linköping University acting as a key actor in IS project development. Knowledge sharing with academia has created value for the IS projects at Händelö which has helped maintain interest and excitement from the private actors. Although the municipality is an actor in the IS projects, engaging the municipality in the benefits of IS for the region has been a challenge. Cleantech Östergötland as the facilitator understands the opportunity IS has to attract new businesses to the region, however they have not been able to successfully engage with all actors about the benefits that it could offer to the region.

"The industrial actors will be easier because I feel that they get a lot of benefit. But the other actors are just as important, but not that obvious what they really get out of the time they sit there. But I think they see the benefit by actually reaching the other type of entities that they need to have contact with."- Interviewee from Cleantech Östergötland

4.4.4 Malmö

External Stakeholder Involvement from: industry, universities, **government**

The city of Malmö has been facilitating IS projects with different actor groups since 2012. The connections to academia and research institutions have been well developed, with Linköping University and Sustainable Business Hub. In addition, Malmö has been a part of EU level projects with international partners outside of Sweden. The city sees a lot of potential in networks of research, for example the newly launched National Centre for Industrial Urban Symbiosis that the Research Institute of Sweden (RI.SE) has kickstarted. Most of the partnerships that Malmö has developed with external actors have been associated with official projects, where actors are working together towards specific goals.

"Along the way, you saw new opportunities, so it's kind of a snowball effect. [Opportunities for developing IS] gains momentum over time once you get the right people in the room" -City of Malmö Interviewee

The City of Malmö has an interest in the citizens and broader community and has indirectly been involved in the operation of education programs and pilot projects that are focused on bringing the community together for circular sustainability goals. For example, one pilot project involved a local recycling centre combined with a community café and flea market that acted as a meeting place for social activities and education. Innovation competitions have also been used to stimulate innovative ideas from the community to for example utilize residual heat from industry. However, interaction with civil society directly related to IS in Malmö is limited to mostly waste management actors, but indirectly they keep citizens in mind when developing projects.

"We don't have any direct involvement with the citizens, but they're the end benefactors of these things. For instance, one very obvious thing is that they use their heat in their homes and so on. Or the busses get maybe get gas from biofuel."- City of Malmö Interviewee

4.4.5 Lidköping

External Stakeholder Involvement from: industry, universities, **government**

Lidköping is a small municipality that has built on historical symbiosis partnerships in a more informal way until recently. The recent projects that have been externally financed have really initiated communication between different actor groups. The politicians and people working within the municipality have shown an increased interest based on the value provided by these projects. Lidköping has communicated with Linköping University for almost ten years, with the push for initiating a project coming from a key researcher who had seen the potential in the municipality for IS since at least 2012. The main challenge at the municipality is prioritizing IS in the region, and having decision-makers on board to continue projects that expand the network in Lidköping. In addition, different departments within the municipality are working with IS, and coordinating siloed government groups can be difficult. The scale of IS in Lidköping is still small, but there exists high potential for new partnerships in the future and the municipality is continuing its effort to grow their network.

4.4.6 Food Valley of Bjuv

External Stakeholder Involvement from: **industry**, universities, municipality

Bjuv municipality has a history of working closely with academia to develop innovation and business designs. Food Valley of Bjuv keeps high transparency of business operations and decisions as a key priority for integrating stakeholders. They inform, arrange study visits, and collaborate closely with stakeholders to communicate the benefits of the IS network. The focus of the IS network is to bring more business into the region, so transparency with the region is important to these practices being conducted smoothly. The facilitator role that the municipality takes also allows for the connection and mutual exchange of benefits between industrial actors and research institutions. Bjuv municipality tries to collaborate with official institutions like universities to join important projects and increase private actor engagement in research. This can benefit the industrial actors through increased knowledge and innovation, and it can benefit the researchers by having access to private companies to implement their research. Food Valley of Bjuv operates under an informal policy that "*Anyone with a good idea is welcome to bring their contribution to the table*" (Bjuv Municipality Interviewee). Bjuv has also played a role setting up education programs in schools about IS and the food and energy industries involved in IS in the municipality.

4.4.7 Stenungsund

External Stakeholder Involvement from: **industry,** universities, municipality

Stenungsund chemical cluster is an example of an IS network which operates almost exclusively between the industrial companies. The companies themselves meet independently of other stakeholders to develop partnerships and contracts between industrial actors. Projects have been initiated by different industrial actors based on specific needs or availability of resources, to find solutions for joint infrastructure and resource sharing. However, in the examples given by the interviewee of IS at Stenungsund, the connections with stakeholders like municipalities, the local community, or research institutions was minimal. Follow up questions were sent to the interviewee to get a clearer picture of the interactions with stakeholders, and more details were received. The engagement with industry and businesses is core to collaboration in IS projects and in Stenungsund they work with different sizes of companies including SMEs and startups to collaborate, learn and have a common interest. Stenungsund engaged with the regional government to obtain financial support and support at the national level. The local municipality also engaged with the IS network through arranging meetings on the local and sometimes EU level to communicate the benefits of IS and create positive political conditions for the chemical industry. Stakeholder engagement with government and political leaders is critical to get the right policy environment for the transition the chemical industry. Engaging with the government during the permitting stage of project design is also critical to ensure the right permissions are received. Stenungsund has also worked with universities to develop technical tools for energy efficiency and plastic recycling. The university collaborations offer Stenungsund the opportunity to study how the transition to bio-based and recycled materials can be done. Stenungsund has also communicated with civil society through non-profit organizations about why the chemical industry will play a role in the transition from raw materials to bio-based and recycled materials. This also involved public meetings in Stenungsund to communicate how the chemical industry can be a key player for the transition to net zero. However the interaction with external stakeholders has not directly covered the IS.

4.4.8 High Coast Innovation Park

External Stakeholder Involvement from: industry, **universities**

The High Coast Innovation Park, previously Domsjö Industrial Park, has been closely tied to research institutions for many years. One of the state-owned research institutes which was later integrated into RI.SE was the owner of 60% of Processum shares in 2015-16. Processum as a subsidiary of RI.SE and the facilitator of the industrial park has therefore had access to many contacts and knowledge from the research institutions in Sweden. Processum also concentrated on two main areas, biochemistry and chemistry, which allowed them to hire very skilled scientists and invest in laboratory equipment and resources to conduct very focused research. Many high-level and often international academics have been drawn to Processum as a research hub, with partners in Finland and Norway. Processum is also an advocate of involving external partners in running projects at the innovation park. The members of Processum have organized meetings, invite speakers and organize seminars to keep linkages between the companies of the network. The network also aims to work with the three clover approach of including the public sector, academia, and industry (not just IS tenants). For example, they include waste management companies to investigate how to create value from waste in the region. The regulators have been involved on the national and municipal level as well, supporting and contributing financing for projects. Funding from government has meant pilot projects have been able to take successful laboratory results further to commercialization,

making Processum a forward moving innovation system. The rebranding of Domsjö Industrial Area to High Coast Innovation Park has been a way to increase international visibility and credibility and increase engagement with other partners in the future.

4.4.9 The Quadruple Helix of IS in Sweden

The integration of the four major actor groups (industrial actors, businesses; public actors, government; research institutes, universities; and community, civil society) is different for each IS network (Figure 4). On one corner of the diagram, there is Stenungsund chemical cluster which has a long history of industrial actors working together to create IS connections- long before it was labelled as such. The network operates independently of many external stakeholders or influence, with engagement with researchers limited to technical studies and municipalities limited to political interactions. There are also several IS networks in Sweden that operate closely with researchers but lack connections to other stakeholders. Closer to the centre, you have a network like Sotenäs Symbioscentrum which has emerged more recently with more intentionality around engaging different actor groups from the beginning. This IS network has made an active effort to integrate the ideas and perspectives of different stakeholder to create the highest value for the region. IS networks that have been facilitated or organized by municipalities often engage a higher number of stakeholders. External facilitators that are member-based are another way IS networks are bringing together interested parties to develop IS projects. Overall, the interaction with communities and civil society is limited to informing the general public through reporting, presentations, and study visits.

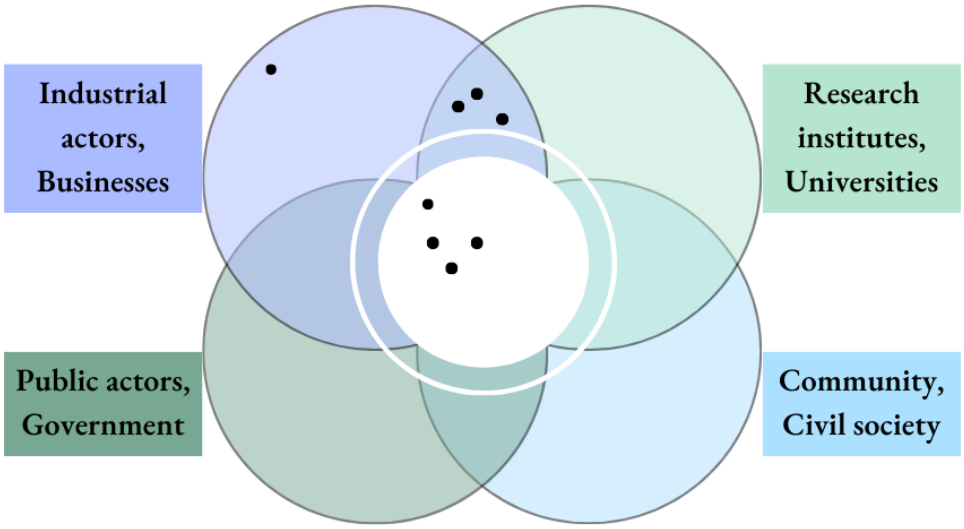

Figure 4- The quadruple helix model of stakeholder engagement including industrial actors and businesses; research institutes and universities; public actors including government; and the local community and civil society. The eight case examples of industrial symbiosis in Sweden have been plotted on the graphic according to how they interact with each of the four major stakeholder groups.

4.4.10 Motivations for External Stakeholder Interaction

It is clear from interviews with different IS networks across Sweden that the cooperation between different actors gives the best results, with the development of symbiosis depending on the participation of many different actor groups. The facilitators of each IS network had different motivations for initially engaging with each group of stakeholders, but there was high alignment in the benefits that each group produced for the IS network overall.

Industry actors and companies

The industrial actors are critical to creating symbiosis. These stakeholders are therefore crucial to engage with to implement IS. Industrial actors have access to large amounts of resources and sometimes financing, and there is a lot of potential to include them during the IS development process. Industrial actors and companies are included in projects to understand how they can collaborate, learn from each other, and develop a common interest in IS. Many IS facilitators work to bring SME companies and smaller scale startups into such projects since without this it would be difficult to bring them into collaborations with big companies on their own.

Public actors and government

IS networks are dependent in a lot of ways on public actors and government. In some cases, municipalities are the facilitators of IS in their regions, and they are engaged as project leaders and information brokers. Internally, these municipalities can share knowledge and opportunities for symbiosis and showcase good examples of how systems changes can occur. Many municipal companies (e.g., waste management, water management) are active in symbiosis networks. Many IS networks also engage nationally with the government to pressure legislative and regulative changes that promote circular economy and IS policies. Creating the right conditions for the transition to a more circular economy is important to the success of IS. Authorities and public actors have larger mandates and must focus on increasing the benefit for their region, and this is important at many stages of IS development. Municipalities are also critical actors when it comes to getting the right permissions to develop an IS project. Municipalities can arrange meetings with key stakeholders, communicate the right political conditions needed to develop IS, and bring regional concerns to other levels of government. Different levels of government are also engaged in many IS networks to gain financial support and funding for different projects and ongoing work.

Research institutes and universities

Research institutions and universities that are working on IS in Sweden are numerous. These actors act as an important link and knowledge carrier for the public sector and businesses to promote and develop valuable symbiosis. Researchers and academics are integrated into many IS projects that are conducted in Sweden. They can bring funding and knowledge to build studies on *how* the transition towards a more circular economy can be done. For example, the energy IS in the Stenungsund cluster worked with Chalmers University to develop a tool to determine the most effective way to use excess heat from another plant. Connections with universities also give IS networks access to student resources for capstone and thesis projects which provide mutual benefit for both the industries and the students. The industrial actors are the participants in many of these studies, which create collaboration and an understanding of the opportunities that exist within the concept of IS. Research institutes fill a gap that companies and public actors cannot fill where expertise and knowledge are needed. Researchers have also acted as the link between individual IS networks by sharing knowledge, exciting findings, technologies and processes to inspire the whole IS network of Sweden.

