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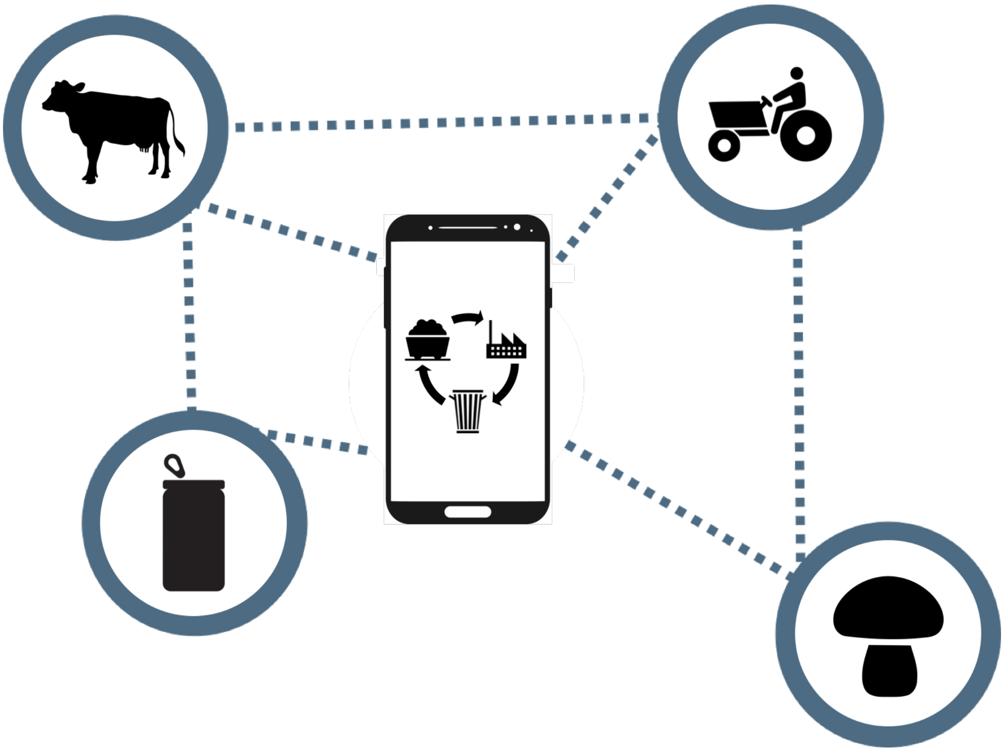

Identifying opportunities for bottom-up industrial symbiosis

Evaluating a method of data gathering for information exchange platforms

Master's thesis at the Challenge Lab

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Gothenburg, Sweden 2017

Master's thesis FRT 2017:10

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Cover: Information exchange platform visualising opportunities for symbiosis

Typeset in LaTeX
Gothenburg, Sweden 2017

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Abstract

Industrial symbiosis is a way to reduce the demand on the earth's resources by enabling the use of waste from one industry as raw material in another. Different interventions are needed to facilitate industrial symbiosis and one of these are information exchange platforms. There is no existing platform for promoting regional symbiosis in the Gothenburg area. For such a platform to be able to facilitate industrial symbiosis it has to contain relevant data. The purpose of this thesis is to investigate what data that should be included in such a platform. We will also evaluate a method of how the data should be collected and organised to make it comprehensible. This will be explored in the thesis by answering the following research question:

> **How can data be collected and organised for an information exchange platform to support bottom-up industrial symbiosis?**

This project maps the closed loop supply chains of beer and mushroom in the Gothenburg region and quantifies the recurring waste streams related to those industries to identify symbioses opportunities with other industries. 18 interviews were conducted with companies in the two supply chains as well as other relevant stakeholders to gather data and understand the current system. Furthermore, the approach of this thesis is evaluated in order to develop a method that could be used for an information exchange platform to support industrial symbiosis. Five steps were identified; (i) collect data, (ii) structure data, (iii) identify opportunities, (iv) investigate feasibility of opportunities, (v) facilitate the opportunities.

Opportunities for symbiosis in the case studies were identified both within and outside of the investigated system. The most promising opportunities in the beer chain is to use the spent grain and yeast as animal feed. For the mushroom chain the most feasible opportunities are to recirculate spent mushroom compost as soil amendment and mushroom leftovers as animal feed or further refine it to additional products. Some of the stakeholders have symbiotic relationships in place for those resources and these could be mimicked by the ones not already engaged.

This thesis is conducted at Challenge Lab, at Chalmers University of Technology, which aims to guide master students to become change agents and take on complex societal sustainability challenges. The thesis process in Challenge Lab utilises backcasting to find research questions and to find strategies for a sustainable future.

Keywords: Industrial symbiosis, bottom-up, opportunity identification, information exchange platform, material recirculation

Acknowledgements

This thesis have been a true challenge and we would like to send our gratitude to the people that have supported us during this journey. First and foremost, we would like to thank our supervisor, Leonardo Rosado, who boosted us through our weekly therapy sessions every Friday. João Patrício has also been supportive and provided valuable feedback at these sessions.

Also, we would like to thank the Challenge Lab team for creating this space and making this thesis possible, John Holmberg, Örjan Söderberg, Johan Larsson and Andreas Hanning, with extra thanks to the coordinator of the lab Andreas for his constant support. Our fellow master thesis students at Challenge Lab should also have great thanks for sharing this roller coaster journey with us and making it to an unforgettable experience.

Furthermore, we would like to thank all stakeholders, we really appreciate that you took your time, answering our questions. Without you, this thesis would not have been possible.

Lovisa Axelsson & Simon Blomé, Gothenburg, June 2017

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List of Abbreviations

BOD Biochemical oxygen demand

ICT Information and communications technology

IS Industrial symbiosis

MFC Microbial fuel cell

MLP Multilevel perspective

MWH Municipal waste handling

NISP National industrial symbiosis programme

SMC Spent mushroom compost

1

Introduction

The world today is facing many complex challenges such as climate change and disturbances of natural cycles that have to be dealt with in the near future (Rockström et al., 2009). The former UN Secretary-General Ban Ki-moon states that these challenges are universal and calls for a transformative and integrative approach (United Nations, 2014), or as Geels (2011, p.25) puts it *"[...] sustainability transitions are necessarily about interactions between technology, policy/power/politics, economics/business/markets, and culture/discourse/public opinion."* Therefore, collaborations between different actors will be needed. John Holmberg (2014) the founder of Challenge Lab at Chalmers University of Technology, stresses the importance of collaboration within the triple helix - academy, industry and public sector. At Challenge Lab, where this thesis is conducted, the students are empowered to become change agents and take on regional sustainability challenges (Holmberg, 2014). In the lab, the students define their own research questions by applying the backcasting methodology. Criteria for a sustainable future are developed and compared with the current situation and within this gap a challenge is identified that lead to a research question.

Our challenge was identified through stakeholder dialogues and desk research as how the use of resources can be done more efficiently. Intensified global competition for resources is also one of the global megatrends identified by European Environment Agency (2017), this increased demand of resources is driven by an increasing global population, economic growth and a growing middle class. The demand for resources is expected to grow but the supply is more uncertain which can lead to unreliable access and price volatility for some resources (European Environment Agency, 2017).

One way of dealing with this problem is with the concept of circular economy. Circular economy is according to Ellen MacArthur Foundation (2015, p.5) *"[...] restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles."* In a circular economy waste is reduced since products and materials are designed to be repaired, reused, remanufactured and recycled. The European Commission (2011) states that one key to circular economy is to turn waste into a resource and one way of doing that is through industrial symbiosis where waste from one industry become a resource in another industry (European Commission, 2011).

Industrial symbiosis is widely explored in literature (Chertow, 1998; Côté and Cohen-Rosenthal, 1998; Chertow, 2007) and one of the most well-known examples is Kalundborg, where the companies are situated nearby and exchange waste and by-products with each other (Ehrenfeld and Gertler, 1997). This is an effort that started in the 1960's through bottom-up collaborations inheriting from that the management of several companies were acquainted.

Industrial symbiosis can also be performed on a regional level (Jensen et al., 2011; Costa and Ferrão, 2010) with the National Industrial Symbiosis Program, NISP, in the United Kingdom as one well-known example. That is a private sector initiative but with governmental support (Jensen et al., 2011). In this program a third party facilitates the resource symbiosis by identifying possible symbiosis and conducting workshops with the companies involved. Another regional project is Grøn industrisymbiose in Denmark where an external party screened the participating companies for symbiosis potential and then matched different companies (Steinhausen, 2017).

Coordination plays an important role to strengthen and encourage new industrial symbiosis initiatives and Chertow (2007) suggests three potential programs to bring forward industrial symbiosis possibilities; disclosure of possibilities for IS, assisting the possibilities to grow and catalysing new possibilities. These three actions could be performed by different actors in society, for example academic researchers can disclose possibilities for IS by mapping resource flows in an area and business associations can assist possibilities for IS to grow (Chertow, 2007). Costa and Ferrão (2010) summarise different interventions that are beneficial for promoting symbiosis with the perspective of different agents, see table 1.1.

Table 1.1: *Excerpt of table on findings from a literature study regarding interventions by different actors to promote industrial symbiosis (Costa and Ferrão, 2010, p. 986)*

Agent	Intervention
Government	Environmental regulation: water, air and waste (target/limits requirements; management process)
Government Institutions	Emission of permits
Private Associations (e.g. Industry, Business, Environment)	Information exchange platform Network development and promotion Mediation role Monitoring
Universities	Uncovering of linkages Economic/Environmental analysis of linkages Report of synergies
Business	Identification of business opportunities in resource management Economic validation of linkages Funding of uncovering/discovery opportunities - network promotion Regional networks/clusters R&D for reuse/recycling technologies Green twinners

As it can be seen there are four interventions related to private associations; information exchange platform, network development and promotion, mediation role and monitoring. All of these interventions might not be required to support symbiosis in all cases. NISP and Grøn Industrisymbiose mainly works with network development and promotion, and mediation between companies in their role as facilitators. However, an information exchange platform can be a helpful tool to facilitate industrial symbiosis. One example of an existing information exchange platform is Loop Rocks[1], initiated by NCC in Sweden, that works as a facilitator and recirculate secondary raw materials at construction sites by making it easy for the users to match supply and demand. However, this platform is only applied for occasional resource flows, nevertheless, it would be interesting to see if a similar platform could be developed for recurring resource flows and what information that has to be included.

1.1 Purpose and Research Question

The purpose of this thesis is to investigate what data that should be included in an information exchange platform to support industrial symbiosis. We will also evaluate a method of how the data should be collected and organised to make it comprehensible in such a platform. This will be explored in the thesis by answering the following research question.

- **How can data be collected and organised for an information exchange platform to support bottom-up industrial symbiosis?**

This research question will be investigated by addressing the following objectives:

- *What type of data needs to be collected?*
- *How can data be gathered and how can it be assured that the collected data is complete?*
- *What possibilities for symbiosis can be identified through this data collection?*

1.2 Approach

The approach used in this thesis is to evaluate a method for collecting and organising data in order to validate its suitability for identifying possibilities for industrial symbiosis. This is done through two case studies in the region around Gothenburg covering small and micro companies producing beer and mushrooms.

The data is collected through interviews with producers of beer and mushroom to be able to map the closed loop supply chains of the products. The data contains information about resources, infrastructure and stakeholders within the supply chain. Existing symbioses within the system as well as symbioses opportunities outside of the system are identified through the interviews and literature review. To evaluate the feasibility of these opportunities drivers and barriers for symbiosis are identified among the stakeholders.

[1] looprocks.se

1.3 Outline of the thesis

Phase 1 introduce a background of the Challenge Lab and the methodology of backcasting including the tools used throughout the first phase of the thesis, such as self-leadership and dialogue. In the results of phase 1 the outcome of the backcasting methodology is presented with the research question as a final output.

In Phase 2 the research question is explored through a theoretical framework regarding industrial symbiosis and state of the art solutions to utilise by-products and waste from mushroom and beer production. In the method the different tools applied, such as mapping of the closed loop supply chains, semi-structured interviews and opportunity identification, are presented. The data gathered from the interviews as well as a map of the existing symbioses are presented in the results. A discussion of possibilities to implement new symbioses within or between different supply chains is also presented, along with a discussion of how the method used supports data collection and identification of new opportunities for symbiosis. In the end is the conclusions and possibilities for future research presented.

Phase 1

This part aims to describe the process of Phase 1 which includes a description of Challenge Lab and the backcasting methodology with the research question as the main output.

2

Introduction to Challenge Lab

Challenge Lab, at Chalmers University of Technology, is a student-driven transition arena where students take on sustainability challenges during their master theses. These challenges are complex and include different elements of the socio-technical systems e.g. legislation, norms, technology and infrastructure. A transition of these systems require changes of both technology as well as changes of other included elements (Geels, 2005). To achieve these transitions there is a need for collaboration between different actors in the system. Both between the three actors in the triple helix; academia, business and society but also between the three parts of the knowledge triangle; education, innovation and research (Holmberg, 2014). The Challenge Lab is centred in the triple helix with the possibility to increase the collaboration between the actors, see figure 2.1. The lab is physically located at a science park which is a neutral arena where collaborations between different actors are promoted.

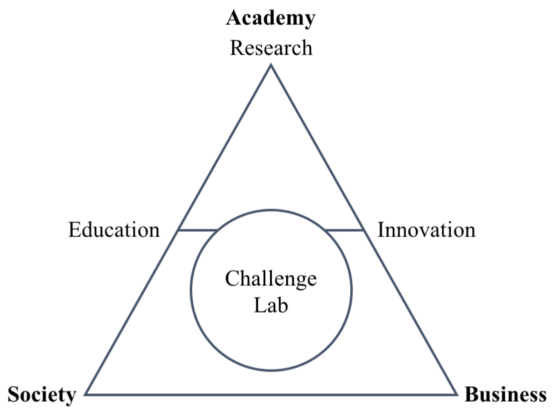

Figure 2.1: *Challenge lab in the middle of the triple helix and knowledge triangle (adapted from Holmberg (2014)).*

The neutrality of the students is an important feature to enhance the collaboration between the actors since they do not represent any organisation. Students have the possibility to be non-threatening and challenging at the same time which is crucial to deal with the needed changes. In Challenge Lab space is created for students to become change agents and equipped with different methods and tools including backcasting, dialogue facilitation, self-leadership and tools to understand their own values and strengths. This is done during the master thesis but the students have the opportunity to take a preparatory course *Leadership for sustainability transitions*. Challenge Lab works cross-disciplinary with students from different master's programmes and with different nationalities (Holmberg, 2014). A quote by the founder of Challenge Lab that is a good representation of the mindset in the lab is:

> “*Think big, start small, act now*
>
> *- John Holmberg*”

3

Theoretical framing of phase 1

The overarching framework which the Challenge Lab is based on is a backcasting methodology with the starting point in a criteria formulated upon non-overlapping principles for sustainability. This theory section will give a background into backcasting and the tools used within the methodology.

3.1 Backcasting - from sustainability principles

To be able to handle complex system transitions in a structured way, backcasting from sustainability principles can be used. Five points has been identified in the literature for when the backcasting process is a useful methodology (Dreborg, 1996, p.816).

- *when the process to be looked at is complex*
- *when the change required is on a fundamental level where it is not sufficient with a change that is only incremental*
- *when the current trends are part of the problem*
- *when the problem is to a great extent caused by externalities that can not be treated satisfactorily*
- *when the time line is long enough to take deliberate choices*

The backcasting methodology is divided into four steps. The first step is to define a framework for the future that is wanted, the second step is to define the present situation in relation to the framework, the third step involves envisaging future solutions that could bridge the gap's identified between the first and the second step, and the forth step is how to find a way of reaching those future solutions (Holmberg, 1998). A schematic of the process can be seen in figure 3.1.

The different steps are approached from two different perspectives, using an outside-in perspective to understand the requirements for a sustainable future on a system level and an inside-out perspective to understand personal values and strengths as well as the interaction with and between the stakeholders that are connected (Holmberg, 2014).

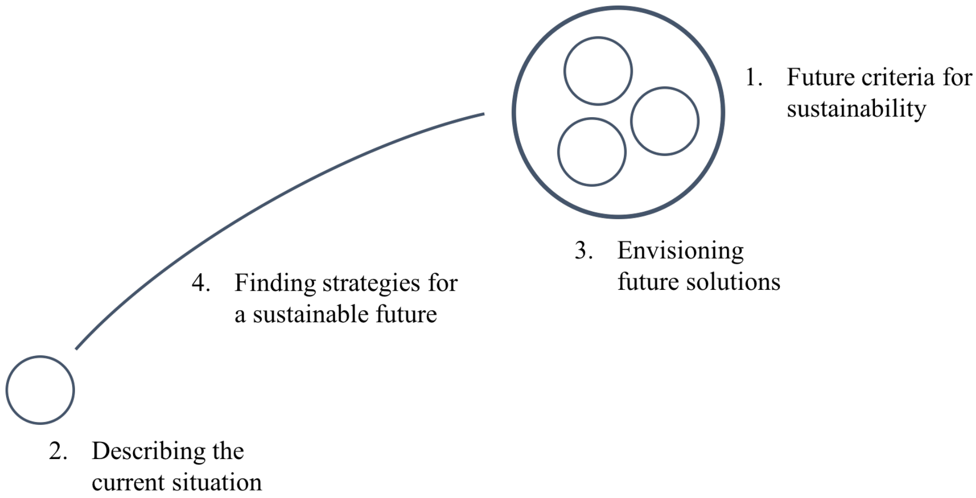

Figure 3.1: *A schematic of the methodology of backcasting from sustainability principles (adapted from (Holmberg, 1998)).*

3.1.1 Step 1 - Defining criteria for sustainability

The backcasting methodology starts with defining criteria for a sustainable future, by approaching from this future state the method avoids extrapolating current processes which might be part of the problem (Holmberg, 1998). The criteria is divided into four pillars relating to different aspects of sustainability, the theory is based on Herman Daly's triangle of means and ends, but developed by John Holmberg into the four pillars, with the nature as the base and society and economy as required building blocks to create well-being which is located at the top, as can be seen in figure 3.2.

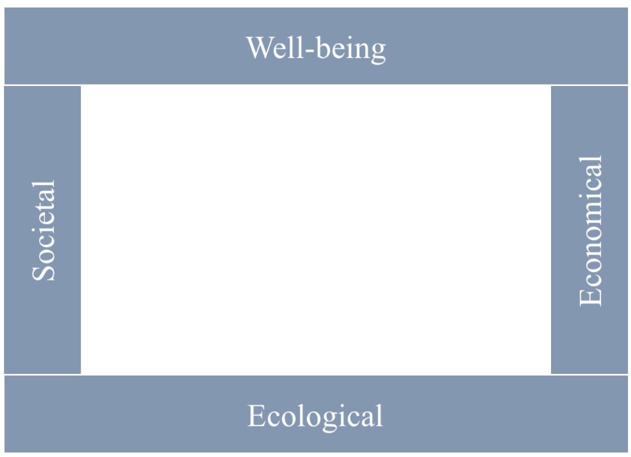

Figure 3.2: *The four pillars needed to build the future criteria for sustainability, developed by (Holmberg, 2014).*

Holmberg and Robèrt also define four system conditions that are required for ecological sustainability and how society should use resources (Holmberg and Robèrt, 2000, p.301):

In order for a society to be sustainable, nature's functions and diversity are not systematically

- *... subject to increasing concentrations of substances extracted from the Earth's crust;*
- *... subject to increasing concentrations of substances produced by society;*
- *... impoverished by over-harvesting or other forms of ecosystem manipulation*
- *... resources are used fairly and efficiently in order to meet basic human needs worldwide.*

Outside-in perspective

The UN Sustainable Development Goals is one way of defining a sustainable future from an outside-in perspective. It consists of 17 goals to end poverty, protect the planet and guarantee prosperity for all. It is planned to be accomplished within 15 years from its adoption in 2015 (UN, 2015).

Rockströms planetary boundaries propose a framework to maintain the stable Holocene state where the earths regulatory capacity can cope with the environmental changes (Rockström et al., 2009). This is a way of defining the safe operating space for humanity in regard to earths own systems by identifying threshold values that if crossed, can generate unacceptable environmental change. Nine such thresholds have been identified as crucial for processes related to the stability of earths resilience. The planetary boundaries that Rockström et al. (2009) have described are: Climate change, Rate of biodiversity loss, Nitrogen and phosphorus cycles, Stratospheric ozone depletion, Ocean acidification, Global freshwater use, Change in land use, Atmospheric aerosol loading and Chemical pollution.

Inside-out perspective

Climate change, global poverty and biodiversity loss are referred to as "bigger-than-self" problems in the WWF-report Common Cause (Crompton, 2010). These are, according to that definition, problems that individuals do not have immediate self-interest to invest energy in. What is identified with these problems is that facts only play a limited role in decision making and that emotions often are more important (Kahneman, 2014), which in particular are led by dominant cultural values. This is the reason why the inside-out perspective must be included when creating criteria for the future.

3.1.2 Step 2 - Understanding today's situation

The second step of the backcasting methodology is to define and understand today's situation from the two perspectives, outside-in and inside-out. Systems thinking, including multi-level perspective (Geels, 2002) and leverage points (Meadows, 1997) helps to see the system from an outside-in perspective and stakeholder dialogues provide the inside-out perspective.

System thinking is useful when handling complex problems, which is one of the characteristics of sustainability challenges. According to Senge's *Fifth discipline* reviewed by Flood, it is not possible to solve complex problems by breaking them into parts since the interrelatedness of the parts will get lost. By breaking it apart you remove the possibility of seeing possible repercussions of the actions (Flood, 1998).

Outside-in perspective

The multilevel perspective (MLP) is one way of looking at complex systems. The MLP defines three analytical and heuristic levels to understand socio-technical changes and system innovation and this is illustrated in figure 3.3. The three levels are interlinked with each other and a transition of the system occurs through interactions between dynamics at the three levels (Geels, 2002).

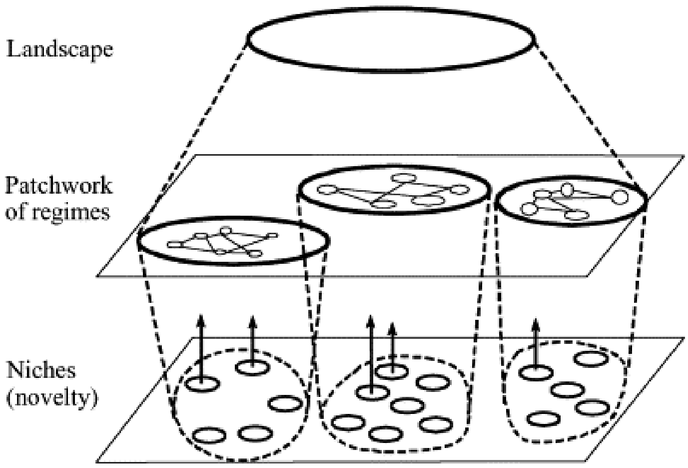

Figure 3.3: *The multi-level perspective with the macro-level (landscape), meso-level (regimes), micro-level (niches) (Geels, 2002).*

The macro-level is formed by socio-technical landscape and it is defined by external factors such as demographic trends, environmental problems and globalisation. Changes at the landscape level are often slow and cannot be changed at will, however changes at this level may put pressure on the regime (Geels, 2002, 2005).

The meso-level is formed by socio-technical regimes with seven dimensions: technology, user practices & markets, infrastructure, industrial networks, sectoral policy, techno-scientific knowledge and culture & norms (Geels, 2002). Those elements are interlinked with each other and are created and maintained by several social groups. This makes the regimes stable, but the stability is dynamic which means that innovation still occur even though it is incremental changes (Geels, 2002, 2005).

The micro-level is formed by technological niches which are protected spaces where radical innovations are generated. Radical novelties can be developed in the niches without competing with the existing regime, which is needed since they often have low technical performance and are expensive (Geels, 2002, 2005).

Another way of looking at transitions of complex systems is the theory of leverage points, *"[...] where a small shift in one thing can produce big changes in everything"* (Meadows, 1997, p.78). Meadows also states that *"Leverage points are points of power"* (Meadows, 2009, p.145). In complex systems leverage points are not intuitive and they are often used to push the system in the wrong direction, making the problems in the system worse instead of improving the system (Meadows, 2009).

Inside-out perspective

The system can be understood from an inside-out perspective by dialogues with stakeholders in the system. According to Isaacs (1999), dialogue is the art of thinking together and can be used to share perceptions and perspectives as well as surface ideas. This way dialogues can also be a tool for increasing trust in the system since it increases listening and understanding (Isaacs, 1999). This is illustrated by (Jewell-Larsen and Sandow, 1999) in figure 3.4. Collaboration is important to achieve creativity and innovation in a system which is crucial for system transitions.

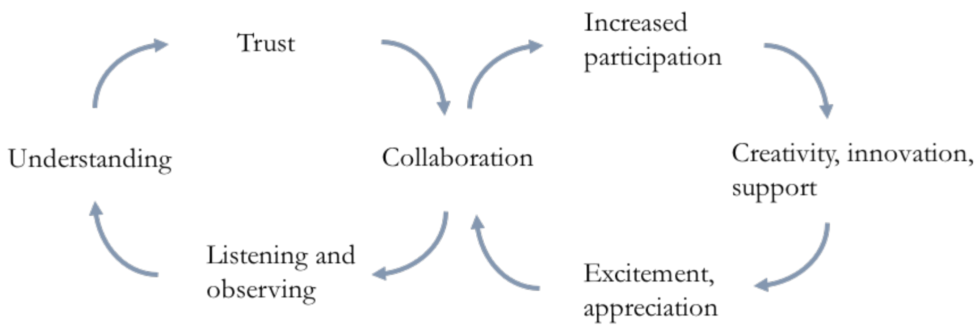

Figure 3.4: *Collaborative process adapted by (Jewell-Larsen and Sandow, 1999).*

If the system lacks listening and understanding it can lead to social separation and resource depletion instead as illustrated by Jewell-Larsen and Sandow (1999) in figure 3.5. Industries today do often focus on increasing efficiency and reducing costs instead of on reflection and learning within the organisation. However, dialogues can be one way of increasing organisational effectiveness by thinking together (Isaacs, 1999).