Local community and civil society

In Sweden, the local community and civil society is viewed most prominently from the market perspective. Without civil society and the demand for circular services and products, the foundation for a circular economy and IS does not exist. In some cases, civil society is engaged

through networks of non-profit organizations to communicate to a broader range of stakeholders about the importance of a circular economy. In cases where municipalities are facilitating the IS, the greater mandate to serve the public, so the connection to the community may be stronger in those cases. Making the public feel included in the value chain of an IS network, spreading knowledge, inspiring innovation, and raising awareness are key ways that IS facilitators can engage civil society.

4.5 Benefits of Industrial Symbiosis

Through interviews and survey results, the benefits of IS were assessed. The benefits from the eight interviewees were validated further through survey results. Firstly, the major benefits as perceived by the eight interviewees is summarized in the below section. The following section describes the results of the survey that was conducted on stakeholders of IS networks in Sweden.

4.5.1 Facilitator Perspectives of IS Value

The facilitators of the eight IS case examples were interviewed on their perceptions of the major value and benefits that are gained from the IS network that they are affiliated with. The major themes are described below, but it is important to note that each interviewee identified specific benefits in addition to these generalized ones, and this varied across sites. Three major values were identified by multiple IS case examples in Sweden:

1. IS can attract new business to the region.
2. IS gives businesses an opportunity to develop new business practices in a future-proof and sustainable way.
3. IS builds networks for collaboration, knowledge sharing, and innovation.

IS can attract new business to the region.

IS networks in Sweden are often located near industrial hubs, in either urban or rural settings. One of the major benefits of having an IS network is attracting new businesses and therefore sustainable employment to the region. Mentioned by multiple interviewees was the way IS offers green jobs and economic value for the region. This can be of interest to municipalities and particularly politicians that can highlight the economic growth and innovation happening within their constituency. Regions with IS can emphasize their capacity for technical services, collaboration with industries and other infrastructure that can attract businesses and outcompete other locations. The establishment of these businesses is important for long-term job security and growth of the regions.

IS gives businesses an opportunity to develop new business practices in a future-proof and sustainable way.

IS also offers businesses, municipalities, and industrial actors the opportunity to develop in a future proof and sustainable way that they can be proud of. Principles of the circular economy and sustainable development were mentioned by interviewees that consider IS as a direction that companies can strive towards for more sustainable business. Global business risks such as increasing energy prices, political instability, and scarcity of materials were also mentioned as motivations for companies to use resources differently. The move towards a no-waste and resource-efficient society to become more resilient to these risks is becoming increasingly important. In response to the climate crisis, many businesses want to show that they are part of the solution, through IS and reorienting towards a circular economy. Industrial and Urban

Symbiosis has come up as a solution to future-proof businesses. These changes act as a signal externally to customers but also internally to attract and keep good talent and be seen as an attractive employer. At the municipality level, climate goals are also a motivator to achieve net-zero and IS is one possibility to move closer to these ambitions.

IS builds networks for collaboration, knowledge sharing, and innovation.

IS networks bring together a lot of actors that would not traditionally work together. The frequency of meetings and networking allows for knowledge exchange that can be valuable to individual actors and the network as a whole. This collaboration between actors creates innovation that can create value for the region. Many of the IS networks in Sweden (e.g., High Coast Innovation Park, The Paper Province) are based around more specific goals and industries, making them hotspots for innovation and experimentation. For example, the High Coast Innovation Park creates value with its comprehensive knowledge about bio-refining. The roots of the Innovation Park are based in traditional pulp and paper making, but the competence, technical opportunities, network, and infrastructure built around fiber industries creates a level of expertise around the IS that is unique to the region. The network itself also involves resource sharing and collaboration, where members can work together towards common goals.

The benefits offered by IS are diverse and are perceived differently from different stakeholder groups.

The diversity of benefits offered by IS networks was another common theme from interviewees. Identifying the main value proposition of their IS network was a challenge for many and they emphasized that there are so many benefits coming out of them. The benefits are also perceived differently by different actors. The benefits perceived by different actors depends on their core business. Some actors will also have a more idealist view where the environmental and social benefits of an initiative are worth a higher economic cost, however other actors will put economic value as a higher priority.

"I would say if you ask the different six [IS project] actors, you will get six different answers."- Händelö interviewee

Many industrial actors for example feel they get a lot of benefit from the economic perspective. Many of the companies involved in the IS networks in Sweden are attracted to the economic benefits and the business case for IS connections. The pipeline system between companies sharing by-products also brings economic benefits of increased revenues from new products, reduced waste management costs, and potentially economically beneficial partnerships. Some actors are quite familiar with the benefits of IS and will invest more time and resources into making it happen, while others recognize primarily the economic benefit.

"There are always idealists that want to do the absolutely the best thing and then it can cost a bit extra and they can put aside the time and effort to find these residual streams. But I think for others it's just pure business, I would say."- Malmö interviewee

It was also noted that in many cases of IS in Sweden, the benefit of the network is not obvious to all actors. There exists a gap in understanding of the benefits across stakeholder groups, and it can be challenging to communicate the value to some groups.

4.5.2 Stakeholder Perspectives of IS Value

The survey that was distributed to stakeholders of IS in Sweden asked respondents to rank the importance of specified benefits of IS. The survey received 12 responses from four actor groups (Figure 5). Participants in the survey were associated with seven of the eight case examples: High Coast Innovation Park, Paper Province, IS in the City of Malmö, Sotenäs Symbioscentrum, Händelö Eco-Industrial Park, IS in Lidköping, and Stenungsund Chemical Cluster. There were no survey responses from the Bjuv IS case example. Many respondents to the survey were associated with more than one project, particularly those that identified as external actors (e.g., researchers). One key actor identified involvement on six IS networks in Sweden, and four other actors were involved in two or more. One of the actors that had been involved in more than one IS network was a private actor from a large electricity provider, but the other associated with multiple networks were all researchers.

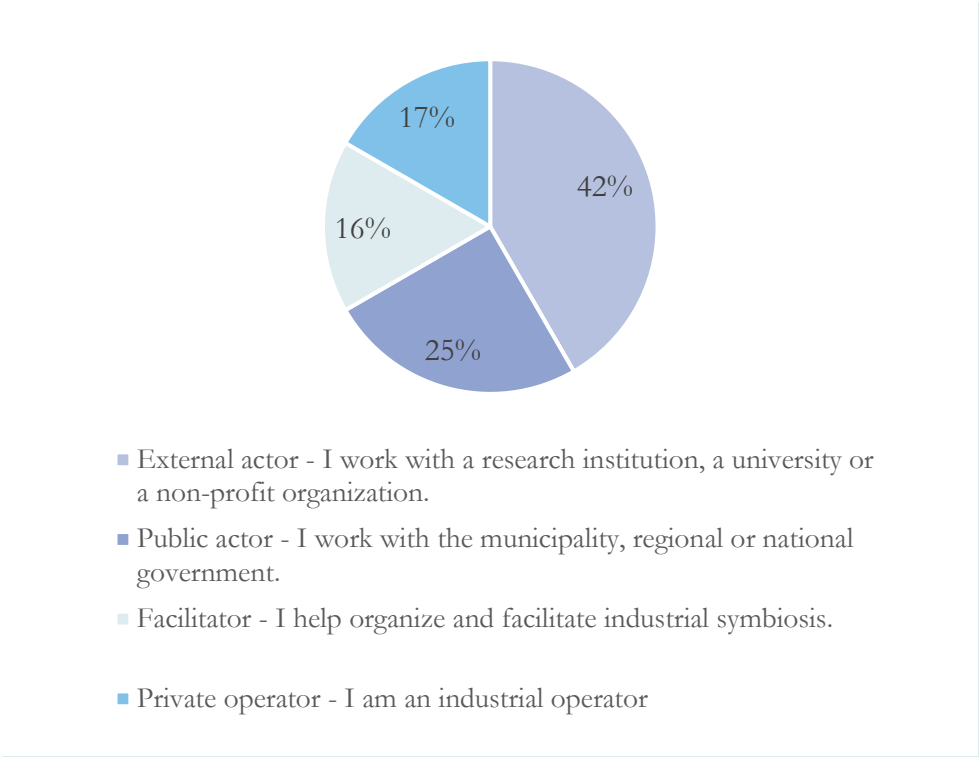

Figure 5- Distribution of survey respondents from four major actor groups, as identified by the respondent.

The survey results were analyzed for alignment on the importance of different benefit statements for three benefit types (Table 5). When 7 or more of the 12 respondents identified a certain benefit statement as high or very high importance, the statement was categorized as Aligned High Importance, and when 7 or more identified it as no, low, or not present importance, it was identified as Aligned Low Importance. When there was no alignment on the importance of a benefit statement across responses, the statement was categorized as Mixed Results. Statements that had the same importance score are presented together as the same ranking.

Table 5- Ranking the importance of the economic, environmental, and social benefits offered by IS based on responses from stakeholders across Sweden.

Benefit Type	Aligned High Importance (>50% alignment)	Aligned Low Importance (>50% alignment)	Mixed Results
Economic	1. My IS network leads to economic growth for my region or community 2. My IS network leads to a competitive advantage for me or my company 3. My IS network leads to higher levels of employment for my region or community 4. My IS network leads to higher revenues for me or my company		My IS network increases the material efficiency for me or my company My IS network increases the energy efficiency for me or my company My IS network reduces costs for me or my company
Environmental	1. My IS network reduces the impacts of climate change by reducing atmospheric CO_2 or other greenhouse gases	1. My IS network limits ozone depletion or reduces the use of ozone-depleting substances	My IS network reduces chemical pollution and hazardous waste My IS network reduces biodiversity loss and extinction of species My IS network reduces acidification effects My IS network impacts the way land is used or converted My IS network reduces impacts from biogeochemical flows such as nutrients like phosphorus and nitrogen My IS network reduces freshwater use or has a positive benefit on water quality My IS network reduces particulate matter in the atmosphere
Social	1. My IS network provides increased income and/or job opportunities to me and/or my community 2/3. My IS network improves knowledge and education including learning, training, innovation or skill building for me and/or my community 2/3. My IS network has increased my or my community's network in which we work, share, and cooperate 4. My IS network provides equal opportunity for all genders 5/6. My IS network has increased my community's engagement and participation 5/6. My IS network provides equal opportunity for all individuals	1. My IS network has improved justice through workers' rights and other means	My IS network improves the water supply or sanitation for me and/or my community My IS network improves food security and food supply for me and/or my community My IS network improves the physical, mental, and social well-being of me and/or my community My IS network has a benefit for housing, living costs, or residential comfort My IS network has increased energy access for individuals and/or households My IS network has increased peace and/or regional identity in my community

Going into more detail for each of the three categories, Figure 6 was created to display and compare the Aligned High Importance Benefits across the three categories of benefits. Figure 7 displays the Mixed Results where there was less alignment on the importance of the benefits. For the Aligned Low Importance, these statements are described in the text but no figure was created because only two existed- ozone depletion and improved justice.

Economic Benefits

From the perspective of economic value that IS brings to regions and communities, four out of the seven benefits were perceived by most respondents as important or very important:

1. My IS network leads to economic growth for my region or community
2. My IS network leads to a competitive advantage for me or my company
3. My IS network leads to higher levels of employment for my region or community
4. My IS network leads to higher revenues for me or my company

The highest alignment came from the statement "My IS network leads to economic growth for my region or community", with 10 of 12 respondents agreeing that this benefit was highly important or very highly important. It is clear that the economic growth brought to regions by introducing IS is a major and noticeable benefit. The statement about IS bringing a competitive advantage also had high alignment on its importance with 9 of 12 respondents agreeing that it held high or very high importance. The statements on higher levels of employment and higher revenues also fetched high alignment with 7 of 12 respondents agreeing on its high importance for both statements (Figure 6).

Interestingly, the remaining three economic benefit statements drew mixed results: My IS network increases the material efficiency for me or my company; My IS network increases the energy efficiency for me or my company; and My IS network reduces costs for me or my company (Figure 7).

Environmental Benefits

Only one of the nine environmental benefits, based on planetary boundaries, was perceived as highly important by most of the stakeholders who took the survey:

1. My IS network reduces the impacts of climate change by reducing atmospheric CO_2 or other greenhouse gases

Nine out of twelve respondents ranked the statement about reducing the impacts of climate change as high or very high importance. The remaining three respondents ranked this statement as neutral importance (Figure 6). The statement "My IS network limits ozone depletion or reduces the use of ozone-depleting substances" received the lowest importance rating, with seven respondents saying it had no/low importance or that the benefit did not exist for there is. However, a few did mention that it was high or very high importance, making this alignment quite low. All the other environmental benefit statements had mixed results of importance with some stakeholders identifying some benefits as important and others not (Figure 7).