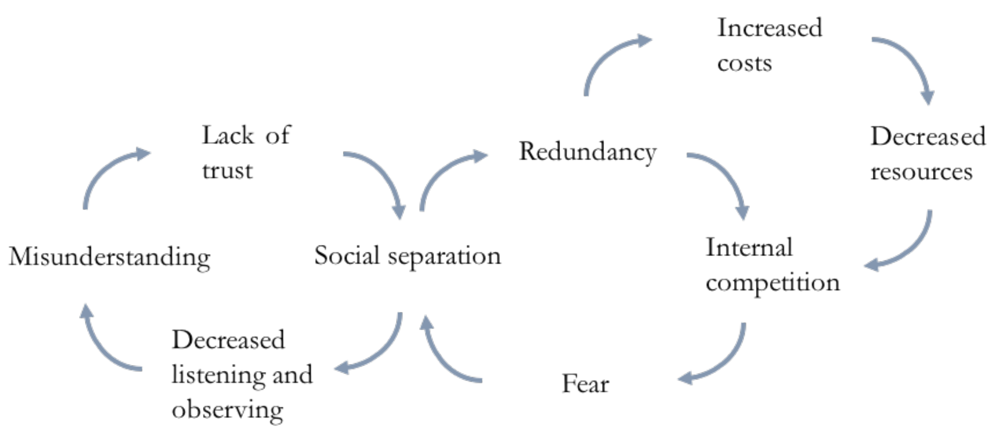

Figure 3.5: *Internal competitive process adapted by (Jewell-Larsen and Sandow, 1999).*

Dialogue does not have to seek agreement among the participants but it opens up for increased coherence in the group and the possibility for shared thinking (Isaacs, 1993). Dialogue requires a facilitator who is neutral and aware of ones own reactions to set up the principles and intention of the dialogue. The facilitator should be Isaacs (1993, p.33) state initial guidelines of how to facilitate a dialogue:

- *Suspend assumptions and certainties*
- *Observe the observer*
- *Listen to your listening*
- *Slow down the inquiry*
- *Be aware of thought*
- *Befriend polarisation*

A dialogue can be facilitated in many different settings and one of them is the fishbowl setup, which is illustrated in figure 3.6. This is a useful approach to reveal the knowledge of experts and increase the collective understanding of a topic in a larger group and to gain new perspectives. In this setup the inner circle is where the actual conversation takes place while the outer circle is listening and taking notes of what is said (UN, 2011).

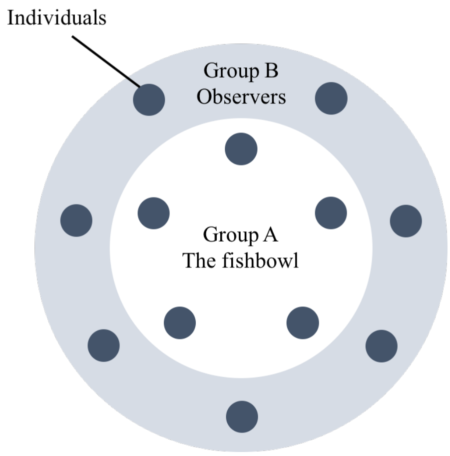

Figure 3.6: *The fishbowl setup (adapted by (UN, 2011).*

3.1.3 Step 3 - Envisaging future solutions, Design thinking

Future solutions, that fits within the criteria for sustainability, can be envisaged to bridge the gap that can be identified between what should be and what currently is. In this step it is important to avoid having a static view of the current circumstances in order to be receptive to future possibilities. Design thinking is a tool that can be used to structure these types of creative design processes. The process is divided into three parts, pre-study, development and verification, each containing overlapping steps that are iterated (Söderberg, 2014). The different parts with the overlapping steps are displayed in figure 3.7.

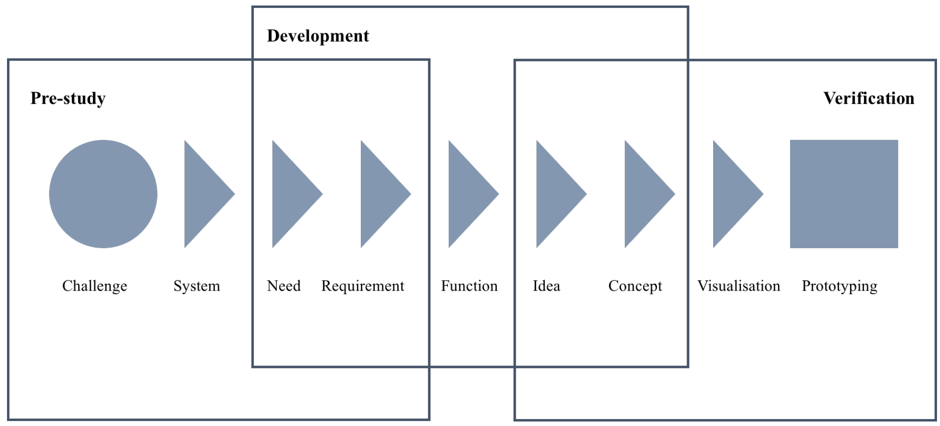

Figure 3.7: *The nine steps of design thinking showing the overlapping parts, adapted from (Söderberg, 2014).*

The pre-study consists of both the inherent knowledge of the team as well as the information that is acquired to be able to complete the project. This part is of utmost importance for the success of the project as this is where you define the direction of the project and the delimitations. In the second part, development, it is important to be open minded and to challenge the right factors, this is the part where you brainstorm and have discussions to create a frame for the pre-study findings. Verification is the last stage of design thinking and this is where the development phase is concretised in text, drawings, pictures etc. both for the sake of the designer but also to enable discussions with stakeholders apart from the project (Söderberg, 2014).

The multilevel design model (Joore, 2010), brings a new perspective on design thinking inherent from the rapidly changing environment of product design. The multilevel design model relates design thinking to the MLP-model (Geels, 2005), by connecting design thinking of products to the socio-technical or societal context where it takes place. Joore identified that the previous design models were not suitable for sustainable development either because of being too product related without connecting to the societal aspects or of being too abstract which makes it hard to turn it into reality (Joore, 2010).

3.1.4 Step 4 - Finding strategies towards sustainability

The fourth step of the backcasting methodology is to find strategies of how to implement the solutions generated in step 3 and move towards the envisaged future. When creating this strategy, these points should be considered (Holmberg, 1998, p. 39):

- *Will each measure bring us closer to sustainability?*
- *Is each measure a flexible platform for the next step towards sustainability?*
- *Will each measure pay off soon enough?*
- *Will the measures taken together help society to make changes at a sufficient speed and scale to achieve sustainability without too many losses of human and other species during the transition?*

These points have to be combined to design the measures that should be implemented to achieve a sustainable future.

4

Method of phase 1

In this chapter is the approach to apply backcasting in the Challenge Lab context described. Since Phase 1 of the thesis only involved Step 1 and Step 2 of the backcasting methodology those two steps are the only ones conveyed here. The overarching goal of the method was to result in well formulated research questions.

4.1 Backcasting Step 1 - Defining future criteria for sustainability

The first step of the backcasting process was created within the whole group of 16 students to make sure that everyone would feel ownership of the criteria upon completion. The broad distribution of backgrounds both culturally and academically brought a wide perspective to build the criteria on. To enhance the outcome, it was built on the criteria created in the preceding course *Leadership for sustainability transitions*, which the vast majority of the group took part in, and the criteria that was made by the last years Challenge Lab students. The theory background from the UN sustainability goals (UN, 2015), and Rockströms Planetary boundaries (Rockström et al., 2009), also played a role in defining the criteria.

The criteria was created in smaller groups where each one were responsible for one of the four pillars, nature, economy, society or well-being. After the separate building blocks had been processed, the whole group reunited to discuss the principles that had been created. This way everyone in the group could add to each of the pillars of the criteria and feel that their personal values were included in the criteria for sustainability in the future.

During the first step there was also a workshop on self-leadership where focus was on defining personal values together with strengths and weaknesses. This enhanced the ability to add the inside-out perspective during the process. The workshop incorporated exploration of the personal values by having monologues in smaller groups, where the values could be expressed thoroughly by talking, without interruptions, for 15 minutes about them. There were also group discussions about what values are and where they come from but also why they are important.

4.2 Backcasting Step 2 - Understanding today's situation

The second step of the backcasting process was performed in the whole group by engaging with people that are part of the system. The climate strategy and the focus areas of the Västra Götaland region were presented to the group to increase the understanding of what is happening on a strategic level in the region. To get a deeper knowledge of the system, three stakeholder dialogues were conducted with themes that were chosen with respect to the climate strategy and ongoing projects in the region. The themes of the dialogues were circular products and services, urban futures, and mobility. To enhance the outcome, information on the themes was gathered through the internet, one to one talks and discussions within the group prior to the dialogues. The participating organisations can be seen in tables 4.1.

Table 4.1: *The organisations participating in the three dialogues*

Dialogue 1 - Circular products and services
Chalmers Industriteknik
Innovation and Chemistry industries in Sweden
West Swedish Chemistry and Material cluster
Chalmers University of Technology
Dialogue 2 - Urban futures
Chalmers University of Technology
Yes In My BackYard - YIMBY
Göteborgs Stad - Kretslopp och Vatten
Älvstranden Utveckling AB
Chalmers University of Technology
Framtiden AB
Dialogue 3 - Mobility
Göteborg Stad - Trafikkontoret
Chalmers University of Technology
DenCity
Yes In My BackYard - YIMBY
RISE Viktoria
Chalmers University of Technology

The gathered information resulted in a map of challenges for each of the themes, based on gaps that were discovered between today's situation and the envisaged future. These maps were used as a background for the dialogues to see if the stakeholders saw the same or other challenges in the system and if there were any ongoing projects or processes connected to them. The goal with the dialogues was to identify leverage points where it was possible for us to intervene in the system.

The dialogues were held in a fishbowl setting with two students acting as facilitators and between four and seven stakeholders from the triple helix. The stakeholders were placed in the inner circle together with a few students while the other students were placed in the outer circle listening and observing the conversation. The outer circle did also get the opportunity to comment on the conversation and ask questions to the stakeholders.

The information from the dialogues were compiled within the group and added to the maps of the challenges. This was an iterative process where the leverage points were refined, new were added and some were discarded through further information gathering. Personal perspectives were added to the leverage points with respect to study background and personal interest. All leverage points were iterated until a clear starting point was identified and it was possible for all students to make a qualified choice of where to focus their effort. With respect to these choices it was possible to form eight thesis pairs. These pairs continued to refine the chosen leverage point with further investigation until it was possible to formulate a research question.

5

Results of phase 1

The final outcome of Phase 1 is a defined research question, but this chapter does also include sub-results from the backcasting process. This chapter starts with highlighting the results of the first step of the backcasting method with the future criteria for sustainability and proceeds with the outcome of the dialogues. A reflection around phase 1 is presented in the end of the chapter.

5.1 Future criteria for sustainability

The group defined the criteria for sustainability based on the criteria of Challenge Lab 2016 as well as the criteria from the course *Leadership for sustainability transitions*, 2016:

Nature (Ecological conditions)

- Substance[1] emission: Nature is not subject to systematically increasing concentrations of substances.
- Substance extraction: Substances are not extracted in a way it disturbs the balance of natural cycles.
- Ecosystem balance: Exist in harmony as one system, enabling ecosystem services and biodiversity.

Inspired by Holmberg and Robèrt (2000), UN (2015) and Rockström et al. (2009).

Economical

The economic system is an instrument that enables the other criteria, to be met efficiently and effective in such a way that:

- Resources[2] are used indefinitely non-depleting.
- It ensures a fair distribution of resources
- It is resilient to disturbance and disruption and is flexible enough to adapt to changing conditions
- It facilitates transparency and trust

Inspired by UN (2015).

[1]Substance is in this context defined as a species of matter of definite chemical composition.
[2]Resources include natural and man-made.

Societal

A sustainable society is a system of individuals built upon the following criteria:

- Empowerment
- Equity & justice
- Trust (such as between individuals, transparency)
- System for well-being (maintain access to food, medical service, support & safety)
- Openness to development and novelty

Inspired by UN (2015).

Well-being

- Everyone should have the right to human basic needs (subsistence, protection), such as health, security, food, water, sanitation, recreation, shelter, energy
- Human life should fulfil psychological needs, such as affection, understanding, participation, idleness, creation, identity
- Everyone should have the equal opportunity and freedom
  - To choose or to opt out
  - To express one's identity
  - To define and pursue their own goals, objectives and commitments without limiting others' freedom or harming others

Inspired by Cruz et al. (2009) and UN (2015).

5.2 Outcome from the dialogues

The first dialogue was around circular products and services which proved to be the most useful of our topic, following are the major takeaways from that dialogue. From the dialogues we got the understanding that there is a lot happening around industrial symbiosis. The stakeholder from Chalmers Industriteknik mentioned that viable business models are required to create a circular economy and that the transition is easier if it is taken in small steps. The researcher from Chalmers was talking about that bottom-up initiatives can aid transitions of policies and behaviour. Upon the topic of waste management did the stakeholder from the Chemistry and Material cluster say that a way to improve waste management could be to connect industries, and it was added that digitalisation can aid this connection to support the transition to a circular economy.

There was also a discussion about value chains and how to track them, it was mentioned that for some industries it is relatively easy but for others it is very complex. In addition to that, some companies is not responsible for the material cycles themselves but the suppliers, while other companies work closely with their suppliers to have control over them but it is very complicated to organise and maintain such a system. Another issue that was brought up is the lack of communication but it is not only about spreading information, it is also that we have to much information which hinders us from receiving the information that we need.

5.3 Pathway to research questions

The iterative process and refinement resulted in a leverage point centred around industrial symbiosis, i.e. how waste or byproducts from one industry could be used as raw material by another industry. The leverage point is mainly connected to the nature criteria since an increased circularity can lead to less substance emissions and substance extraction. Industries in the system could however, be affected on an economical level as well through lower costs and the evolution of new business opportunities.

Our perspectives on the leverage points differs depending on our backgrounds and interests. Simon studies Materials Engineering and wanted to add the perspective of how material usage can be made more efficient throughout the industry sector. Lovisa studies Sustainable Energy Systems and wants to apply a system perspective to increase the sustainability in the system and avoid sub-optimisations.

With these perspectives in mind we gathered information about ongoing projects of industrial symbiosis through different sources e.g. websites, articles and technical reports. We found that there is a lot happening in the field right now and that it seems to be a very hot topic. To further enhance the understanding of the topic we talked with people with different perspectives on the leverage point, one stakeholder with a researcher perspective and one with an entrepreneurial bottom-up perspective. To get a more top-down perspective a meeting was held with two project leaders who have experience of facilitating industrial symbiosis projects. They saw different barriers for more industrial symbioses to happen but all of them were interested in overcoming those barriers. For example they knew that coffee grounds could be used for growing mushrooms, but the nutrients in the coffee grounds is not used today, instead the coffee waste is used for producing biogas. This made us interested in how to spread knowledge about and visualise different waste streams in Gothenburg. This information can then be used to investigate if that would increase the probability of industrial symbiosis to happen and also to see if something in addition to knowledge is required.

The project will focus on how industrial symbiosis can be aided for smaller companies from a bottom-up perspective. We decided to focus on smaller companies because it appeared like many of the current industrial symbiosis efforts are directed towards larger industries that are located next to each other. We want to investigate how regional industrial symbiosis could be facilitated and supported for companies without prior connections.

5.3.1 Research Questions

The processes resulted in a research question:

> **How can data be collected and organised for an information exchange platform to support bottom-up industrial symbiosis?**

This research question will be investigated by addressing the following objectives:

- *What type of data needs to be collected?*

- *How can data be gathered and how can it be assured that the collected data is complete?*
- *What possibilities for symbiosis can be identified through this data collection?*

5.3.2 Reflection around phase 1

A large part of phase 1 were conducted in the whole group which was both challenging and worthwhile. We were able to learn a lot from each other since we have different academic and cultural backgrounds but it was also difficult to find consensus in such a large group with different perspectives. The development of the criteria for sustainability is an example of when we experienced all of this. Since everyone had to agree upon the criteria, the result is quite general and may not be as useful for all groups in their respective project. This could have been improved if the criteria were developed in smaller groups but then you will loose the common ground that is created in the group through the criteria.

One thing that could have been improved with phase 1 is how we prepared and managed the dialogues. Instead of reading articles about initiatives in the topics for the dialogues more specific research should have been performed on the stakeholders who attended. We had a hard time identifying leverage points after the dialogues, which inherited from that the conversations were mainly held on a quite general level without going into detail about what the stakeholders were working on or where they saw a lot of interest in the city. The following process became more difficult because of this and we had to spend a lot of time defining leverage points, this could have been prevented by more thorough research of the stakeholders.

Industrial symbiosis were not vastly discussed in the dialogues but when we started to look with more detail into the topic we found a lot of interest and several ongoing projects in the field. However, it has been very hard for us to define a problem owner that find interest in our project. This is important for us since we want our findings to be seen to be able to have some impact. It would be motivating if our thesis could be used in any way to increase industrial symbiosis initiatives in the city.

Phase 2

This part explores the research question, which is the outcome of phase 1, and starts with a background to industrial symbiosis including how information and communication technology can be used to support it.

6

Background and theoretical framing of industrial symbiosis

One of the most commonly used definitions of industrial symbiosis is the one presented by Chertow (2000, p.314):

> “
> *The part of industrial ecology known as industrial symbiosis engages traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity.*
> ”

Kalundborg is one of the most well-known industrial symbiosis initiatives and it involves physical exchange of both energy, water and by-products within a geographic proximity. The linkages between the companies have developed over a long time with the goal to reduce their costs of compliance with environmental regulations and making use of their by-products. In the case of Kalundborg the economic feasibility has played a major role and it has been important that both the producer and the user have gained on the transaction (Ehrenfeld and Gertler, 1997).

Kalundborg is a small town where the managers at the different companies meet on a regular basis which makes it easier to know about the surrounding industries inputs and outputs. This information is required for a symbiosis to take place but the information can be hard to acquire and the discovery costs can be high (Ehrenfeld and Gertler, 1997).

Lombardi and Laybourn (2012) argues that neither geographic proximity nor physical resource exchange is necessary for a synergy to be defined as industrial symbiosis and they have developed a new definition, Lombardi and Laybourn (2012, p.31):

> “
> *IS engages diverse organisations in a network to foster eco-innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes.*
> ”

One well-known industrial symbiosis project where the companies does not have to be located next to each other is the National Industrial Symbiosis Programme, NISP in the UK where IS is facilitated over large regions. The ambition is to increase resource efficiency by encouraging companies to reuse other companies by-products or waste. NISP establish contact with companies through both one to one talks and with workshops with several stakeholders. NISP try to identify all possibilities for synergies at the companies, both resources they need and resources they have and it can be regarding both expertise as well as material flows. Identified resource matches are then facilitated and completed. An analysis of the completed synergies showed that the median distance was 32.6 km and three-quarter of the synergies through material exchanges were within a distance of 62.6 km (Jensen et al., 2011).

A study of the regional potential for closing material loops in the Rhine-Neckar region in Germany showed that regional areas might be a good option for industrial symbiosis. It can have advantages due to greater numbers of actors that increase the possibility to match resource flows. However, a regional approach might bring some other challenges like additional cost for overcoming both mental and spatial distances, with increasing importance of indirect communication (Sterr and Ott, 2004). To overcome this and increase the possibility for industrial symbiosis to happen, at least two different instruments were identified as necessary. A research team developed two instruments according to this (Sterr and Ott, 2004, p.958):

- *An adequate network structure for the creation and promotion of mutual trust between relevant actors and for the discussion and preparation of coordinated actors.*
- *A waste management software for the standardisation, automation, and facilitation of data exchange within and between firms.*

These instruments can be related to the interventions identified for private associations to promote symbiosis in table 1.1; information exchange platform, network development and promotion, mediation role and monitoring (Costa and Ferrão, 2010). NISP intervene by developing networks and use their information database to mediate between different stakeholders when matching resource flows, which is more similar to the first instrument mentioned above.

Loop Rocks which was described in the introduction can be seen as an example of primarily the second instrument since it facilitate data exchange of resources between different companies as well as private persons. This is an example of an information exchange platform to support industrial symbiosis.

6.1 Information and communication technology for industrial symbiosis

Several information and communication technology (ICT) tools have been developed to support the creation of IS networks, though many have not had any significant impact (Grant et al., 2010). One of the problems of the early tools were said to be the lack of tacit knowledge such as experience and trust (Desrochers, 2004). Recycled metals and similar commodities can be traded on explicit knowledge but trading with waste materials typically requires more tacit knowledge than traditional material flows since they normally differ from the standard and is of varying quality (Grant et al., 2010).

By reviewing multiple ICT tools five primary phases have been identified for the development of IS through the use of these tools (Grant et al., 2010, p. 744).

1. *Opportunity identification*
2. *Opportunity assessment*
3. *Barrier removal*
4. *Commercialization and adaptive management*
5. *Documentation, review, and publication*

The first phase have been the focus for many ICT tools for IS and this phase can be divided into three different approaches for identifying symbiosis opportunities (Grant et al., 2010). Firstly, new process discoveries - when a by-product is turned into a resource through a novel approach. Secondly, input-output matching - where a raw material resource can be exchanged with a by-product instead. Thirdly, mimicking - where synergies that has already been implemented within similar organisations can work as a template for other companies (Grant et al., 2010). Input-output matching is an approach that is commonly performed through workshops and can be challenging to achieve through an ICT tool since the material flows might involve characteristics that are hard to put into code since they are more of tacit information. Mimicking on the other hand can be easier to codify since it can be done in a more standardised manner consisting of more explicit information about which companies that it connects and what they are doing. This information can then be applied to other companies of the same type (Grant et al., 2010).

6.2 Opportunity identification

As mentioned, mimicking is one way to identify opportunities for industrial symbiosis which implies that the existing solutions of how to use different resources has to be known. This section includes a summary of identified opportunities on how to use the by-products and waste created in beer and mushroom production. According to Ellen MacArthur Foundation (2017) it is beneficial to circulate resources at as high utility as possible, and this is how opportunities are used in this context. For example, energy recovery is not considered an opportunity for symbiosis if it is possible to use the resource at a higher utility.

6.2.1 Symbiosis opportunities related to beer production

Beer production can be performed in many different ways but the core concept stays the same. According to Olajire (2012) there are six major waste flows related to the production of beer however they might differ according to the process used:

- Wastewater
- Spent grain
- Spent yeast
- Kieselguhr sludge
- Trub
- Packaging material

Wastewater is the biggest waste flow with 3-10 liter per liter beer produced (Kanagachandran and Jayaratne, 2006), this derives from both the brewing process and the cleaning of the equipment. The part that comes from the brewing process is nutritious and its characteristics can be viewed in table 6.1 (Wen et al., 2010).

Table 6.1: *Characteristics of brewery waste water where COD is chemical oxygen demand, NH3-N is ammoniacal nitrogen, TN is total nitrogen and SS suspended solids (Wen et al., 2010)*

Characteristic	pH	COD (mg/L)	NH3-N (mg/L)	TN (mg/L)	SS (mg/L)
Value	6.5±0.4	1250±100	16±5	24±3	500±50

Most breweries today either dispose the wastewater directly into waterways, the municipal sewerage or the breweries own wastewater treatment plant. It is becoming an increasingly important part with water treatment plans since, the cost of water is rising and legislation is stiffening around the treatment of wastewater because if it is left untreated it will cause eutrophication of nearby lakes and streams (Simate et al., 2011). There are several research projects and businesses investigating possibilities of turning the wastewater from breweries into a resource instead of a cost.

A recent study in Sweden is looking into how the wastewater can be used to grow fungal biomass in order to clean the water and at the same time create value from it (Hultberg and Bodin, 2017). This is still in a very early research stage but shows that there is future potential in the subject. An example that is closer to implementation is how the wastewater can be treated and at the same time create electric energy through the use of a microbial fuel cells (MFC). The company Waste2Watergy[1] have developed this technology together with a brewery in order to commercialise a full scale solution (Kauffman, 2015). Cambrian Innovations EcoVolt system[2] is using a similar process called electromethanogenesis where MFC is combined with methane producing microbes. They are already fully commercial with on-site water treatment plants that can produce biogas from the wastewater and thereby fuel breweries with energy from their own waste product as well as clean water.

Algae is another way of cleaning brewery wastewater and at the same time create value from it. This can be done through harvesting the algae for the creation of biofuel, feed for animal or aquaculture or as organic fertilisers and research is looking in to it with promising results (Raposo et al., 2010; Mata et al., 2012). Water treatment plants for breweries using algae is also something that is approaching commercial viability (Economist, 2014).

Spent grain is the major solid waste that the breweries have with an average of around 14 kg/hL wort with a water content of 80% (Olajire, 2012). Fillaudeau et al. (2006) states that the most common use for spent grain today is as livestock feed and it can be sold for an average close to 5 €/ton. Another possible disposal is to bake bread out of it (Witkiewicz, 2012). The addition of hops after the wort has been boiled creates a wasteflow of trub which is seperated using a whirlpool. This waste is commonly mixed with the spent grain (Fillaudeau et al., 2006).