Social Benefits

Six of the statements about the social benefits of IS received high alignment from the stakeholders that took the survey that they had high or very high importance (Figure 6):

1. My IS network provides increased income and/or job opportunities to me and/or my community
2/3. My IS network improves knowledge and education including learning, training, innovation or skill building for me and/or my community
2/3. My IS network has increased my or my community's network in which we work, share, and cooperate
4. My IS network provides equal opportunity for all genders
5/6. My IS network has increased my community's engagement and participation
5/6. My IS network provides equal opportunity for all individuals

The top social benefit that received the highest alignment on high importance was about increased income and job opportunities for the community. 11 of the 12 respondents said this statement was of high or very high importance to them. Two of the next highly relevant benefit statements were about improved knowledge and innovation and increased community networking. Both statements were ranked as high or very high importance from 10 of the 12 respondents. In addition, statements about IS networks offering equal opportunities for all genders and individuals were viewed as important and relevant by the respondents. Overall, it was also important to respondents that their IS network increased community engagement and participation. Only one statement was aligned as having low or no importance- "My IS network has improved justice through workers' rights and other means", with no respondents ranking it as important. The remaining social benefit statements received mixed results depending on the individual respondent (Figure 7).

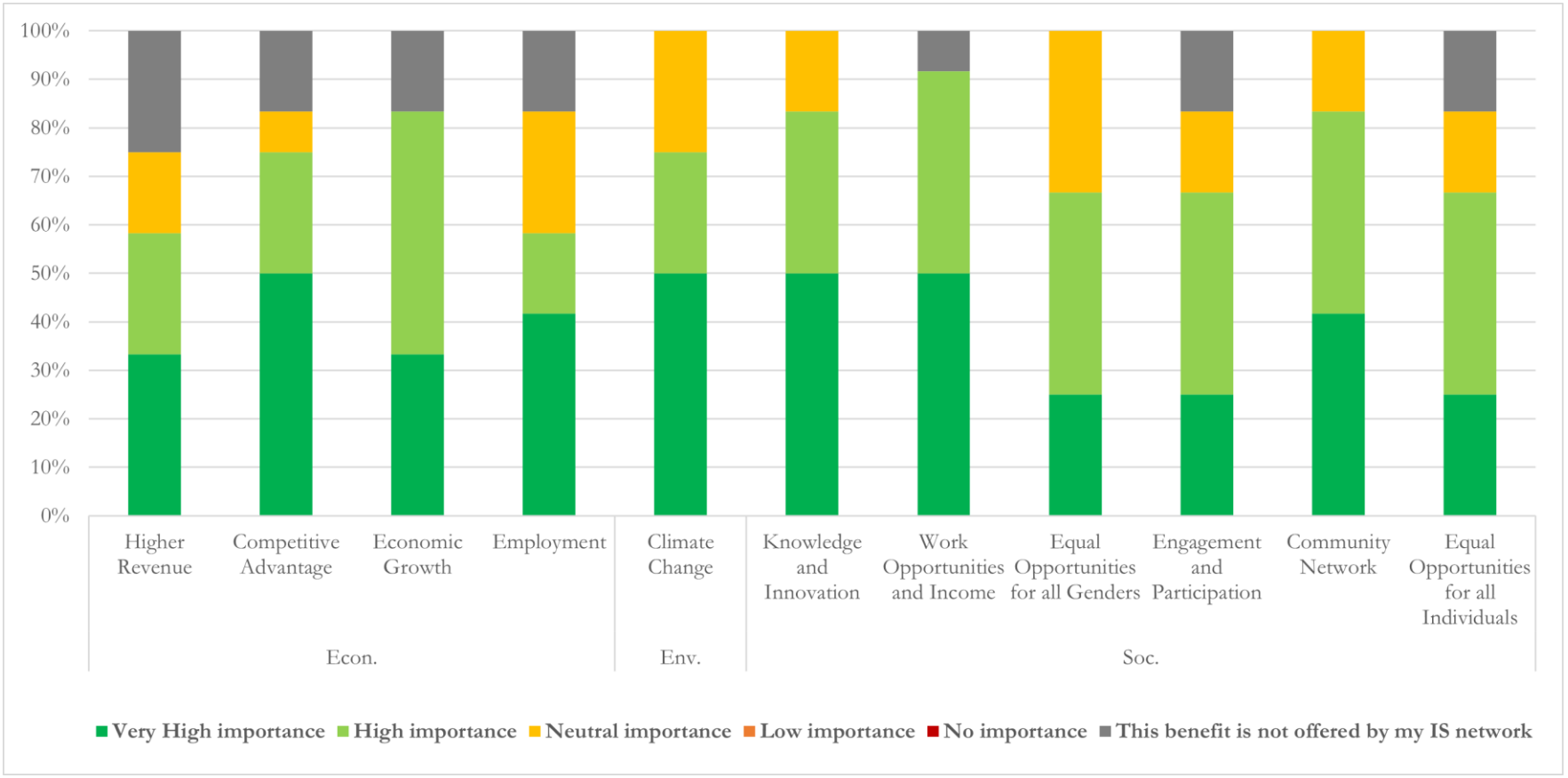

Figure 6- High Aligned Importance Benefits of IS from the survey results of the perceived levels of importance displayed for each benefit of IS for economic, environmental, and social categories.

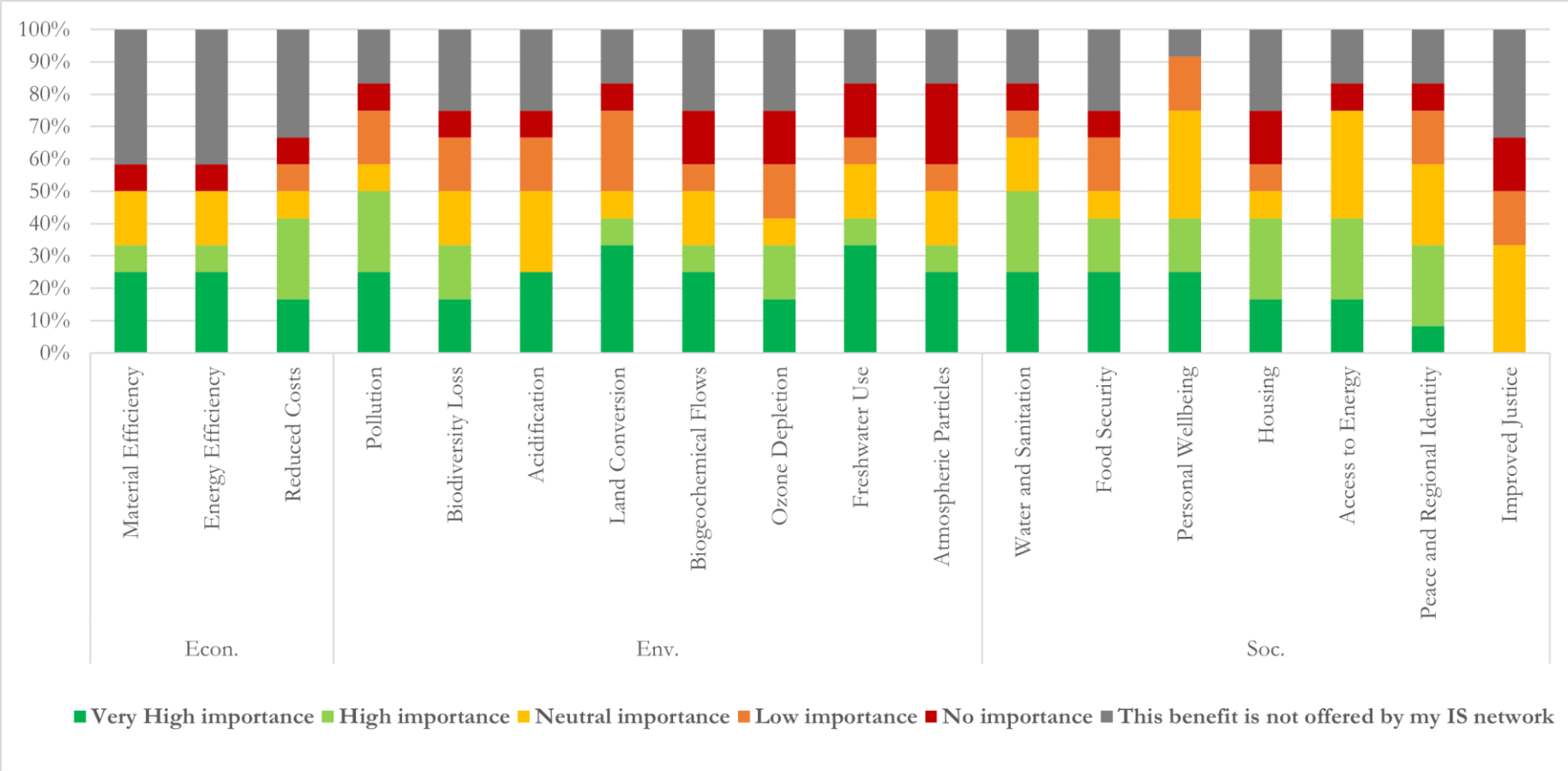

Figure 7- Mixed Results Benefits of IS from the survey results of the perceived levels of importance displayed for each benefit of IS for economic, environmental, and social categories.

5 Discussion

This section will present the results in the context of previous research and existing literature. Section 5.1 and 5.2 will address RQ1, Internal Organization, and External Stakeholder Interactions of IS networks in Sweden and Section 5.3 will address RQ2, the Perceived Benefits of IS by Stakeholders in Sweden. Section 5.4 will address the limitations of the data and results.

5.1 Internal Organization of IS in Sweden

5.1.1 Origins of IS in Sweden

The way IS networks are organized varies across different locations, motivations and have changed and evolved over time. In Sweden, many IS networks have emerged from self-organization dynamics of IS. One reason for this is the long history of CHP and district heating in Sweden which started the circular mindset of recycling waste streams and seeing waste as a resource (Domenech et al., 2019). The unplanned IS links in Sweden are often based on business cases and relationship building between companies in close proximity. Unplanned IS ecosystems are initiated by private actors who decide that exchanging resources has benefits like cost reduction, revenue, business expansion, with no conscious effort to form an IS network (Chertow, 2007). Self-organized local IS in Sweden linked to manufacturing industrial clusters emerged from a high level of environmental responsibility driven by companies' license to operate in Sweden, often with support from local governments (Domenech et al., 2019). District heating can be considered a driving force of symbiotic relationships in Sweden. Of the eight cases studied, seven have some form of district heating involved in their IS operations. The one exception from the case examples is Sotenäs Symbioscentrum which has no district heating connected to its symbiosis network. The Symbioscentrum was driven by the desire to build the regional economy in a sustainable way while addressing the region's unique challenges. The challenge that brought IS to life at the Symbioscentrum was related to the ability to treat process water from three local fish processing companies. It was out of this challenge that a solution to build a biogas plant alongside a wastewater treatment plant to produce electricity and heat, and fertilizer for local farms (Mirata, 2018). In the end, the solutions at Symbioscentrum did create symbiosis around electricity and heat production, however this was not the starting point, and the outputs are used exclusively by the industries that produce it rather than the typical Swedish district heating model. This more recent IS network established outside of the traditional district heating model may indicate a shift towards a higher knowledge about the possibilities of IS in the country.

5.1.2 Pilot Projects to Overcome Barriers

Many IS networks use projects to engage different actor groups in IS to collaborate towards a common objective. Of the seven dynamics of IS described by Boons et al. (2017), pilot project facilitation is common in IS networks across Sweden. Overall, project based IS work can create benefits for all actors involved and help overcome many barriers to IS. The major benefits of initiating a project around IS in an existing network were determined through the case examples and can be described in Figure 8. Pilot projects can help companies and facilitators to overcome barriers to the implementation of IS.