[1]http://www.waste2watergy.com
[2]http://cambrianinnovation.com

To start the fermentation process yeast is added in the fermentation tank which results in a waste source of yeast sludge of between 1.5-3% of the produced beer. This can be commercially sold as feed for animals after it has been heated to inactivate the yeast cells (Fillaudeau et al., 2006). Another possibility for the spent yeast is to turn it into nutritional brewer's yeast by debittering and drying it. It is usually sold in the form of flakes, powder, tablet or a liquid and is rich in protein and vitamin B which makes it a good supplement for vegetarians (Bekatorou et al., 2006). Fish feed is another possible usage for this by-product and up to 50% of the protein fed to fish be substituted without negative impact, there was even a positive growth rate achieved when substituting up to 30% of the feed with brewer's yeast.

Among some beer producers kieselguhr is used as a deep filtration agent to clarify the produced beer, in Europe the amount used is around 1,7 g/l beer. The sludge produced from this production step is a wasteflow that reaches amounts of 6 g/l of clarified beer, this is commonly disposed of as fertilizer for agriculture. The cost related to this wasteflow is ranging from an income of 7.5 €/ton to a cost of 1100 €/ton of purchased kieselguhr (Fillaudeau et al., 2006).

Table 6.2: *Identified opportunities for the waste and by-product flows in the production step of the beer closed loop supply chain*

By/waste-product	**Identified opportunity**	**Additional process required**	**Maturity**
Spent grain	Animal feed Bread ingredient		Commercial Commercial
Waste water	*Source for:* Biogas Fungi Algae	 Electromethanogenesis Fungi production Algea production	 Commercial Research Pilot
Yeast	Livestock feed Fish feed Nutritional brewer's yeast	Pasteurising Pasteurising Pasteurising and drying	Commercial Commercial Commercial
Kieselguhr sludge	Fertilizer		Commercial

6.2.2 Symbiosis opportunities related to mushroom production

According to the literature the biggest by-product flow from mushroom production is the spent mushroom compost (SMC) which accounts for 5 kg for every 1 kg of mushrooms produced (Williams et al., 2001). Most mushroom producers buy the mushroom substrates from a centralised substrate manufacturer. When the producer has received the substrates the mushrooms will be ready for harvest in a few days and will yield around 4 flushes. Phan and Sabaratnam (2012) states based on a literature study that producers on average creates 24 tons/month of SMC, in Ireland reaching a total of around 254 000 tons, in the Netherlands 800 000 tons. Mushroom substrate is commonly created by mixing agriculture residues such as wheaten straw, horse and/or chicken manure, gypsum, cottonseed meal and mushroom mycelium and is then bagged ready for production (Jordan et al., 2008).

When the mushroom is harvested a common disposal of SMC is as soil amendment and fertilizer on farmland, this has been investigated thoroughly and it has been shown to increase the yield of the farmlands (Stewart et al., 1998; Curtin and Mullen, 2007). There are also examples of how the SMC can be sold to private persons as compost to grow in, commonly under the name Champost[3][4], this is however not as commonly done in Sweden.

Table 6.3: *Identified opportunities for the waste and by-product flows in the production step of the mushroom closed loop supply chain*

By/Waste-product	Identified opportunity	Additional process required	Maturity
SMC	Soil amendment	Curing	Commercial

[3]http://www.eurocompost.be/producten/bodemverbeteraars/champignonmest/57
[4]http://www.thecompostshop.co.uk/products/#!/Mushroom-Compost/p/14437184

7

Method

Different tools have been applied in the approach of this thesis to be able to answer the research question and objectives. A schematic illustration of the method is shown in figure 7.1. The left box shows that the research question are used as an input for the method and the green box to the right illustrates the output of the method, including the organised data, identified opportunities for IS and a method evaluation. The blue box displays the tools used; closed loop supply chain, semi-structured interviews and opportunity identification, that are applied in this thesis. The yellow box represent how this thesis is managed, with two case studies including different parts. Some of these were carried out in parallel as illustrated in the figure and the process was also iterative when necessary. The interviews were refined throughout the process as well as the structure of the data. The three coloured boxes and their content are explained further in this chapter.

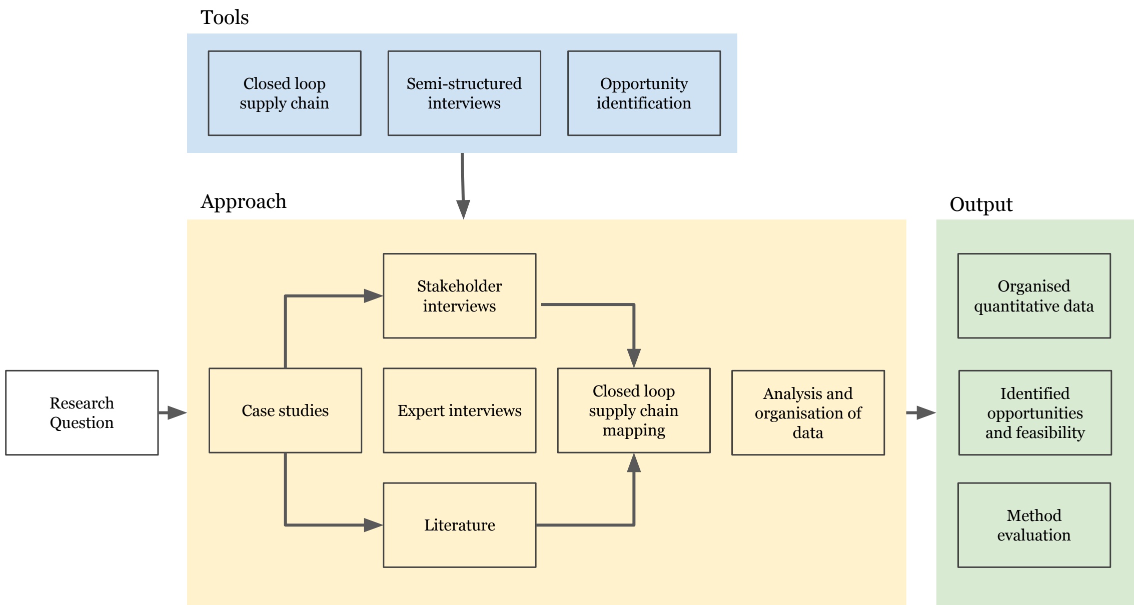

Figure 7.1: An illustration of the used method, with the research question as input, the blue box including the applied tools, the yellow box shows our approach and the green box the output of the method.

7.1 Closed loop supply chain

With the perspective of resource recirculation through industrial symbiosis, it is valuable to look into the entire product supply chain to uncover where symbiosis can be achieved. Both within the product supply chain but also between different supply chains. A supply chain can be seen as a process where different business entities work together with the intention to acquire raw materials, convert these raw materials into final products and to deliver these products to final consumers through retailers (Beamon, 1998).

In contrast to a forward supply chain that usually ends with the customer; a closed loop supply chain includes the return processes with the purpose of capturing additional value. According to Guide et al. (2003, p.3) these additional activities include:

- *Product acquisition to obtain the products from the end-users*
- *Reverse logistics to move from the points of use to a point(s) of disposition*
- *Testing, sorting, and disposition to determine the product's condition and the most economically attractive reuse option*
- *Refurbishing to enable the most economically attractive of the options: direct reuse, repair, re-manufacture, recycle, or disposal*
- *Remarketing to create and exploit markets for refurbished goods and distribute them*

The product supply chain includes different steps and business entities such as suppliers, manufacturers, distributors and retailers (Beamon, 1998) and for the purpose of this thesis the steps in the supply chain have been simplified to include five steps and an illustration of the closed loop supply chain is illustrated in figure 7.2.

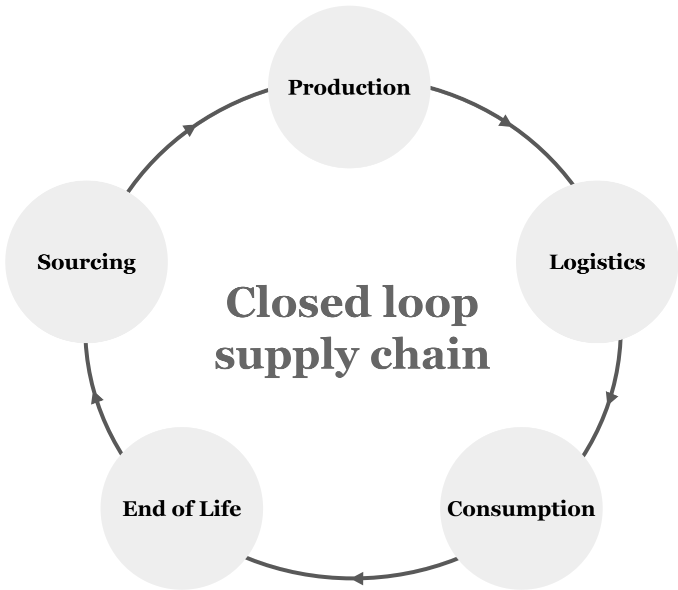

Figure 7.2: *The five steps of the closed loop supply chain considered in this thesis*

These five steps have been considered to be able to uncover resources, including by-product and waste flows as well as stakeholders and infrastructure from the entire life of the products in the case studies.

- **Sourcing** - includes identification of all input needed in the production process as well as the stakeholders and infrastructure.
- **Production** - the main products, by-products and waste obtained in the production process as well as infrastructure and stakeholders are identified.
- **Logistics** - additional management processes needed to get the product to the final consumer are identified. It can include transport and storage among others. Stakeholders and infrastructure are also identified.
- **Consumption** - waste flows and stakeholders are identified in this step of final consumption of the product.
- **End of Life** - includes the disposal of the product after consumption as well as infrastructure, waste flows and stakeholders.

Various types of symbioses can be achieved between the different steps, both within and between closed loop supply chains. Symbioses can include sharing of infrastructure and resources such as materials, human resources and knowledge. An example of a symbiosis is if a by-product created in the production step of product 1 is useful in the sourcing step of product 2 which will reduce the need of virgin raw material for product 2. Another symbiosis can be sharing of transportation by one stakeholder in the logistics step of product 1 with one stakeholder in the logistics step of product 2.

7.2 Semi-structured interviews

Semi-structured interviews are often used in qualitative research when the researcher has a quite clear focus on some specific issues from the beginning but the perspective of the interviewee still should be able to come through. Those interviews are flexible and the interviewers does often prepare a series of question but with the possibility to vary the sequence of the questions and to ask new questions to follow-up on answers from the interviewees (Bryman and Bell, 2015). The type of questions in semi-structured interviews can vary and according to Kvale are there different types of questions, such as: introducing questions, follow-up questions, probing questions and specifying questions (Kvale, 1996).

Semi-structured interviews are often recorded since it increases the possibility for the interviewer to be alert and to ask relevant follow-up questions instead of concentrating on taking notes (Bryman and Bell, 2015). Recording and transcribing of interviews also allows for a more accurate review of what people said and it allows for repeated examinations of interviewees' answers (Heritage, 1984).

7.3 Opportunity identification

As mentioned in the theory, there are three different approaches that can be applied to identify opportunities for symbiosis; new process discoveries, input-output matching and mimicking (Grant et al., 2010). Independent on which approach that is used, some investigation of the resources and stakeholders has to be done and both literature review and interviews can be suitable methods. When discovering new processes it is necessary to have a lot of knowledge about the by-products and waste to be able to come up with ideas of how to turn it into a resource. The solutions that are in the pilot stage in table 6.2 is regarded as new processes. Input-output matching also requires detailed information of the by-product or waste flow to be able to know if it is possible to exchange a virgin raw material with it. There might be constraints on the input that the output needs to fulfil. Less detailed information is required when a solution is copied since it is already known that the by-products can be used in a symbiosis. Examples of solutions that can be mimicked are referred to as commercial in table 6.2 and 6.3.

7.4 Our approach

The three tools; closed loop supply chain, semi-structured interviews and opportunity identification are used in our approach to come up with a result and answer the research question. Two case studies are used in order to try out and develop the method and identify possibilities for industrial symbiosis. The two cases are the closed loop supply chains centred around beer and mushrooms.

Beer and mushroom producers in the Västra Götalandsregionen were identified through allabolag.se[1], as a first step to map up the closed loop supply chains. The producers were sorted by size, distance from Gothenburg and if they have their own brewing facility. Five suitable mushroom producers were identified and those were contacted through e-mail. This was done in Swedish with a small explanation of our project and the purpose of the interview. The same procedure was done with 13 identified breweries. The goal of the interviews was to gather information about stakeholders, resources and infrastructure included in the closed loop supply chains of beer and mushroom to be able to map these supply chains and find existing symbiosis and opportunities for new ones.

To increase the possibility of getting an interview with the stakeholders, they were contacted by phone a couple of days after the first contact was done through e-mail. It was easier to get a better connection and to give a more in-depth explanation of the purpose over phone. However, many of the stakeholders were really busy which resulted in seven scheduled interviews with breweries and four scheduled interviews with mushroom producers. All interviewees were offered a face-to-face interview at their office.

Prior to the stakeholder interviews an interview was conducted with an expert on IS, with a lot of experience in screening companies to identify potential for IS. This interview was used to gain knowledge of what kind of information that is important to get when screening companies and how to approach stakeholders to get the most out of the interviews. The required information

[1]allabolag.se is a web service with public information about different companies registered in Sweden.

was categorised in five categories, which are presented in the list below. Those were then used to structure the data gathering in the stakeholder interviews.

- Basic company information - *location, number of employees, yearly production*
- Types of waste - *what it includes, possible contamination*
- Amount of waste - *preferably comparable units*
- Occurrence of waste - *what periodicity the waste flow follows*
- Current disposal - *how the stakeholder dispose of it now*

The focus of the interviews with the producers was to identify the waste and by-products and to find already occurring symbiosis in the system. The interviews started with a question about the production process used by the interviewee, which made them think and reflect upon their resources and infrastructure. To be able to evaluate the feasibility of identified opportunities drivers and barriers for industrial symbiosis were identified. These were discussed in relation to an information exchange platform to find out if such a platform would support industrial symbiosis for them.

Shorter interviews were also conducted with identified symbiosis stakeholders in connected closed loop supply chains that were able to use the waste from the mushroom producers and breweries. The purpose of these interviews was to understand how the waste or by-product were utilised and if any additional processes were required before usage.

In total, 18 interviews were held with interviewees from different categories and the distribution among these can be seen in table 7.1.

Table 7.1: *Amount of interviewees in the different interview categories*

Category	Number of interviews
Beer producers	7
Mushroom producers	4
Symbiosis stakeholders	5
Expert stakeholders	2

A literature review and an expert interview were conducted to find opportunities for industrial symbiosis for the two cases. The main focus was to identify solutions that make use of the by-products and waste flows, that is possible to mimic. It was important to find out if and what kind of additional processes that are required to use the by-product or waste as a resource in another supply chain. The maturity of the technology was also relevant to be able to indicate how feasible the solution is to implement for the stakeholders in the two cases. As stated in table 6.2 and 6.3 the maturity was classified in three categories, research, pilot and commercial depending on the stage of development.

The data gathered through the interviews was treated qualitatively and to provide an overview of the information it was organised in a table. The data was harmonised to comparable units to ease the correlation of different resource flows and stakeholders. Continuous improvements of the structure of the data were done throughout the thesis. The stakeholders did not always have all the knowledge about the amount of by-products and waste flows they produce which resulted in data gaps. The gathered data was used to map the closed loop supply chains and the connections to other supply chains, and it was further analysed to identify new opportunities for symbioses. The largest by-products and waste flows were in focus when looking at new opportunities.

7.5 Output

The applied tools and our approach lead to three main outputs that are visualised in figure 7.3. The collected and structured data made it possible to map the closed loop supply chain of beer and mushroom, including resources, stakeholders and infrastructure as well as existing symbiosis. The figure in the middle shows the existing symbiosis which, together with the literature review, were used to identify opportunities for new symbioses. The last figure illustrate the evaluation of the method that is an important part of this thesis, to learn lessons from the case studies and see how the method can be improved. These outputs are further presented and discussed in chapter 8.

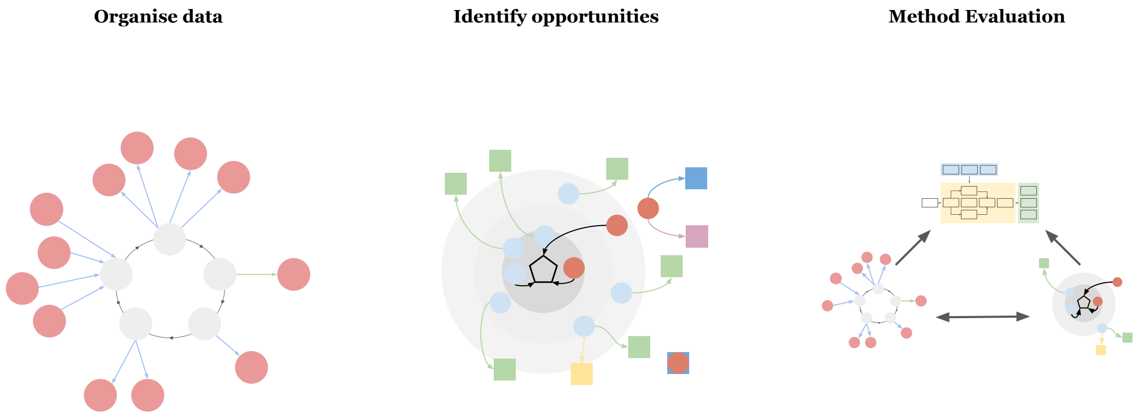

Figure 7.3: *The pathway for the results and discussion*

7.6 Limitations and assumptions

This thesis focus on the production step in the closed loop supply chain since the main part of the by-products and waste flows arise there, which is of value when possibilities for IS should be identified. It is only for the main by-products and waste flows that symbioses are identified for the two cases. For a larger picture of the potential for industrial symbiosis in the closed loop supply chain, possibilities at the input side should also be considered as well as symbioses related to infrastructure.

A limited number of stakeholders are interviewed, both in the case of beer and mushrooms but this is considered to be enough to give an idea of what is required to map up a closed loop supply chain and identify symbiosis potentials.

Similar products are considered to be a part of the same closed loop supply chain, i.e. different types of beer produced by the breweries are considered to be in the same closed loop supply chain. The same goes for mushroom soy and mushrooms.

8

Results and Discussion

This chapter includes a presentation of the data that was collected through the interviews. This information was used to map the closed loop supply chains for the two case studies and to show the resource and infrastructure connections to stakeholders in other supply chains. To make the data comprehensible and to distinguish the material flows that are the most promising for opportunity identification, only the most relevant resource flows are presented. The existing symbioses for the main by-products are presented in a more detailed map followed by an evaluation and discussion of the feasibility to mimic those symbioses by other stakeholders as well. As a final part of this chapter the used method is discussed, including if this method could be suitable to gather data for an information exchange platform to support industrial symbiosis.

8.1 Closed loop supply chain mapping

The two maps presented in this section shows the connections to other supply chains through different resource flows such as input, output, by-products and waste as well as internal connections within the closed loop supply chain. To simplify it, the stakeholders and infrastructure that exist within the supply chain are not included in the figure, as for instance the breweries and their facilities. The red circles illustrate the stakeholders in connected supply chains and the resources connecting them are illustrated by blue arrows. If the stakeholders are connected through infrastructure instead, it is represented by a green arrow.

8.1.1 Map of the closed loop supply chain of beer

The map of the closed loop supply chain of beer with the identified connections to different stakeholders in other closed loop supply chains is presented in figure 8.1.

As can be seen there are many connections in the sourcing step since this is where all the input for the production process is introduced. The breweries are connected with many different stakeholders in this step and different breweries use different suppliers so these are clustered in groups to make the picture comprehensible. The arrow marked with additional inputs represents different inputs that are not common for all breweries and used in smaller amounts, such as water adjustments, cleaning detergents and filters.

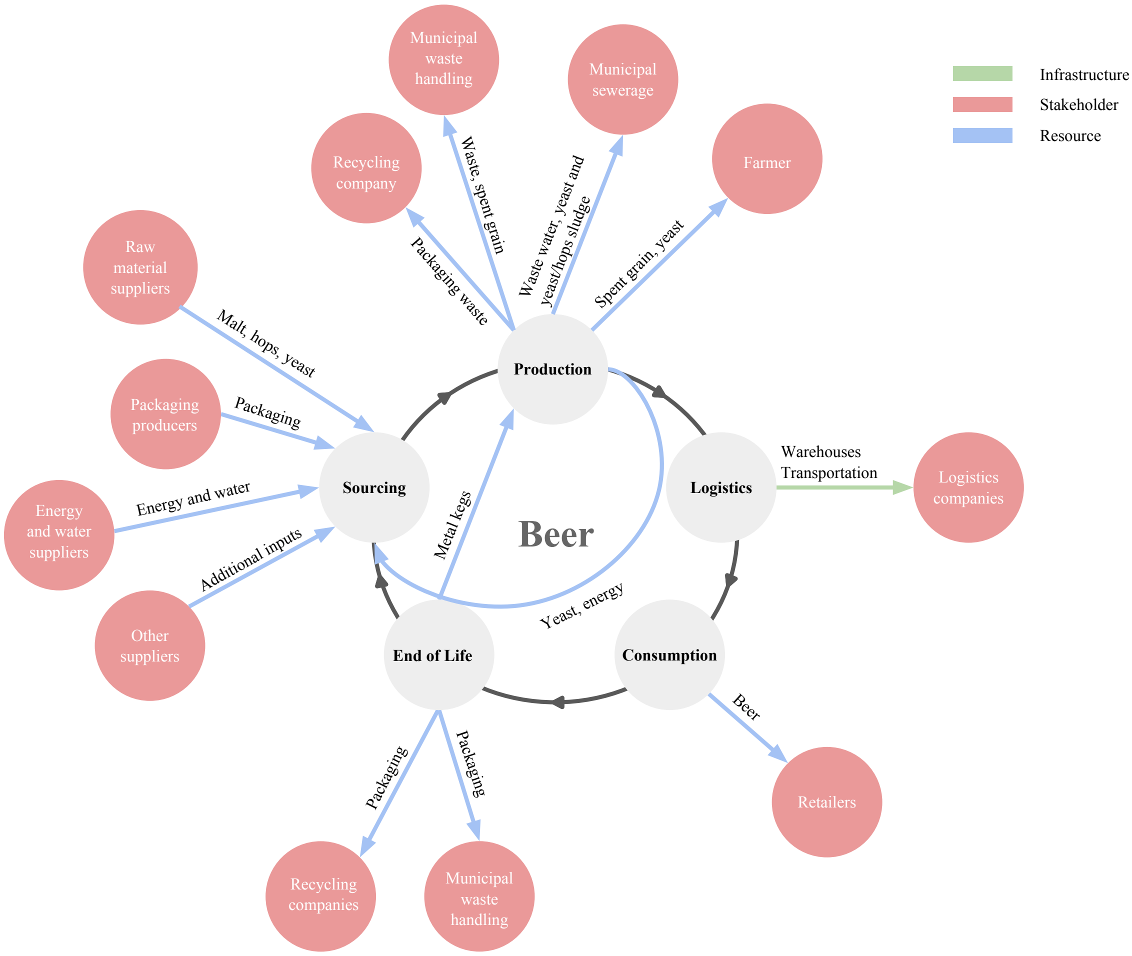

Figure 8.1: *A map of the beer closed loop supply chain with connections to other supply chains through different resources.*

The production step also have many connections to other stakeholders since that is where the by-products and most of the waste are produced in the closed loop supply chain of beer. As stated in table 8.1 the breweries dispose of their spent grain in different ways which connect them with different stakeholders in other supply chains. These stakeholders include farmers and municipal waste handling system. The blue arrow between production and sourcing illustrates an existing symbiosis that occurs internally in the supply chain. Some breweries are reusing their yeast to reduce the need for virgin yeast. All of the breweries are also recovering the heat from the wort boiling through a heat exchanger in order to reduce the energy demand in the process.

There are not many connections with additional stakeholders in the logistics step. The ones identified are logistics companies that are connected with the breweries through infrastructure, such as warehousing and transportation. In the consumption step the beer is sold to different kinds of retailers such as Systembolaget, bars and restaurants and no other resource exchanges than the beer was identified. In the end-of-life it is only packaging waste left, since the product is already consumed at this step. In this step it is up to the consumer if the packaging goes to recycling or municipal waste handling. The metal kegs used by some of the breweries are returned to the brewery that cleans and reuses them.

8.1.2 Map of the closed loop supply chain of mushroom

A similar map, as the one for beer, is made for the closed loop supply chain of mushrooms as can be seen in figure 8.2. This closed loop supply chain includes less by-products and waste flows compared to the beer chain.