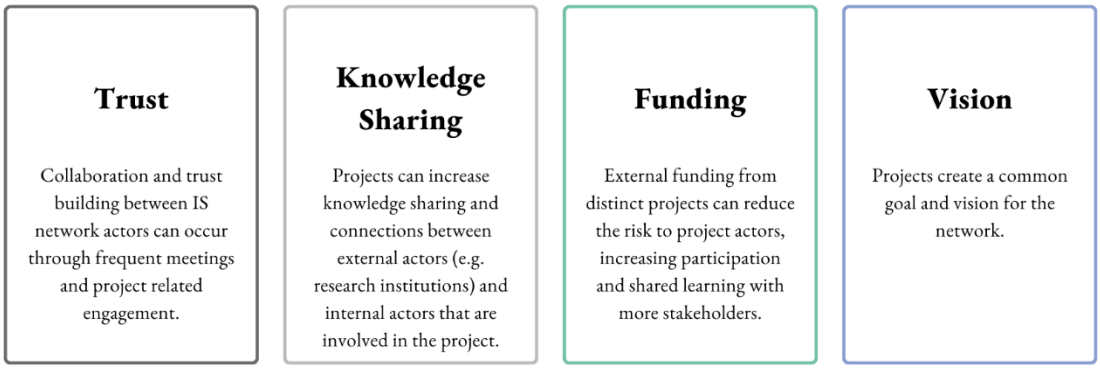

Figure 8- Based on interviews from case examples across Sweden, four major values of project-based work within existing industrial symbiosis networks were identified in this research.

Trust between actors is gained through collaboration during pilot projects. Frequent meetings and project related work can overcome social barriers related to information sharing, cooperation and trust between key players that are needed to develop synergies (Golev et al., 2015). Projects also increase knowledge sharing and connections between external actors like researchers. Involving research organizations can help to overcome technical barriers about logistical and technical knowledge (Golev et al., 2015), which is a common occurrence in IS pilot projects across Sweden. Pilot projects also frequently come with external funding. This can reduce the risk to project actors and therefore get more companies on board to advance IS. Lack of funding and investment from private or public sources is a major financial barrier (Fichtner et al., 2005; Henriques et al., 2021) which pilot projects can help overcome. Lastly, pilot projects can create a common vision for an existing IS network where one did not exist before. For example, the EU-funded project for Händelö Eco-Industrial Park created a large work package on developing a common vision. This can overcome challenges around lack of engagement, but also bring actors into a more active role. For successful IS implementation, active company participation is an important element (Heeres et al., 2004). Pilot projects therefore play a huge role in overcoming information barriers, such as lack of understanding of the IS concepts, lack of information sharing, and lack of facilitation capacity (Södergren & Palm, 2021b). Pilot projects can also bring about new opportunities to test new technologies, facilitators, and processes, leading to further innovation potential. Collective problem definition, solution discovery, and enhanced learning through collaboration can greatly enhance innovation in IS (Mirata & Emtairah, 2005). However, there is a need to explore the continuity of IS once a project comes to an end, a concern that was expressed by multiple facilitators of IS in Sweden. Without a growth in established IS strategies, government policies, and long-term planning of IS in Sweden, it will be difficult for these networks to be sustainable and for these collaborations to continue into the future.

5.1.3 Towards a Holistic IS in Sweden

The evolution of IS networks in Sweden is apparent, as they have undergone a shift over time, becoming more organized and attracting a greater number of actors who are increasingly aware of the benefits of IS. The recognition of the need for cross-sector collaboration in IS has brought together a wider range of stakeholders including knowledge actors and governments creating a more interdisciplinary approach drawing from a wider range of expertise. It is common for a given IS network to display one dynamic for a certain time and then shift to a new dynamic (Boons et al., 2017), and it is clear that this is developing across Sweden. Although many IS networks in Sweden emerged from unplanned business cases for improved material efficiency and seeing the value of side streams, many have since seen greater value in other

aspects of IS. As more actors become more involved in IS in Sweden, the dynamic they use will change and different perspectives will be brought to the discussion. For example, municipalities have often led projects related to IS, like Malmö and Lidköping municipalities. The learnings of IS projects in both municipalities are envisioned to guide the municipal policy to develop policy tools that can enable IS in the region, therefore shifting the dynamic from pilot projects towards a future of government planning. Many regions are recognizing the role that IS can play in developing a circular economy, positioning it as a key policy goal for many places in Sweden.

The shift in awareness of IS, increasing collaboration, and circular economy transitions can be displayed by looking at an example in Sweden that has transformed from self-organization to a more facilitated IS establishment, Händelö Eco-Industrial Park. In the early stages of Händelö for example, its commitment to support business development was essential to the region being able to grow its IS practices (Baas, 2011). Some factors that have given Händelö the opportunity to transition its IS dynamics start from its beginnings of self-organization. For example, in the unplanned beginnings of Händelö, IS was dependent on personal contacts and knowledge sharing, and uncovering existing links to build trust and create new relationships between companies (Baas, 2011). Low population areas can provide this close interaction between diverse actors on a more frequent basis than in bigger cities giving an advantage to industry towns in rural areas (Baas, 2011) but can be limiting when it comes to expansion. The early practices driven by the CHP plant have been a basis for new IS activities and markets in Östergötland area. As the potential of IS is "uncovered" (Chertow, 2007), the positive feedback of learning from successes can increase a region's intention towards IS and therefore further develop the network (Boons et al., 2017). Over the course of over 20 years, Händelö Eco-Industrial Park emerged as an established symbiosis between industry and city rooted within the concepts of a bio-based and circular economy concepts. Their engagement with different stakeholders, openness to public engagement, and integration of circular and bio-based economy concepts into the business model has shifted the network from a self-organized industrial cluster towards a facilitated centre for IS and sustainable development in the region.

Under the right circumstances, self-organized and unplanned IS developments in Sweden can transform into facilitated networks that have the potential to attract new businesses and IS activity to regions. In the future, as the emphasis on engaging more stakeholders including communities in IS in Sweden, greater public awareness and approval of the approach will only increase this shift in IS towards more integrated models that involve all relevant stakeholders to transition towards a more sustainable and circular economy.

5.2 Interaction with External Stakeholders

It is clear that the development and sustainability of IS networks is dependent on several entities to identify and implement exchanges of resources (Hein et al., 2017). For an IS network to be successful, it requires the active participation of stakeholders including government, local companies, leaders, financers, researchers, and other external organizations (Heeres et al., 2004). Approaches to IS development that include increasing institutional capacity with local and regional actor network while creating supportive conditions within the greater context of regional and external actors have high potential for success (Harris et al., 2018). The collaboration between actor groups and building up the institutional capacity of this network is therefore important to the success of IS. To connect IS to the virtue of sustainable business models, the engagement of stakeholders is critical. Additionally, effective stakeholder engagement can build trust, foster transparency, and create interest in the development of new partnerships and symbioses.

There exists a large discrepancy between IS networks in Sweden and how they are engaging with external actors. The networks operate largely independently of each other and take different approaches to engaging with stakeholders. All the networks have strategies for engagement that reflect their history, the regional culture, and regional challenges. They operate within different parts of the quadruple helix of stakeholder engagement used in this study (Figure 4). In this study, all the IS networks involved see the importance of cross-sector collaboration and knowledge sharing but face challenges in engaging community stakeholders and recognizing the benefits of IS for the region. All the IS networks engage with private actors and companies through different ways including workshops, joint meetings, study visits, and project collaborations. Most IS networks work with universities and academia to some extent in ongoing project and actively involve them in the network. Some networks interact with other levels of government for collaborative projects and networking. Public engagement is recognized as an important area to engage with for all IS networks, however, the level of advancement and engagement varies across different sites.

One critical part of the quadruple helix that is relatively empty in terms of IS in Sweden, is community and civil society. The civil society sphere of the quadruple helix allows for the extension of innovation and flows of knowledge to the social aspects (Arsova et al., 2021). This means that engagement with the local community is critical to achieving the social benefits of IS networks. There are some projects that have been realized in Malmö that strive to engage the public with circularity in the community, as well as other education efforts in Bjuv. However, when it comes to engaging the community on the development of projects and the business model design and innovation, the public is largely left out. Community awareness of the impacts of industry can be a driver of industrial projects, and a well established system of communication and education between industry and the local community can act as a strong enabler of new synergies in an IS network (Golev et al., 2015). According to the IS maturity grid described in Golev et al. (2015), the case examples in Sweden covered by this study are not currently recognizing the community or only have initial efforts to engage the community. In most case examples, the community is not recognized as an equal negotiation member for the development of IS. In a few cases, the community opinion is becoming more recognized, and people are informed on important environmental aspects of the industrial development. For example, community engagement efforts were shown to not be as developed as other engagement efforts in a study on the emerging Sotenäs Symbioscentrum, but are viewed as a continuous process and an area that the IS network is actively pursuing (Martin & Harris, 2018). Not yet are any of the IS networks in Sweden active in their efforts to engage the community as part of their business strategy. Eventually, the goal for maturity of an IS network is that "community is an active power in the decision-making process for current and future industrial development in the region." (Golev et al., 2015). By leaving communities out of the conversation, IS networks are missing a key actor group that can drive and support the development of IS. In addition, communities are needed to recognize the social benefits of IS and understand the beneficiaries of sustainable business model design. Currently, even the most ambitious Swedish IS networks are engaging the community in surface ways, such as reporting and opening presentations and tours to the general public. It will be important for IS networks to begin to integrate the community into IS practices including recognizing them in the negotiation process for development, informing the community through an established communication plan that incorporates feedback into decision making, and have contributions to the community as an important part of the business strategy (Golev et al., 2015).

To create sustainable business models for IS, stakeholder interaction will play a critical role. The engagement with and creation of value for stakeholders is demanded by the concept of the SBM (Goni et al., 2021). To ensure positive stakeholder interaction in sustainable

businesses, it is important to build high quality relationships, recognize the influence and power dynamics of the stakeholders, build capabilities for organizations and communities, and align value perceptions (Fobbe & Hilletofth, 2021). IS networks will have to first identify and assess the stakeholders that exist before they can actively engage in including them in processes for business development and innovation. It is recommended that IS networks across Sweden undertake a stakeholder mapping exercise to make a list of all potential stakeholders from the four groups of the quadruple helix. Further, an assessment of stakeholder needs can help identify concerns, interests, and priorities in the area of IS. By doing this in the format of the quadruple helix, overlapping interests can be prioritized, and conflicting ones can be addressed with individual actor groups. A stakeholder engagement plan can be used to create a clear plan for IS networks to outline how they will engage and communicate with different stakeholder groups at different stages of IS development and implementation. Value propositions for a sustainable business model can be created *for* stakeholders, or *with* stakeholders (Fobbe & Hilletofth, 2021). IS networks can use this model to bring stakeholders of all actor groups closer to the development and implementation of sustainable business models (Table 6).

Table 6- The goals of IS to create value for and with stakeholders including the tasks and key questions that networks can ask to achieve these goals (goals adapted to suit IS context from Fobbe & Hilletofth (2021))

Goal	**Tasks**	**Key Questions to Ask**
Creating value *for* stakeholders	Conduct a stakeholder mapping exercise to identify and consider the needs, expectations, costs, and benefits of all stakeholders.	Who do we want to propose value for in our IS? How will we prioritize the stakeholders that are the most important to our IS? Have any groups of people been left out?
	Develop a clear value proposition for each stakeholder group, highlighting the potential benefits they can gain from the IS	What benefits do the different stakeholder groups perceive from IS? How are the value propositions different for each group? Are the benefits of the IS fairly distributed among stakeholder groups?
	Communicate the benefits of IS in a compelling way to individual stakeholders, focusing on the economic, environmental, and social value	How can we communicate effectively with our stakeholders and keep them informed about the benefits and progress of our IS? How can benefit communication be tailored to each individual group?
	Measure and report on the value created from the IS network for stakeholders to build trust and accountability	How can we measure and report on the social, economic, and environmental impacts of our IS, and ensure we are delivering value to our stakeholders?
Creating value *with* stakeholders	Collaborate with stakeholders to identify new opportunities and co-create innovative solutions and new IS ideas	How can we create an environment where innovation is valued? Who should be involved at the initial ideation stages? How can we involve stakeholders in the planning and decision-making processes?
	Co-design and co-implementation of IS projects with stakeholders to ensure they are	How will the project be accepted? Is there any dissonance from any groups?

	tailored to the local context and needs and gather feedback along the way	Are there stakeholders we can partner with to strengthen relationships and processes?
	Create opportunities for collaboration, capacity building, and knowledge-sharing among stakeholders to encourage innovation and learning	How can we share knowledge and expertise with our stakeholders, and provide them with the resources they need to participate effectively in our IS? Who can we partner with to enhance learning and education of the network?
	Foster long-term relationships with stakeholders and maintain trust between actors	How will we keep connected with stakeholders over time? How can we highlight and recognize the achievements of stakeholders to a broader audience?