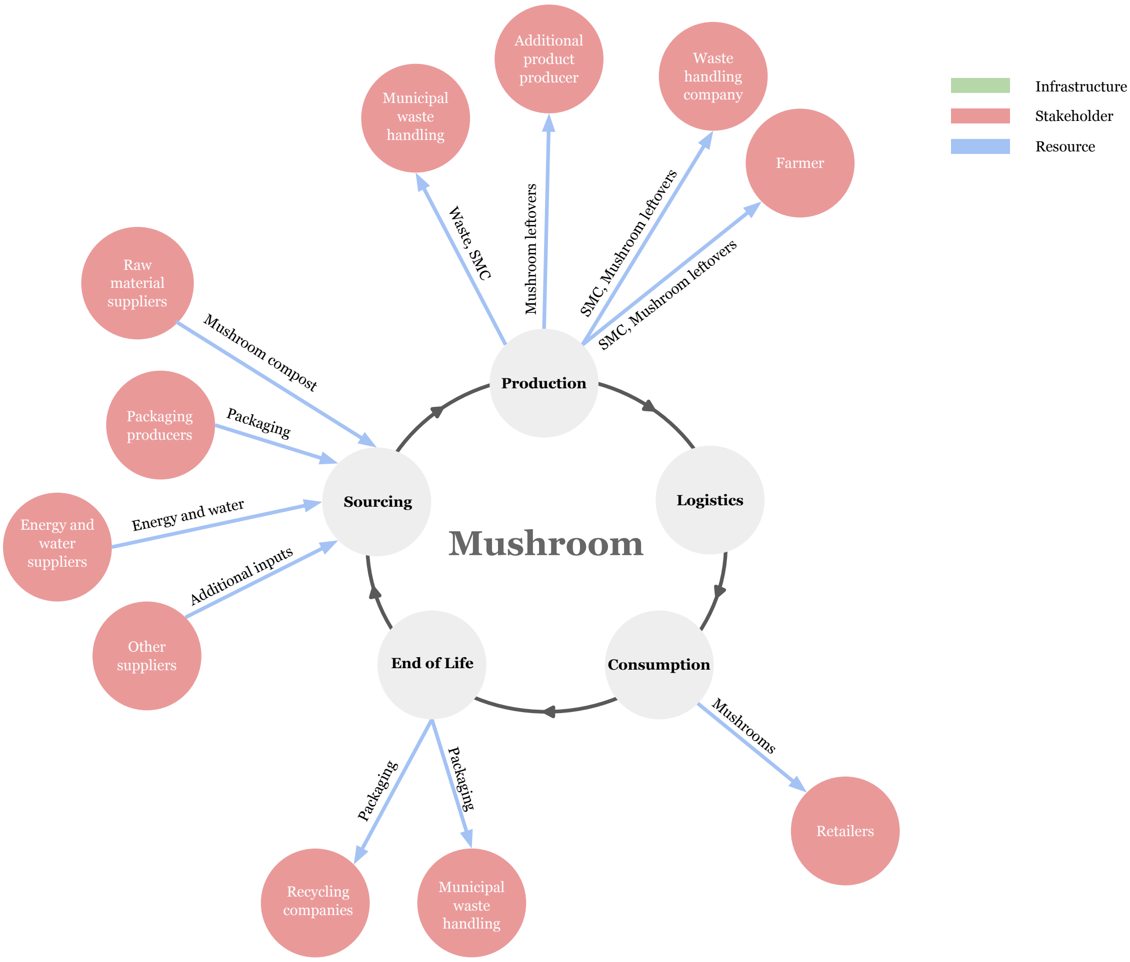

Figure 8.2: A map of the mushroom closed loop supply chain with connections to other supply chains through different resources.

The sourcing step for mushroom does also include all the input for the production process and has many connections to different stakeholders. The additional inputs does in this case represent resource flows such as plastic gloves and paper towels.

As can be seen, the spent mushroom compost (SMC) and mushroom leftovers are connected to other stakeholders who use it as filling material and soil improvement. The production step is also connected to the municipal waste handling system through both waste flows and disposal of SMC.

There are no additional stakeholders or infrastructure required in the logistics step of the closed loop supply chain for mushrooms, since all the stakeholders warehouse and deliver their mushroom themselves. They deliver to different retailers in the consumption steps, both smaller local stores as well as larger supermarkets. As with the supply chain for beer, the end-of-life products are also packaging materials, since the product is consumed before this step in this chain as well.

8.2 Resource data

Most of the resource flows are occurring in the sourcing and production steps as can be seen in the closed loop supply chain maps. This is where all of the input to the production process is introduced and also where the main by-products and waste flows are produced and hence, the majority of the collected data is related to these steps. The most relevant data regarding those steps is presented in this section including the current disposal of the by-products and waste as well as the costs for disposal. Some data was excluded as for instance cleaning detergents and plastic gloves. The data can be found in its entirety in appendix A.1. The interviewees did not always have the knowledge or the possibility to acquire the wanted information which resulted in some unknown data points. The lack of information is not considered crucial since it mostly occurred on the input side.

8.2.1 Beer data

The main resource flows that were identified in the sourcing and production step of the beer closed loop supply chain can be seen in figure 8.1. It can be seen that the size of the breweries vary from a production of 60 000 to 500 000 l/year. They produce various types of beer and these differences bring differing production processes but the main ingredients; malt, hops, yeast and water, are used by all of them. Most of the interviewed breweries rely entirely on bagged malt but some buy it in bulk in order to improve the working conditions by removing the heavy lifting. However, buying the malt in bulk requires a high production volume to be profitable because of the big investment cost of a storage silo. Another difference is that some breweries filter their beer, one brewery is using kiselguhr to do this which results in an additional waste flow compared to the rest.

The size of the material flows differ, also between the breweries with similar sizes. This does in some cases inherit from differences in the production process which give rise to various amount of by-products and waste flows. Another reason for the differences is that the breweries do not have the knowledge about the exact sizes and have made approximations. The data is also affected by how the interviews were conducted, the interviews that were recorded and carried out in a more structured way gave more complete data sets than the ones where the setting did not allow that.

Table 8.1: *Main resource flows in beer production with the current disposal and costs*
x = the resource appears in the brewery but the amount is unknown
- = the resource does not appear in the brewery

	Brewery 1	Brewery 2	Brewery 3	Brewery 4	Brewery 5	Brewery 6	Brewery 7
Employees	9	Unknown	5	7	7	3	1.5
Production [hl/year]	5000	4000	4000	3500	3000	1000	600
Sourcing input							
Malt (ton/week)	2.5	2.5	2	1.5	1.5	0.8	0.5
Hops (kg/week)	50-500	x	50	x	35	10	40
Water:Beer ratio	x	x	5:1	x	3-4:1	x	x
Yeast (Weekly)	20-40 l	x	0.5 kg	x	1 l	2 kg	x
Kieselguhr (kg/week)	-	-	-	15	-	-	-
Production waste/by-products							
Spent grain (ton/week)	5	5	4	3	3	1.6	1
Current Disposal	Livestock feed	MWH*	Livestock feed	Game feed	Livestock feed	Game feed	Livestock feed
Cost (SEK/month)	3000	5000	0	0	0	0	0
Yeast/hops sludge (l/week)	1250	x	100	250-1000	0	100	x
Current Disposal	Municipal sewerage	Municipal sewerage	Municipal sewerage	Municipal sewerage	-	Municipal sewerage	Municipal sewerage
Cost (SEK/month)	0	0	0	0	0	0	0
Yeast (l/week)	400	x	50	x	30	40	10-20
Reused	Yes	Unknown	Yes	No	Yes	Yes	No
Current Disposal	Municipal sewerage	Municipal sewerage	Municipal sewerage	Municipal sewerage	Horse feed	Municipal sewerage	Municipal sewerage
Cost (SEK/month)	0	0	0	0	0	0	0
Kieselguhr sludge (kg/week)	-	-	>15	-	-	-	-
Current Disposal	-	-	-	Municipal sewerage	-	-	-
Cost (SEK/month)	0	0	0	0	0	0	0
Woven plastic bags (pcs/week)	x	x	7	40	60	32	10-20
Current Disposal	MWH	MWH	MWH	MWH	MWH	MWH	MWH
Cost (SEK/month)	>0	>0	>0	>0	>0	>0	>0

*Municipal waste handling

As can be seen the main by-product from the production is the spent grain which is originated when the malt is boiled with water to produce word. The wort is then fermented into beer. Based on the interviews with the breweries it is estimated that the weight of spent grain is twice the weight of the malt used due to its water content after the wort boiling process. The spent grain is commonly used as feed for either livestock or wild animals, in the table expressed as game feed. To donate the spent grain as animal feed is common practice for breweries since it eliminates the disposal cost which can be as high as around 30 000 SEK for 20 tonnes monthly months according to one of the breweries. However, one of the interviewed breweries are still using the municipal waste handling service, for its spent grain and are paying around 5000 SEK/month for it. For brewery 1 it is not entirely free to dispose of the spent grain as livestock feed either since they share the cost for transportation with the connected farmer.

After the fermenting process yeast and hops is accumulated in the bottom of the fermentation tank. Parts of the yeast can be collected and reused but the majority is disposed of as yeast/hops sludge. The yeast/hops sludge is a resource that is nutritious and relatively high in volume but it is difficult to exploit. Currently all the breweries flush it down the sewerage.

The input of yeast is given in different units since the breweries use different types of yeast, dry or liquid. Most of the breweries reuse their yeast between 4-20 times depending on the brewing process, to reduce the cost spent on virgin yeast. The breweries that are not reusing their yeast showed interest in starting to do it in order to cut costs but did not have the knowledge or equipment required at the moment. When the yeast is discarded it is flushed down the sewer in all of the breweries except one who donates it as horse feed.

The water to beer ratio was hard for the breweries to estimate and only two could give any numbers regarding it. One of the difficulties is that the breweries does not know how much water is used in the cleaning process, though most have a good estimate of the rest of the water input.

One waste flow that could be used for something but is currently disposed of as waste to the municipal waste handling, are the used malt bags. These bags are clean and of high quality and might have a value for the right stakeholder. One of the breweries donated a few bags to a neighbouring business who used them as containers for growing vegetables.

8.2.2 Mushroom data

The main resource flows, current disposal and costs found through the interviews with the four mushroom producers is presented in table 8.2. Mushroom producer 1, 2 and 3 buy ready-made champignon mushroom substrates that is delivered in trays from Germany. The mushrooms can be ready for harvest a few days after delivery. It is possible to have several yields from the same substrate but after the third yield it is disposed of. Producer 4 grows shiitake mushrooms and instead of buying ready-made mushroom substrate it is produced on-site from cutter shavings, wheat, rape seeds and chalk. Mushroom producer 4 does only harvest twice from the substrate before disposal, and as can be seen the production volume is lower.

Table 8.2: *Main resource flows in mushrooms production with the current disposal and costs*
x = the resource appears in the process but the amount is unknown
- = the resource does not appear in the process

	Mushroom producer 1	**Mushroom producer 2**	**Mushroom producer 3**	**Mushroom producer 4**
Employees	4.5	2.5	3	1
Mushroom produced [ton/week]	2	1.2	0.8	0.025
Sourcing input				
Mushroom substrate (ton/week)	7.5	7.5	7.5	0.1
Production waste/by-products				
SMC (ton/week)	7.5	7.5	7.5	0.1
Current disposal	Waste handling company	Farmer	Farmer	Municipal waste handling
Cost for disposal (SEK/month)	7000 - 8000	0	0	600
Mushroom leftovers (kg/week)	500	<100	200	2
Current disposal	Waste handling company	Additional products	Farmer	Municipal waste handling
Cost for disposal (SEK/month)	200	0	0	>0

As can be seen in the table the weight of the mushroom substrate is the same as the weight of the SMC for all producers. This might not be accurate due to the added water in production, but the weight of the SMC is estimated by the producers to be the same as the known input weight. The current disposal of the SMC as well as the cost for it differs between the producers and the possibilities are often limited due to location of the production site. For producer 2 and 3 the SMC is used by a farmer as soil amendment for agriculture. Producer 3 is located at a farm and thereby utilises the SMC itself and producer 2 has struck a partnership with a nearby farmer who collects and process it. Producer 1 dispose of the SMC with a waste handling company that classifies the SMC as contaminated soil and processes it to filling material for different applications. The smaller amount of SMC originated from producer 4 is disposed of to the municipal waste handling.

The mushroom leftovers include both the mushroom feet, which are cut off in production, and mushrooms that are sorted out due to size or aesthetic problems. Producer 2 sells the whole mushrooms which reduces the amount of leftovers. The mushrooms that are sorted out can still be used for producing other products, such as mushroom soy. This is done by both producer 2 and in a very small scale by producer 3. The most common disposal route is to mix it with the SMC as soil improvement.

8.3 Opportunity identification

This section is a compilation of the most promising by-products that occur in the production processes of beer and mushroom and the existing symbioses connected to these resource flows. An illustration of some of these symbioses is presented in figure 8.3 in relation to the setting of the production sites. The by-product flows that is illustrated is the SMC for the mushroom producers and the spent grain for the breweries as well as the yeast flow that connects a brewery with a horse farm.

The big circles illustrate a map of the Gothenburg area and the color of the circle illustrates what kind of setting the stakeholders are located in but the map is not according to scale. The black square in the middle represents both the municipal and private waste handling services and the central location is not literal, it is a representation that they can pick up waste from all around the city independent of the location of the breweries and mushroom producers. The by-products that go to waste are represented by the black arrows, and those are also opportunities for symbioses. The blue circles represent the breweries and the green arrows their spent grain that is utilised by different stakeholders. The stakeholders that use the grain for livestock and game feed are represented by the green boxes. The synergy with yeast between one brewery and a horse farmer is illustrated with a yellow box and arrow.

The red circles illustrate the mushroom producers and as it can be seen they are located mostly in the suburban and rural areas. The SMC is shown by the dark blue arrows which connects the producers with farmers. It can be seen the mushroom producer in the lower right corner is located at a farm and hence utilises the SMC as soil improvement for themselves. The purple box is the producer who makes additional products from the mushroom leftovers.