5.3 Perceived Benefits of IS in Sweden

The perceived value of IS across IS networks in Sweden depends on many factors. Different actors have different views on the most important benefits that IS can offer to themselves and their communities and regions. However, there were interesting outcomes when it came to alignment in opinions across actors from different IS networks. The doughnut economics model for a safe and just space for humanity (Raworth, 2012) was used to display the perceived environmental and social benefits of IS in Sweden (Figure 9). Interestingly, there was high alignment on some but not all benefits of IS. From the perspective of sustainable business model scholars, aligning stakeholders towards a joint value or purpose is a key precondition of stakeholder interaction (Fobbe & Hilletofth, 2021; Freudenreich et al., 2020). In the context of IS however, it is clear that the value perceptions of stakeholders can compete or converge across different sectors and key actors (Wadström et al., 2023). Conflicting value perceptions could lead to conflict and tension over time in developing or expanding an IS network. To avoid such conflict, stakeholders should be engaged early in conversations of value propositions being proposed by IS networks. It has been shown in previous work in the sustainable urban development sphere that dialogue around value can lead to successful cooperation between actors with diverging views (Lazoroska & Palm, 2019).

In line with the recommendations for stakeholder engagement from Table 6, the importance of conducting a value mapping exercise prior to engaging in IS to enhance collaboration amongst actors and understand perceptions to collectively align on joint goals and build consensus has been emphasized in the literature (Wadström et al., 2023). It is important that throughout engagement and particularly in these early engagements, the power relationship amongst stakeholders is well understood (Hein et al., 2017). In IS, the trust between partners is of utmost importance, and the flows between them make up the system of the network (Golev et al., 2015). In IS, often the highest relative power among stakeholders comes from actors that finance the symbiosis (e.g., the project owner) followed by those who provide critical resources (e.g., lease agreements, water provisions) (Hein et al., 2017). It is therefore important to understand the power dynamics when engaging in stakeholder dialogue about value to ensure that no stakeholder needs are excluded or overlooked. IS networks should develop strategies to achieve effective stakeholder engagement that uses a holistic understanding of value perspectives to facilitate the highest value for all actors.

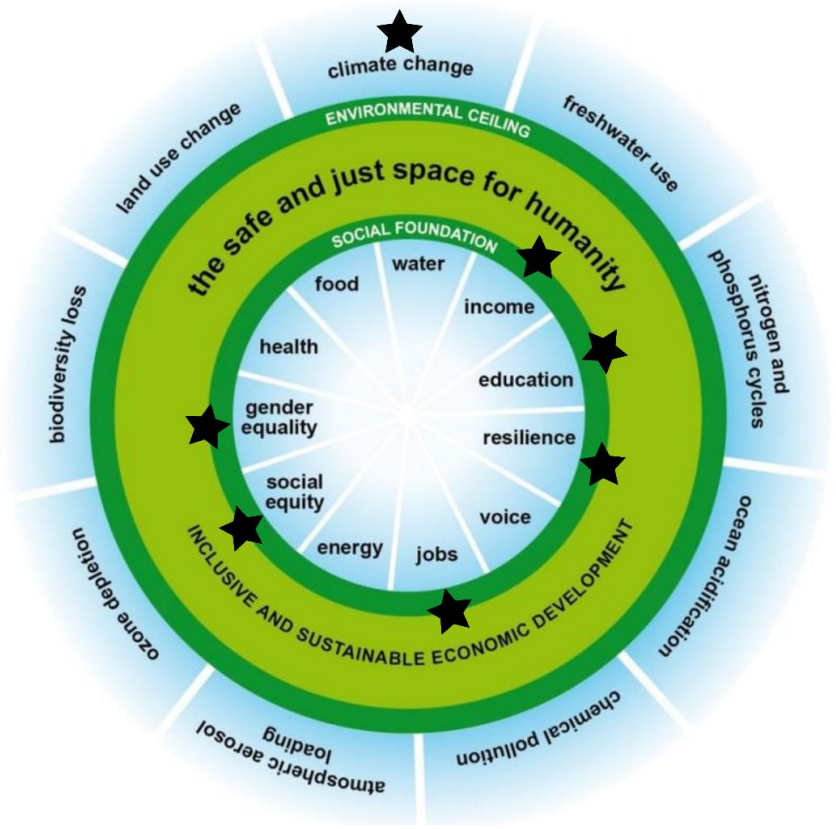

Figure 9- The safe and just space for humanity diagram of Doughnut Economics displaying the social foundation and environmental ceiling components (Raworth, 2012). The benefits that were identified as highly important in the stakeholder survey are identified with a black star.

5.3.1 Confirming the Obvious: Economic Value

The economic value of IS is well understood and the survey results corroborated this longstanding knowledge. Of the economic benefits stated in the survey, the most alignment on high importance was for economic growth, competitive advantage, increased employment, and higher revenues. The highest alignment came from the statement about economic growth for the region or community. This aligns also with facilitator interviews that identified IS as attracting new business to their regions. It is clear that IS in Sweden has the ability to lead to economic growth of the communities in which they exist. This is also supported by literature on Sotenäs Symbioscentrum, for example, that the IS positively contributed to local prosperity and maintenance of industry in the region (Martin & Harris, 2018). Creating a competitive advantage was another benefit of IS that had high alignment on its importance across stakeholders. This too relates to bringing prosperity to the regions that the facilitators discussed. There are examples in Sweden of IS networks attracting new companies to the regions based on the IS capacity and the benefits associated with it. As also discussed in facilitator interviews, IS gives businesses the opportunity to develop their business practices in a sustainable way, and this can lead to a competitive advantage for the company. This leads to greater positive feedback mechanisms that enhance learning and brings forth more IS exchanges (Boons et al., 2017). The economic benefit statements around IS increasing employment and bringing higher revenues align well with the benefits of IS in the literature (Mirata & Emtairah, 2005; Wadström et al., 2021), rooted in the idea that industrial growth and new product streams will produce more economic activity. Interestingly, the economic benefit statements that received mixed importance levels from stakeholders also included some

benefits that are traditionally stated as IS benefits (e.g., material and energy efficiency, reduced costs). Since economic benefits of IS are not often quantified (Wadström et al., 2021), it is possible that respondents are not aware of these specific economic benefits, or that they do not have the information to decide if that benefit is important to them. Since these benefits are more focused on specific processes, it is also possible that there are mixed outcomes of these benefits at different IS networks. For example, one IS might be more focused on energy efficiency if it is utilizing low-grade heat as a resource, but another may not involve any energy exchanges. It is therefore important to assess these mixed results with caution because it may not indicate true misalignment between actor perceptions but in fact just differences between the IS networks that they are operating within.

5.3.2 Beyond Climate: The Misunderstood Environmental Benefits

The results from this study found that the environmental value of IS beyond that of reducing the impacts of climate change are still widely misrepresented or misunderstood by stakeholders of IS. The environmental benefit statements were each associated with a planetary boundary that if exceeded will threaten the safe operating space for humanity (Rockström et al., 2009). Of all the statements, the statement "My IS network reduces the impacts of climate change by reducing atmospheric CO_2 or other greenhouse gases" had the highest alignment of importance. Interestingly, this was the only of the nine planetary boundaries that had aligned high importance amongst respondents. Most of the other statements received mixed results. This outcome aligns with previous research on the environmental benefits of IS, where studies have found that the main benefit to the environment is emissions reductions and associated climate change benefits (Domenech et al., 2019; Wadström et al., 2021). It is uncertain whether the respondents of the survey are familiar with the typical literature and narratives around IS being a solution for climate change mitigation, or if there are other reasons for the high alignment of this value. Sweden is considered a pioneer of climate mitigation policies and a leader in eco-innovations focused on reducing emissions (Sarasini, 2009). It makes sense that a country with such high political and public consensus on climate change would understand its abstract risks (Linde, 2020). Climate change is considered to be a core planetary boundary, at higher importance since it is highly integrated into all systems and is connected to all of the other planetary boundaries (Steffen et al., 2015). It is possible that the respondents are most familiar with the abstract risks of climate change and therefore ranked the importance of this benefit consistently high.

The survey results focused on climate change also aligned with the interview results, where facilitators identified a key benefit of IS as giving businesses the opportunity to develop new sustainable business practices. Many facilitators spoke about improving the climate situation in their regions, and wanting to use IS as a solution to climate change mitigation for their largest emission industries. In both Malmö and Lidköping municipalities, the interviewees mentioned IS as a solution and as part of their climate goals.

One environmental benefit about ozone depletion received low importance ranking, which shows that the stakeholders are aware of the highest risks to the environment in Sweden and understand that ozone depletion is not a high priority at present. According to the planetary boundary assessment, humanity has taken the appropriate actions to return within the safety zone (Steffen et al., 2015). According to the UN panel of experts, the Montreal Protocol actions have decreased the atmospheric abundances of ozone-depleting substances and advanced the recovery of the stratospheric ozone layer, expected to recover by 2040 (World Meteorological Organization, 2022). Therefore, it is unlikely that a lack of understanding of the risk of the environmental statements contributed to the misalignment of perceptions of importance.

As for the other environmental benefits of IS that received mixed results, this could be a case of unique IS networks offering unique benefits that did not align more generally across different networks. For example, some IS networks have a higher focus on chemicals and hazardous waste, while others may include a greater impact on reducing freshwater use. It may also be that the investigations on the environmental benefits of IS have not been comprehensive and therefore the respondents are only aware of those that have been tested and are communicated to them by their networks. If this is true, then a broader investigation of environmental benefits should be conducted so that the range of value that IS can bring can be better communicated to and understood by stakeholders. Not all respondents will have the full comprehension of environmental benefits of the IS network they are associated with, depending on their role. This could also influence results; however, it is still valuable to understand the perceptions of different stakeholders to improve communications and knowledge transfer in the future.

5.3.3 Socially Oriented Stakeholders of IS: Unexpected Social Benefits

The highest alignment on statements came from the social value section of the survey, with six statements having an outcome of aligned high importance, indicating that the stakeholders involved in IS in Sweden have a high social orientation. This result was somewhat unexpected since most literature on IS benefits identify economic and environmental benefits as the highest relevance with social aspects largely left out (Domenech et al., 2019; Wadström et al., 2023). The highest aligned important value statements were for increased jobs and income for the region. In this case, this social value could also be categorized as fundamentally economic value, and this aligns well with the literature that most social values accounted for in IS are actually economic values (Wadström et al., 2021). However, an interesting outcome from this study is that other more clearly social benefits were identified as important by stakeholders. These included improving knowledge and education including learning, training, innovation and/or skill building. IS networks have the capacity to bring organizations together to stimulate systems change and build innovative capacity (Mirata & Emtairah, 2005). This innovative value that IS brings to regions has been shown particularly at Sotenäs Symbioscentrum, with improved business opportunities and a growing network of researchers increasing future innovation in the region (Martin & Harris, 2018). It is clear that the capacity that IS has to grow innovation is important to stakeholders of IS in Sweden.

This also relates to the next social benefit that showed high aligned importance, that IS increases the community's network to work, share, and cooperate. Given that IS in essence creates networks of traditionally separate entities (Chertow, 2000), it is obvious that the symbiosis connections would enhance a community's network, and this has been mentioned consistently in the literature as a widely accepted social benefit of IS (Wadström et al., 2021). This was meaningfully supported by the facilitator interviews who spoke of collaborations between industry, municipalities, and researchers. In order to increase the networks' ability to grow and spark innovation in regions, it is therefore important for diverse actor groups to be included. Although the IS case studies from this research are not yet meaningfully engaging the civic society actor group, the survey still identified the benefit of increasing community engagement and participation as an aligned high importance value. Although this statement "My IS network has increased my community's engagement and participation" can be interpreted in many ways, and the community can be defined differently between survey respondents, it is interesting that there was high alignment on this statement. Literature found that meso-level CE projects (i.e., eco-industrial parks) focused mostly on stakeholder collaboration issues, followed by the local community level issues related to community development, community integration and participation in circular economy-related projects, community education, community well-being and local employment opportunities (Mies &

Gold, 2021). On top of the collaborative capacity that IS carries, the community engagement that IS has the potential for is of high importance to the surveyed stakeholders in Sweden. However, it would be interesting to find out from members of the community who were not surveyed in this study what their perceptions of community engagement are. Therefore, it is necessary for community to be built in to the IS network engagement processes in order to identify the priorities for this important stakeholder group.

Two other social benefit statements that were ranked as high importance to many stakeholders were that IS provides equal opportunity to all genders and for all individuals. Although there are no direct connections between IS and gender in the literature, promoting gender equality and diversity can be seen as a way to enhance the success of IS networks. By involving a diverse range of stakeholders, including women and other marginalized groups, IS networks can benefit from a broader range of perspectives and lived experiences leading to more innovative solutions and greater acceptance of the networks. Promoting gender equality in IS can contribute to the social sustainability of the networks and lead to greater community engagement, connecting the social benefits of IS further. Within the CE concept, gender is not discussed often, and shortcomings exist in working conditions, gender gaps in opportunities and labour practices that may be preventing CE from generating shared value (Pla-Julián & Guevara, 2019). By promoting gender equality, fostering women's participation, encouraging gendered innovation, and exploring new niches, organizations can create fresh business prospects and make strides towards achieving sustainable development, ultimately leading to a sustainable future that benefits everyone. (Pla-Julián & Guevara, 2019). IS stakeholders in Sweden recognize the significance of gender equality and equal opportunities for all, and thus, IS networks can strive towards achieving these objectives. Moreover, they can conduct gender analysis of their processes to identify the barriers and prospects for enhancing equality (Pla-Julián & Guevara, 2019).

Many of the mixed results regarding social benefits of IS could be related to the specifics of the particular IS that the respondent was associated with. For example, social factors including energy access, water supply, and food security could vary in importance depending on the offering of the IS. For example, food security might be more important for an IS network involved in sustainable food production. The social benefits of IS require further research to understand the mechanisms by which IS networks have the ability to create these benefits. There is a lack of clarity in the literature about how the CE will lead to greater social equality in terms of social opportunity for individuals (Murray et al., 2017). It is unclear from the survey results what the respondents were thinking regarding the social benefits of IS, so future research should attempt to qualify these connections.

5.3.4 Interdependent Relationships of IS Benefits

Much like the way IS is an interconnected web of material and knowledge exchanges, the associated benefits are also connected in intricate ways. The method of describing sustainability as separate three pillars of economic, environmental, and social becomes complicated by overlap between definitions. For example, many of the social benefits of IS described in this study such as increased jobs and economic growth for communities can also be labelled as economic benefits. When survey respondents asked which benefit (economic, environmental, social) is the most important benefit, many commented on how interrelated and connected the three were. It was difficult to answer directly, with many respondents saying they were equally important, or that the three are clearly linked. Some respondents noted that without one, the others do not exist. For example, one respondent said environmental and economic are prerequisite for social, and another said without environmental and social there is no basis for a functioning economy. Three respondents directly stated that environmental benefits were

most important, and one specified economic as the most important. Interestingly, in the safe and just space for humanity display of results (Figure 9), the most important benefits of IS were found to be parts of building the social foundation. The planetary boundaries that exist on the outside of the diagram had less alignment on importance in Sweden, with climate change being the only benefit with high consensus of importance. It is therefore evident that the social components that are offered by IS in Sweden are highly important to the stakeholders and should be presented and focused on in future research. However, with the dependencies on all the benefits that exist, it is difficult to disentangle and rank the benefits of IS in any tangible way that would suit the views and expectations of all stakeholders.

5.4 Reflections on Methods and Limitations

Reflecting on the methods used in this thesis, multiple *validation* procedures were conducted to check the accuracy of findings. The main strategies included *triangulation, member checking*, and *rich descriptions* as suggested by (Creswell & Creswell, 2018). Triangulation is a method of verifying data by examining different data sources. This was done by assessing 8 different interviews and a total of 12 survey results to cross-check findings between different individuals and sources of data. These offered different perspectives from different individuals, networks, and actor groups. Member checking involves taking the findings back to participants to ensure they feel they are accurate. This was used in some cases when there was potential for misunderstanding of interview results. The interpretation of findings from the interviews were more generally cross-validated by discussions with a practitioner who has been engaged with almost all the case studies under study for over 20 years (M. Mirata, personal communication, 2 May 2023). Rich descriptions of results were used to provide detailed information to the reader and improve the validity of the findings. Some limitations to the validity of this work include the lack of time that was expected in a short thesis that created a more descriptive result than envisioned. To fully understand these case studies and the implications of their internal and external operations, more time in the field would have developed a greater credibility to results. Procedures to ensure the *reliability* of the research were also conducted to ensure results were consistent (Creswell & Creswell, 2018). This includes the close documentation of procedures for each case study (Yin, 2014). Each interview guideline was developed to be consistent between interviewees to avoid researcher bias, however they were specialized for each local example. To ensure reliability of results, transcripts were reviewed immediately to ensure there were no mistakes. Coding was done in a consistent way and cross-checked between interviews to ensure the codes were defined the same way.

This study selected participants based on ease of access, given the limited time constraints and the need for high quality interviewees in the form of facilitators of IS networks across Sweden. Therefore, the eight case examples that were chosen may not be entirely representative of all IS networks across Sweden. In addition, there are limitations to using case studies from only one country given that it is difficult to generalize across other locations and cultural contexts. In addition, only one facilitator was interviewed from each case example (except for Malmö where two individuals were interviewed), so the views and knowledge of the IS network was limited to only one person. This could have biased results and made it difficult to confirm the complete picture of internal and external interactions happening within each network. However, the survey acted to bolster these results and provide new perspectives about the IS networks that were studied. In the end, the survey only received responses from twelve individuals, so this meant that the diversity of perceptions of benefits across different IS networks and different stakeholder groups was still lacking. In this way, it was not possible to fully identify what mattered to who and where, as envisioned in Table 1. The results instead provide a general sense for what is perceived as benefits of IS in Sweden, without being able

to attribute these perceptions directly to each of the stakeholder groups or specific IS networks. It is also possible that some participants in the survey may have misunderstood or were not aware of what benefits the IS network that they are associated with could offer. It should be reiterated that these responses are best described as the stakeholder perceptions of the benefits of IS, and how important each of these benefits are to them and their role and involvement in the IS network. Since the IS network facilitators were the ones distributing the survey, it is also interesting to note who the most engaged of their stakeholders are. Many survey respondents were from external research organizations, and there were no responses received from civil society members. There is a greater need to include the community, especially given the support of literature and the survey responses that indicated that community engagement was an important benefit of IS. It would be of interest to see what the perceptions of value of IS are from the perspective of community members, which was lacking in this study.

6 Conclusions

This thesis aimed to explore Swedish IS networks to identify how they operate internally and interact with stakeholders externally and see how the value proposition of these projects are perceived by each of their diverse actor networks. The internal organization of the case examples used in this study acted as a basis for understanding the operationalization of IS across Sweden. The external interactions were also assessed to see which actors are involved in the IS development and operations processes, and the roles of each actor group that was brought together to generate impact. Table 7 identifies the four actor groups assessed in this thesis, and the typical roles that they play in IS in Sweden, based on the eight case examples. This section will provide recommendations based on findings for the intended audience of IS practitioners, and for future research.

Table 7- The role of each of the four main actor groups in Industrial Symbiosis in Sweden.

Actor Group	**Role**
Industrial actors, businesses	**Creators** of IS- industrial actors build symbioses between partners **Beneficiaries** of IS- businesses can gain value from economic, environmental, and social benefits of IS
Public actors, government	**Facilitators** of IS- municipalities can fund, support and lead IS projects Setting the **conditions** for IS- government policies can set the stage to enable IS
Research institutes, universities	Project-specific **expertise**- technical, IS research Cross- IS Network **Connectors**- knowledge and resource sharing across different IS networks in Sweden
Community, civil society	**Beneficiaries** of IS- the community can gain value from the economic, environmental, and social benefits of IS Creators of the IS **market**- create the demand for circular products and services

6.1 Strengthening Stakeholder Involvement in Value Co-Creation

Research question 1 aimed to describe how IS networks in Sweden are currently organizing internally and externally with stakeholders to develop IS value propositions and business models. It was critical to firstly understand how different IS networks are organized internally to seek connections to external stakeholders. Stakeholder interaction is needed to develop IS networks and the interconnections and exchanges of knowledge and materials within them. Involving the four major actor groups of the quadruple helix model (i.e., industrial actors, public actors, researchers, and civil society) can be a good way to understand the needs of different groups and therefore develop value propositions that can address those needs. Bringing together different actor groups can be done through projects, for example, to build the connections that can then be used to maintain IS in a given region. In addition, there is minimal involvement of civil society in the engagement stages of IS networks in Sweden, so there is very little known about the perceptions and impact to the community members and beneficiaries of IS at this level. Further involvement of the local community can help IS networks in Sweden to complete the quadruple helix model and find overlap between the four actor groups. The success of IS networks relies on the active participation of stakeholders, including industry, government, knowledge actors, and the community. Collaboration between these groups and the growth of institutional capacity of the IS networks is critical for success. While all IS networks in the study recognize the importance of cross-sector collaboration and

knowledge sharing, engaging community stakeholders and recognizing the complex and interrelated benefits of IS for a region is challenging. Engagement with the local community is critical to achieving the social benefits of IS networks, and they must recognize the community as an equal negotiation member during the development of IS. To create sustainable business models for IS, stakeholder interaction is essential. IS networks must identify and assess stakeholders before they can actively engage them in processes for business development and innovation. Undertaking a stakeholder mapping exercise in the format of the quadruple helix and assessing the local stakeholder needs can help identify concerns, interests, and priorities in the IS. By doing so, overlapping interests can be prioritized, and conflicting ones can be resolved, leading to the development of a more sustainable business model. Overall, this study underscores the need for effective stakeholder engagement to achieve the goals of IS networks and to create sustainable business models that benefit all stakeholders.

Research question 2 sought to understand the benefits of IS from the perspective of different actor groups. Although there is limited opportunity to generalize findings across different contexts and locations, this in itself is an important discovery. Although there was some alignment on the benefits of IS across the twelve survey respondents from seven different IS networks in Sweden, there were also many discrepancies. The mixed results from the survey showed that the value proposition of IS is not straightforward, and different stakeholders will hold the importance of some benefits to different levels. With many of the benefits of IS being unquantified, it is difficult for stakeholders with different levels of education on IS to fully grasp the impact that IS can have on the environment, the economy, and society. It is essential that the full breadth of benefits that IS can offer be understood from the perspective of different stakeholders. Although there is alignment on some benefits of IS, conflicting value perceptions can lead to tension and conflict that could limit the ability for collaboration. To avoid such conflict, stakeholders should be engaged early in conversations of value propositions being proposed by IS networks. It is also important that these unique value propositions that IS can bring to different actors be communicated in a way that aligns with what they perceive as the most important benefits. For example, it is clear that the environmental benefit of reducing the impact of climate change is important across all stakeholder groups. This aligned importance is a key finding that can be used to communicate a significant benefit in a more generalized way across all stakeholder types. Practitioners can also strive to communicate the unique value propositions of specific IS networks in a meaningful way that highlights the most important factors in the local community. For example, in a community that has suffered from a loss of industry, the economic benefits of increased employment of an IS development might be a high priority, whereas in a community looking for solutions for water shortages, the environmental benefits of reducing water use might be more important. The economic value of IS in Sweden is well understood, and there is alignment on benefits such as economic growth, competitive advantage, increased employment, and higher revenues. However, there is a lack of understanding and consensus on the environmental benefits of IS beyond reducing the impacts of climate change. It was also found that across all stakeholder groups that were surveyed, the social benefits of IS stand out as important. This finding that IS stakeholders in Sweden are socially oriented in their values highlights a critical need to better understand and communicate the social benefits of IS networks. It is therefore important for practitioners to consider focusing in on and reporting the social benefits that IS can bring to communities. It is unknown how many of these social benefits are being realized in the context of IS in Sweden so there is a need to understand and quantify them because these details are important to stakeholders.

Strengthening Capacity for Value Co-Creation
The involvement of external stakeholders in IS development can be further expanded in Sweden to work together to develop shared value across all groups using methods of value co-creation. Below is an important takeaway that encapsulates the essence of this thesis well and describes the complications and impacts that IS can have. In the end, it comes down to big systemic changes and innovation, so understanding the risks and payoffs is critical to getting diverse stakeholders on board.

"Start from the local conditions. See the possibilities. Dare to test. Collaboration pays off."- Advice from a survey respondent (translated from Swedish)

Starting from the local conditions means focusing the development of IS on what is possible in the local context but can also be interpreted as understanding the local stakeholders and community. By recognizing the local conditions, the possibilities for IS grow in alignment with the stakeholders that support its development. When there exists the support of IS across stakeholders, there is a greater opportunity to test new and innovative ideas and support the growing knowledge transfer between stakeholders. Involving different actor groups can grow trust and increase collaboration, ultimately ending in a "pay off" in the form of economic, environmental, and social benefits. A high potential for value co-creation exists in IS given this sense of collaboration that already exists in many of the case examples in Sweden.

6.2 Recommendations for Future Research

Future research around stakeholder engagement in IS should focus on investigating the effectiveness of different approaches to IS development that increase institutional capacity with local and regional actor networks, while creating supportive conditions within the greater local context. Exploring ways to engage with community stakeholders in IS networks should also be prioritized as a future research topic to achieve the social benefits of IS networks more effectively. The recommendations for goals to create value for stakeholders and the tasks and key questions from Table 6 can be used to create and test new strategies for IS stakeholder engagement. Conducting stakeholder mapping exercises should be prioritized for individual IS network research to identify and assess the stakeholders that exist within the four groups of the quadruple helix in IS networks. IS networks should actively work towards assessing the stakeholder needs to identify concerns, interests, and priorities in the area of IS, and prioritizing overlapping interests while addressing conflicting ones.

Future research can also focus on better understanding how the benefits that were perceived as important by stakeholders are being achieved or could be achieved by IS networks. In particular, there is a need to better understand the social benefits and how they are being achieved by IS networks. The social equality benefits identified as important by stakeholders should be investigated to see firstly how stakeholders believe these benefits are already being achieved by IS, and secondly, how IS networks can engage more actively in bringing the social benefits of IS to life. The qualification and in some cases quantification of benefits that are perceived as important should be completed. This research could involve developing a framework to measure, monitor and track overtime the benefits of IS in a systematic way including key indicators of success. This information could better inform stakeholders to see how their perceptions of benefits change. It would also be interesting to increase the sample size of the survey that was conducted so that researchers can ask how different actor groups and different locations value each benefit- what is important to each actor group, and where? The sample size of the survey in this study could not adequately disentangle this question from the 12 respondents. It would be interesting to further investigate the factors that led to high alignment on some but not all benefits of IS across different sectors and key actors.

Where there is disagreement on the importance of some IS benefits across actors, it is important to find consensus in the expected benefits to communicate to the highest possible audience size (Wadström et al., 2023). When conceptualizing the circular economy, for example, the consensus space shared by the three spheres of industry, government, and researchers focuses on seeing it as a way to create new resources, products and business models based on waste (Anttonen et al., 2018). Future research on the value propositions of IS could focus on the consensus space of the perceived benefits of IS where the perceptions of the quadruple helix space overlap. Sufficient consensus between different spheres can create opportunity for further innovation because they can transcend their individual spheres (Ranga & Etzkowitz, 2013). Finding the consensus space for IS across stakeholder groups can therefore create new opportunities for innovation, and effective communication of its benefits. The value perceptions of stakeholder can only be understood through meaningful and specific stakeholder engagement. Future research can focus on the strategies that facilitators and actors of IS can use to map their stakeholders with value propositions as a guiding light.

Bibliography

Anttonen, M., Lammi, M., Mykkänen, J., & Repo, P. (2018). Circular economy in the Triple Helix of innovation systems. *Sustainability (Switzerland)*, *10*(8), 1–14. https://doi.org/10.3390/su10082646

Arsova, S., Genovese, A., Garcia, D. G., Ketikidis, P. H., Lowe, B., Solomon, A., & Yoon, M. (2020). Realising the Transition towards the Circular Economy: Models, Methods and Applications. *ReTraCE*, 1–96.

Arsova, S., Genovese, A., Ketikidis, P. H., Alberich, J. P., & Solomon, A. (2021). Implementing regional circular economy policies: A proposed living constellation of stakeholders. *Sustainability (Switzerland)*, *13*(9). https://doi.org/10.3390/su13094916

Baas, L. (2011). Planning and uncovering industrial symbiosis: Comparing the Rotterdam and Östergötland regions. *Business Strategy and the Environment*, *20*(7), 428–440. https://doi.org/10.1002/bse.735

Baldassarre, B., Calabretta, G., Bocken, N. M. P., & Jaskiewicz, T. (2017). Bridging sustainable business model innovation and user-driven innovation: A process for sustainable value proposition design. *Journal of Cleaner Production*, *147*, 175–186. https://doi.org/10.1016/j.jclepro.2017.01.081

Bocken, N., Boons, F., & Baldassarre, B. (2019). Sustainable business model experimentation by understanding ecologies of business models. *Journal of Cleaner Production*, *208*, 1498–1512. https://doi.org/10.1016/J.JCLEPRO.2018.10.159

Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production*, *65*, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039

Boons, F., Chertow, M., Park, J., Spekkink, W., & Shi, H. (2017). Industrial Symbiosis Dynamics and the Problem of Equivalence: Proposal for a Comparative Framework. *Journal of Industrial Ecology*, *21*(4), 938–952. https://doi.org/10.1111/jiec.12468

Cecchin, A., Salomone, R., Deutz, P., Raggi, A., & Cutaia, L. (2020). Relating Industrial Symbiosis and Circular Economy to the Sustainable Development Debate. In R. Salomone, A. Cecchin, P. Deutz, A. Raggi, & L. Cutaia (Eds.), *Industrial Symbiosis for the Circular Economy: Operational Experiences, Best Practices and Obstacles to a Collaborative Business Approach* (pp. 1–25). Springer International Publishing. https://doi.org/10.1007/978-3-030-36660-5_1

Chertow, M. R. (2000). Industrial Symbiosis: Literature and Taxonomy. *Annual Review of Energy and the Environment*, *25*, 313–337.

Chertow, M. R. (2007). "Uncovering" Industrial Symbiosis. *Journal of Industrial Ecology*, *11*(1), 11–30. https://doi.org/10.4324/9781351282444-27

Corvellec, H., Stowell, A. F., & Johansson, N. (2022). Critiques of the circular economy. *Journal of Industrial Ecology*, *26*(2), 421–432. https://doi.org/10.1111/jiec.13187

Creswell, J., & Creswell, J. (2018). *Research Design Qualitative, Quantitative, and Mixed Methods Approaches*. Sage Publications. Inc. https://medium.com/@arifwicaksanaa/pengertian-use-case-a7e576e1b6bf

DeepL Translator. (2023). *DeepL Translate: The world's most accurate translator*. https://www.deepl.com/translator

Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D., & Roman, L. (2019). Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy. *Resources, Conservation and Recycling*, *141*, 76–98. https://doi.org/10.1016/j.resconrec.2018.09.016

Ellen MacArthur Foundation. (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From National Systems and

"mode 2" to a Triple Helix of university-industry-government relations. *Research Policy*, *29*(2), 109–123. https://doi.org/10.1016/S0048-7333(99)00055-4

European Commission. (2020). *A new circular economy action plan for a cleaner and more competitive Europe*.

Fernández Campos, P., Trucco, P., & Huaccho Huatuco, L. (2019). Managing structural and dynamic complexity in supply chains: insights from four case studies. *Production Planning and Control*, *30*(8), 611–623. https://doi.org/10.1080/09537287.2018.1545952

Fichtner, W., Tietze-Stöckinger, I., Frank, M., & Rentz, O. (2005). Barriers of interorganisational environmental management: two case studies on industrial symbiosis. *Progress in Industrial Ecology*, *2*(1), 73–88. https://doi.org/10.1504/PIE.2005.006778

Fobbe, L., & Hilletofth, P. (2021). The role of stakeholder interaction in sustainable business models. A systematic literature review. *Journal of Cleaner Production*, *327*. https://doi.org/10.1016/J.JCLEPRO.2021.129510

Fraccascia, L., Giannoccaro, I., & Albino, V. (2019). Business models for industrial symbiosis: A taxonomy focused on the form of governance. In *Resources, Conservation and Recycling* (Vol. 146). https://doi.org/10.1016/j.resconrec.2019.03.016

Freeman, R. E. (1984). *Strategic management: a stakeholder approach*. Pitman.

Freudenreich, B., Lüdeke-Freund, F., & Schaltegger, S. (2020). A Stakeholder Theory Perspective on Business Models: Value Creation for Sustainability. *Journal of Business Ethics*, *166*(1), 3–18. https://doi.org/10.1007/s10551-019-04112-z

Geissdoerfer, M., Bocken, N. M. P., & Hultink, E. J. (2016). Design thinking to enhance the sustainable business modelling process – A workshop based on a value mapping process. *Journal of Cleaner Production*, *135*, 1218–1232. https://doi.org/10.1016/j.jclepro.2016.07.020

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). *A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems*. https://doi.org/10.1016/j.jclepro.2015.09.007

Golev, A., Corder, G. D., & Giurco, D. P. (2015). Barriers to Industrial Symbiosis: Insights from the Use of a Maturity Grid. *Journal of Industrial Ecology*, *19*(1), 141–153. https://doi.org/10.1111/jiec.12159

Goni, F. A., Gholamzadeh Chofreh, A., Estaki Orakani, Z., Klemeš, J. J., Davoudi, M., & Mardani, A. (2021). Sustainable business model: A review and framework development. *Clean Technologies and Environmental Policy*, *23*(3), 889–897. https://doi.org/10.1007/s10098-020-01886-z

Greene, J. C., Carcelli, V. J., & Graham, W. F. (1989). Toward a Conceptual Framework for Mixed-Method Evaluation Designs Jennifer C . Greene ; Valerie J . Caracelli ; Wendy F . Graham. *Educationl Evaluation and Policy Analysis*, *11*(3), 255–274.

Han, D., Konietzko, J., Dijk, M., & Bocken, N. (2022). How do companies launch circular service business models in different countries? *Sustainable Production and Consumption*, *31*, 591–602. https://doi.org/10.1016/J.SPC.2022.03.011

Händelö Eco-Industrial Park. (2023). *Händelö Eco-Industrial Park*. Europeiska Unionen. https://heip.se/

Harris, S., Mirata, M., Broberg, S., Carlsson, P., & Martin, M. (2018). *A Roadmap for Increased Uptake of Industrial Symbiosis in Sweden*. https://www.ivl.se/download/18.14bae12b164a305ba1118a2a/1540309079798/A Roadmap for Industrial Symbiosis in Sweden - final.pdf

Heeres, R. R., Vermeulen, W. J. V., & De Walle, F. B. (2004). Eco-industrial park initiatives in the USA and the Netherlands: First lessons. *Journal of Cleaner Production*, *12*(8–10), 985–995. https://doi.org/10.1016/j.jclepro.2004.02.014

Hein, A. M., Jankovic, M., Feng, W., Farel, R., Yune, J. H., & Yannou, B. (2017). Stakeholder power in industrial symbioses: A stakeholder value network approach. *Journal of Cleaner Production*, *148*, 923–933. https://doi.org/10.1016/j.jclepro.2017.01.136

Henriques, J., Ferrão, P., Castro, R., & Azevedo, J. (2021). Industrial symbiosis: A sectoral analysis on enablers and barriers. *Sustainability (Switzerland)*, *13*(4), 1–22. https://doi.org/10.3390/su13041723

Hofmann, F. (2019). Circular business models: Business approach as driver or obstructer of sustainability transitions? *Journal of Cleaner Production*, *224*, 361–374. https://doi.org/10.1016/j.jclepro.2019.03.115

IPCC. (2022). *Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Vol. 9781107025). Cambridge University Press. https://doi.org/10.1017/CBO9781139177245.003

Jensen, P. D., Basson, L., & Leach, M. (2011). Reinterpreting Industrial Ecology. *Journal of Industrial Ecology*, *15*(5), 680–692. https://doi.org/10.1111/J.1530-9290.2011.00377.X

Kosmol, L., Maiwald, M., Pieper, C., Plötz, J., & Schmidt, T. (2021). An indicator-based method supporting assessment and decision-making of potential by-product exchanges in industrial symbiosis. *Journal of Cleaner Production*, *289*. https://doi.org/10.1016/j.jclepro.2020.125593

Lazoroska, D., & Palm, J. (2019). Dialogue with property owners and property developers as a tool for sustainable transformation: A literature review. *Journal of Cleaner Production*, *233*, 328–339. https://doi.org/10.1016/j.jclepro.2019.06.040

Linde, S. (2020). The Politicization of Risk: Party Cues, Polarization, and Public Perceptions of Climate Change Risk. *Risk Analysis*, *40*(10), 2002–2018. https://doi.org/10.1111/risa.13530

Linköping University. (2021). *Swedish Platform for Industrial and Urban Symbiosis*. https://industrialsymbiosis.se/case.html

Lombardi, D. R., & Laybourn, P. (2012). Redefining Industrial Symbiosis Crossing academic-practitioner boundaries. *Journal of Industrial Ecology*, *16*(1), 28–37. https://doi.org/10.1111/j.1530-9290.2011.00444.x

Lüdeke- Freund, F. (2010). Towards a Conceptual Framework of Business Models for Sustainability. *Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU Conference, Delft, The Netherlands*, *49*(0), 1–28.

Lüdeke-Freund, F., Carroux, S., Joyce, A., Massa, L., & Breuer, H. (2018). The sustainable business model pattern taxonomy—45 patterns to support sustainability-oriented business model innovation. *Sustainable Production and Consumption*, *15*, 145–162. https://doi.org/10.1016/j.spc.2018.06.004

Martin, M., & Harris, S. (2018). Prospecting the sustainability implications of an emerging industrial symbiosis network. *Resources, Conservation and Recycling*, *138*(March), 246–256. https://doi.org/10.1016/j.resconrec.2018.07.026

Mies, A., & Gold, S. (2021). Mapping the social dimension of the circular economy. *Journal of Cleaner Production*, *321*(November 2020), 128960. https://doi.org/10.1016/j.jclepro.2021.128960

Mirata, M. (2018). *International and Swedish State of Play in Industrial Symbiosis A review with proposals for scaling up industrial symbiosis in Sweden*.

Mirata, M., & Emtairah, T. (2005). Industrial symbiosis networks and the contribution to environmental innovation: The case of the Landskrona industrial symbiosis programme. *Journal of Cleaner Production*, *13*(10–11), 993–1002. https://doi.org/10.1016/j.jclepro.2004.12.010

Moodie, J., Salenius, V., & Leino, J. (2019). Industrial Symbiosis in the Baltic Sea Region. *Nordregio*, *1*, 1–12.

Murray, A., Skene, K., & Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, *140*(3), 369–380. https://doi.org/10.1007/s10551-015-2693-2

Naturvation. (2022). *Taking action for urban nature- Business models*. Horizon 2020.

https://naturvation.eu/businessmodels.html

Neves, A., Godina, R., Azevedo, S. G., & Matias, J. C. O. (2020). A comprehensive review of industrial symbiosis. *Journal of Cleaner Production*, *247*. https://doi.org/10.1016/j.jclepro.2019.119113

Padilla-Rivera, A., Russo-Garrido, S., & Merveille, N. (2020). Addressing the social aspects of a circular economy: A systematic literature review. *Sustainability (Switzerland)*, *12*(19), 1–17. https://doi.org/10.3390/SU12197912

Parker, T., & Kiessling, A. (2016). Low-grade heat recycling for system synergies between waste heat and food production, a case study at the European Spallation Source. *Energy Science and Engineering*, *4*(2), 153–165. https://doi.org/10.1002/ese3.113

Pla-Julián, I., & Guevara, S. (2019). Is circular economy the key to transitioning towards sustainable development? Challenges from the perspective of care ethics. *Futures*, *105*(August 2018), 67–77. https://doi.org/10.1016/j.futures.2018.09.001

Prahalad, C. K., & Ramaswamy, V. (2004). Co-creation experiences: The next practice in value creation. *Journal of Interactive Marketing*, *18*(3), 5–14. https://doi.org/10.1002/dir.20015

Preghenella, N., & Battistella, C. (2021). Exploring business models for sustainability: A bibliographic investigation of the literature and future research directions. *Business Strategy and the Environment*, *30*(5), 2505–2522. https://doi.org/10.1002/bse.2760

Ranga, M., & Etzkowitz, H. (2013). Triple Helix Systems: An Analytical Framework for Innovation Policy and Practice in the Knowledge Society. In *Industry and Higher Education* (Vol. 27, Issue 4). https://doi.org/10.5367/ihe.2013.0165

Raworth, K. (2012). *A safe and just space for humanity; can we live within the doughnut?* Oxfam. https://doi.org/10.1163/2210-7975_hrd-9824-0069

Re, B., Magnani, G., & Zucchella, A. (2021). The Future of Sustainability: Value Co-creation Processes in the Circular Economy. In *The Palgrave Handbook of Corporate Sustainability in the Digital Era* (pp. 503–528). Springer Nature Switzerland. https://doi.org/10.1007/978-3-030-42412-1

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., De Wit, C. A., Hughes, T., Van Der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., … Foley, J. A. (2009). A safe operating space for humanity. *Nature*, *461*(7263), 472–475. https://doi.org/10.1038/461472a

Sarasini, S. (2009). Constituting leadership via policy: Sweden as a pioneer of climate change mitigation. *Mitigation and Adaptation Strategies for Global Change*, *14*(7), 635–653. https://doi.org/10.1007/s11027-009-9188-3

Short, S. W., Bocken, N. M. P., Barlow, C. Y., & Chertow, M. R. (2014). From refining sugar to growing tomatoes: Industrial ecology and business model evolution. *Journal of Industrial Ecology*, *18*(5), 603–618. https://doi.org/10.1111/jiec.12171

Södergren, K., & Palm, J. (2021a). How organization models impact the governing of industrial symbiosis in public wastewater management. An explorative study in Sweden. *Water (Switzerland)*, *13*(6), 0–17. https://doi.org/10.3390/w13060824

Södergren, K., & Palm, J. (2021b). The role of local governments in overcoming barriers to industrial symbiosis. *Cleaner Environmental Systems*, *2*, 100014. https://doi.org/10.1016/j.cesys.2021.100014

Statistikdatabasen. (2021). *Totala utsläpp och upptag av växthusgaser efter växthusgas och sektor. År 1990 - 2021*. https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__MI__MI0107/TotaltUtslappN/

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., De Vries, W., De Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223).

https://doi.org/10.1126/science.1259855

Svendsen Lander, N., Kaarsberg, S., Watson, D., Bhasin, A., Klugman, S., Solstad, M., & Larssen, S. (2021). *How can municipalities support the development of industrial symbiosis?*

Teece, D. J. (2010). Business models, business strategy and innovation. *Long Range Planning*, *43*(2–3), 172–194. https://doi.org/10.1016/j.lrp.2009.07.003

Transition ApS. (2021). Guide for Industrial Symbiosis Facilitators. *Baltic Industrial Symbiosis*.

Wadström, C., Johansson, M., & Wallén, M. (2021). A framework for studying outcomes in industrial symbiosis. *Renewable and Sustainable Energy Reviews*, *151*(July). https://doi.org/10.1016/j.rser.2021.111526

Wadström, C., Södergren, K., & Palm, J. (2023). Exploring total economic values in an emerging urban circular wastewater system. *Water Research*, *233*(February). https://doi.org/10.1016/j.watres.2023.119806

Wolf, A. (2007). Industrial symbiosis in the Swedish forest industry. *Linköping Studies in Science and Technology*. www.liu.se/energi

World Meteorological Organization (WMO). (2022). *Executive Summary: Scientific assessment of ozone depletion: 2022, GAW Report No. 278*.

Yin, R. K. (2014). *Case Study Research Design and Methods* (5th ed.). Sage Publications. Inc.

Appendix

Appendix A: Guide for Interviews

Maximum 30 minutes allocated for each interview. E-mails were sent to interviewees in advance to stage the interviews around the main research aim.

Section Name	**Questions**
Describing the Aim of Research	Aim of research: The aim of this thesis will be to explore industrial symbiosis projects in Sweden and identify a strategy to understand the value proposition of these locally unique projects from the perspective of the diverse actor network of different stakeholders. Firstly, what you will help me with: How are industrial symbiosis projects in Sweden currently communicating and working with local stakeholders to develop IS value propositions and business models? Next, I want to address: What are the benefits of industrial symbiosis cases from the perspective of different stakeholder groups?
Interview logistics	Do you agree to have this interview recorded? Your name will remain private Any questions before we get started?
General IS role	What is your specific role in the industrial and urban symbiosis in _____ IS? Were you involved since it was established first in _____?
Value Proposition	What do you think is the major value proposition from your perspective? Do different actors have different views on the value proposition of the IS?
Stakeholder involvement *Stakeholder= "any group or individual who can affect or is affected by the achievement of the organization's objectives"*	How were different stakeholders involved at the development stage of the project? Which stakeholders were involved? Were community members involved? How are different stakeholders involved in the operation of the project? What does that look like today?
Stakeholder network contacts	Do you have contact information for stakeholders that I could send a survey to in order to understand what benefits they see from the IS? Can I send the survey to you to distribute?

Thank you for your time! I look forward to sharing results with you.

Source: Author's own conception

Appendix B: Survey distributed to stakeholders of Industrial Symbiosis in Sweden (English version)

Preamble: Thank you for agreeing to participate in this survey which will ask questions about how you are connected to a particular Industrial Symbiosis in Sweden. It will take a maximum of **10-15 minutes of your time**. We are interested in learning more about what you perceive to be the unique benefits that are offered by the Industrial Symbiosis project that you are connected to.

The results from this survey will be used in the completion of a Master's Thesis in Environmental Management and Policy at Lund University. No personal details will be disclosed. The aim of the research is to explore industrial symbiosis projects in Sweden and develop an understanding of the benefits of these locally unique projects from the perspective of different stakeholders, and to work towards a strategy of focused co-creation of value. **Your participation will help us to better understand how industrial symbiosis projects can integrate different groups of stakeholders to improve decision making and operations.**

The survey will be open until March 15, 2023.

Important Definition:
Industrial Symbiosis Network- the entire network of an industrial symbiosis which exchange materials, energy, water, other by-products and/or knowledge. The network includes all actors and stakeholders and all of the industrial symbiosis project(s).

1. Which Industrial Symbiosis (IS) Network(s) are you connected to? (You can select more than one if you are connected to more than one project)
    a. Paper Province in Karlstad
    b. Sotenäs Symbioscentrum
    c. IS in The City of Malmö
    d. IS in The City of Helsingborg
    e. IS in Lidköping Municipality
    f. IS in Bjuv Municipality "Food Valley of Bjuv"
    g. IS in Stenungsund Municipality Chemical Cluster
    h. IS in Örnsköldsvik Municipality "High Coast Innovation Park"
    i. IS in Norköpping Händelö
2. Which actor group are you a part of? (Please specify the one that you are the most strongly connected to)
    a. Public Actor- I work with the municipality, regional or national government
    b. Private Actor- I am an industrial actor
    c. Funding Actor- I fund Industrial Symbiosis projects
    d. External Actor- I work with a research institution, university, or non-profit organization
    e. Local Community Actor- I am a member of the local community
    f. Facilitation Actor- I help organise and facilitate industrial symbiosis
3. How do you interact with the Industrial Symbiosis Network which you are connected to? (You can select more than one if they apply to you)
    a. I have financed a project (e.g., through investment, loan, or public financing)
    b. I have participated in project development
    c. I have participated in project design
    d. I am a partner in the project operations (e.g., I am an industrial actor in the project)
    e. I have offered consultation services to the project

f. I have been consulted on ongoing changes and operations of the project
g. I have reviewed the project (e.g., government applications, permits)
h. I have received communication about the project (e.g., through newsletters, seminars, information posts or other communication)

4. When considering the following economic, environmental and social benefits of the Industrial Symbiosis Network which you are connected to, please assign each statement one of the following responses:
   - This benefit is not offered by my IS network
   - Very high importance
   - High importance
   - Neutral importance
   - Low importance
   - Low importance

   If the benefit is not offered by your IS network, please select that option. If the benefit is offered by your IS network, please rank it from Very high importance to No importance.

Economic Benefits

a. My IS network increases the material efficiency for me or my company
b. My IS network increases the energy efficiency for me or my company
c. My IS network reduces costs for me or my company
d. My IS network leads to higher revenues for me or my company
e. My IS network leads to a competitive advantage for me or my company
f. My IS network leads to economic growth for my region or community
g. My IS network leads to higher levels of employment for my region or community

Environmental Benefits

a. My IS network reduces the impacts of climate change by reducing atmospheric CO_2 or other greenhouse gases
b. My IS network reduces chemical pollution and hazardous waste
c. My IS network reduces biodiversity loss and extinction of species
d. My IS network reduces acidification effects
e. My IS network impacts the way land is used or converted
f. My IS network reduces impacts from biogeochemical flows such as nutrients like phosphorus and nitrogen
g. My IS network limits ozone depletion or reduces the use of ozone-depleting substances
h. My IS network reduces freshwater use or has a positive benefit on water quality
i. My IS network reduces particulate matter in the atmosphere

Social Benefits

a. My IS network improves the water supply or sanitation for me and/or my community
b. My IS network improves food security and food supply for me and/or my community
c. My IS network improves the physical, mental, and social well-being of me and/or my community
d. My IS network improves knowledge and education including learning, training, innovation or skill building for me and/or my community

e. My IS network provides increased income and/or job opportunities to me and/or my community
f. My IS network provides equal opportunity for all genders
g. My IS network has increased my community's engagement and participation
h. My IS network has increased my or my community's network in which we work, share, and cooperate
i. My IS network provides equal opportunity for all individuals
j. My IS network has a benefit for housing, living costs, or residential comfort
k. My IS network has increased energy access for individuals and/or households
l. My IS network has increased peace and/or regional identity in my community
m. My IS network has improved justice through workers' rights and other means