As was seen in table 8.1 six out of seven breweries have a symbiotic relationship through their spent grain. The map also shows that even though most of the breweries are located within the urban area they still conduct symbiosis with farmers in the suburban or rural area. It can be noticed that two of the most central stakeholders, one brewery and one mushroom producer does not take part in any symbiosis and they also stated in the interviews that having a central location could be a problem when collaborating with for example a farmer. Though many of the farmers transport the by-products quite far hence it might not have to be a problem with the proximity at least which was also shown by Jensen et al. (2011).

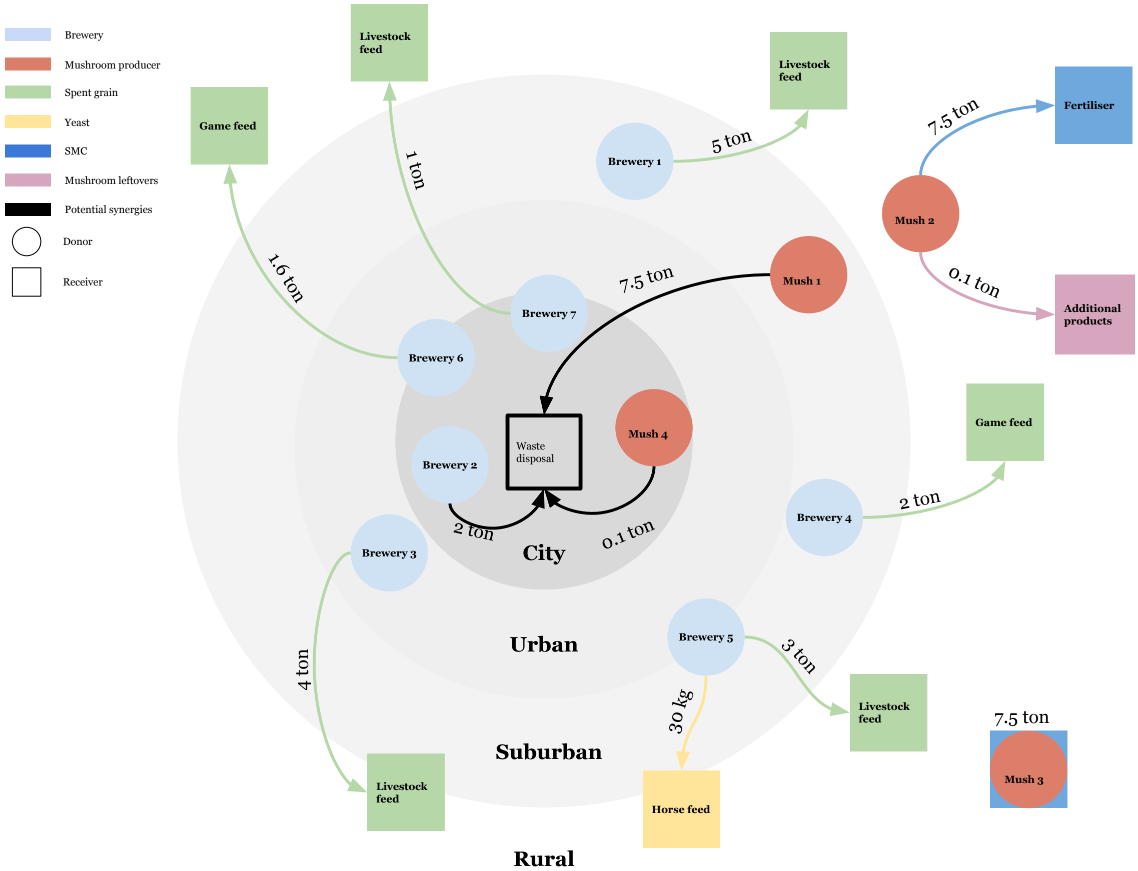

Figure 8.3: *A map of the existing symbioses within the two case studies, with the big grey circles illustrating the distance from the city centre.*

8.3.1 Opportunity identification in the system

This section includes a discussion of how the existing symbioses within the two closed loop supply chains can be mimicked by other stakeholders to increase the use of by-products and waste. The drivers and barriers identified in the interviews are used to investigate the feasibility of the opportunities for specific stakeholders.

Brewery - Spent grain opportunities

It has been seen in both the literature and the case study that the most common use of spent grain is as animal feed, and mainly for livestock. As stated earlier, there is only one brewery that does not have an existing symbiosis for their spent grain. This would be a possibility for the last brewery as well, which will save them 5000 SEK/month. However, the brewer expressed that a future symbiosis has to be as effortless as their existing solution with the municipal waste system. When looking at the other breweries' existing symbioses, the main effort is put on the farmer that has to take care of the transportation and the breweries only have to store the spent grain in one or several containers before the farmer picks it up. The location might add an extra difficulty for the last brewery to create a symbiosis since it is located in the central parts of the city, it will be more complicated and time consuming for a farmer to get into the city centre. Another brewery, that recently moved, did also express this as a problem, when they had a more central location they did not dispose of their spent grains through a farmer, instead they used the municipal waste system. However, the interviewed farmers did not express any problem with the transportation and states that it is worth the effort to get the free feed.

Brewery - Spent yeast opportunities

The possibility to dispose of the spent yeast as animal feed is only performed by one of the breweries in the case study. Several of the other breweries have expressed that the amounts they have are small and thereby there is no point in pursuing any symbiosis for it. However, since one of the breweries is already doing it with a small amount this argument seems to be inaccurate. In order for the yeast to be digestible the yeast have to be heated to kill the yeast cells (Ferreira et al., 2010), this is according to one of the breweries an easy process and does not require a big effort, which indicates that it might not be the problem either.

One of the big differences between spent yeast and spent grain is that the breweries do not have an apparent cost related to the disposal of the yeast since it is discarded in the sewerage which they are not paying any extra for. The brewery that dispose of it as animal feed are not getting an income from it and hence there are not any economic incentives that are the drivers but only the good-will. One of the breweries stated that they want to invest in and install a tank to collect the yeast and donate it. The major driver for this is to decrease the load of the sewerage. Disposing the yeast down the sewerage might lead to an increased future cost in maintenance but is a parameter that is overlooked by most of the breweries and is also very hard to estimate. One brewery is already collecting all of their yeast and hops sludge in a tank in order to mix it with additional water. This is necessary for them to be able to dispose of it in the sewerage since it is otherwise too viscous. When asked about having someone taking care of it they where open to do it but they did not have an incentive themselves of finding someone.

Brewery - Malt bag opportunities

All of the breweries dispose of empty malt bags in various amounts but one of the breweries expressed that a neighbouring business had used a few of them to grow plants. We believe that it is an opportunity for a symbiosis with urban farmers that can use them for cultivation. It could also be used as bags for e.g. potatoes or spent mushroom compost. If one of the mushroom producers started to sell SMC then the malt bags might be useful to pack it in both from a cost perspective as well as a marketing perspective since circularity is a hot topic at the moment.

Mushroom producer - Spent mushroom compost opportunities

One of the mushroom producers dispose of the SMC through an external company that classifies it as contaminated soil. It is then used as filling material but the SMC still contains a lot of nutrients and it would be possible to make use of these by mimicking one of the already existing symbioses. This can reduce the cost for disposing of the SMC, that can be up to 8000 SEK for 30 tonnes per month which can be a substantial cost for small companies. One of the producers dispose the SMC to a farmer and another has its own farm, but the process is similar. The SMC has to be accommodated for around six months to cure and during that time it should be mixed, which requires a tractor and this process is often done by the farmer. A concrete foundation is also required for the accommodation, to take care of the leachate water. This might be hard to achieve for the mushroom producer in the suburban area where the space is limited and the landowner does not want the producer to cure the SMC next to the production site. However, the possibility to donate the SMC to a nearby farmer who can store and process it before spreading it on the fields is still a possible solution, which would reduce the costs for the mushroom producer. The mushroom producer in question has also been searching for a farmer to collaborate with but without success.

Mushroom producer - Mushroom leftover opportunities

The mushroom leftovers are usually mixed with the SMC by two of the producers. Since it is quite big amount every week it seems like waste of resources to mix this with the SMC and not make use of the nutrients in the resource directly. Instead, the leftovers could be used to produce additional products, as it is already done by one of the producers when there are a lot of unsold mushrooms and time permits. Another producer dispose the mushroom leftovers on a regular basis to a stakeholder who does additional products, such as mushroom soy with it. Another possibility for this by-product could be to use it as pig feed, since it is just unsalable mushrooms or soiled mushroom feet.

8.3.2 Opportunity identification outside the system

Additionally, other opportunities for symbioses were identified through the literature review in order to broaden the scope of possibilities. In this section is the possibility to mimic these solutions by stakeholders in the two case studies presented and discussed.

Brewery - Spent grain opportunities

The breweries within the case study are primarily donating their spent grain as animal feed which also is the most common symbiosis according to the literature review. Another possibility for this waste flow is to turn it into human food. One example where this is done is Lottas Bak & Form[1] which is a bakery where spent grain is used to make sourdough bread, this is also commonly done elsewhere e.g. by a bakery in Chicago[2]. ReGrain[3] is also an example of how the spent grain can be refined into a product, grain bars are made from spent grain sourced from nearby craft breweries. A symbiosis like this might be facilitated by an information exchange platform providing information about a cheap resource, which could be a business opportunity.

[1] http://www.lottasbakoform.se
[2] http://www.hewnbread.com
[3] https://www.regrained.com

This would be beneficial both for the donor company, who will get lowered waste handling costs, and the new business, who is getting cheap resources; as well as from a holistic perspective since food waste will decrease.

One of the advantages with making food products of the spent grain is that the production can be located in the central area which is not the case with a farmer. This was one thing that came up during the interviews, that it is harder to setup a symbiosis with a farmer if the brewery is too centrally located.

Brewery - Spent yeast opportunities

As it has previously been stated only one of the breweries shares the spent yeast in a symbiotic partnership. It was apparent from the interviews that several of the breweries did not have knowledge about possible symbioses related to the yeast which might hinder collaborations today. Brewers Association (2017) state that one best practice for yeast disposal is as animal feed since it is an easy way of disposing of it for free without too much extra effort. They also give an example from Ringwood Brewery in the United Kingdom who installed one tank each for storing yeast as well as yeast/hops sludge. The cost related to installing the two tanks of 4900 l was only £800 for the tanks and an additional cost of £500 to install them both. With this small investment they save £3000/year in trade effluent charges which derived from the high biochemical oxygen demand (BOD) from the yeast in the wastewater (Brewers Association, 2017). However, the economic incentive in Sweden might not be as big since the interviewed breweries do not have to pay any additional fees for BOD as is the case in the United Kingdom. According to Chertow (2007) one of the main drivers for industrial symbiosis is the economical benefit, which might decrease the probability of this symbiosis opportunity.

Another possibility for spent yeast is to use it as fishfeed as was stated in the theory (Bekatorou et al., 2006). One of the symbiosis stakeholders was a urban landbased fish farm located centrally in Gothenburg. He was not currently using any spent yeast in his production but could be a suitable symbiosis partner for breweries in his proximity. Fish farms are a new and expanding addition to the urban setting (SDSN Northern Europe, in collaboration with the Maritime Cluster of West Sweden, 2017), this could contribute to using the spent yeast in a more efficient way.

One of the barriers stated by the breweries related to this waste flow is how to store it in a proper way but as was shown in the example at the Ringwood Brewery adding an additional tank that is emptied for free by a farmer or a fish farm does not have to be a big investment, nor an added effort according to one of the interviewed breweries. In this case it might only be that the connection between the stakeholders has to be established which an information exchange platform could provide.

Brewery - Wastewater opportunities

In the theoretical framework Cambrian Innovation was brought forward as an interesting technology to treat wastewater as well as produce biogas. The biogas can then be used as an input for the brewery. They are not charging for their equipment but instead they are charging the brewery per litre biogas and clean water delivered, which removes the risk and investment cost from the brewery and thereby increases the incentive for them to implement it. This is a new technology that is already turning wastewater into a resource for both breweries and wineries however, it is only available in USA today and it requires a production rate that is relatively high. Their smallest solution is dimensioned for water flows between 8000 and 60 000 litre per day which the biggest brewery in the case study barely reaches.

As it was shown in the theoretical framing algae production is another interesting opportunity for wastewater treatment (Mata et al., 2012). Swedish algae factory is currently operating a pilot plant connected to a fish farm in the region in order to clean the water for the fish and at the same time create a valuable resource through the algae. Swedish Algae Factory have shown that the region is feasible for algae production which indicates that it could be a feasible opportunity for the brewery wastewater as well.

Most of the brewers conveyed a desire to reduce their water usage but none of them had any intention of using their wastewater as a resource. This can be because of lack of knowledge or economic incentives since the current disposal to the municipal sewerage is a low cost alternative. However, the breweries were positive to the idea of making a better use of all of their waste flows and if there was a demand for the nutritious wastewater they would donate it.

Mushroom - Spent mushroom compost opportunity

The opportunity of champost is similar to the existing symbioses where the mushroom producers dispose of the SMC to a farmer to be used as a nutrient source on the fields. However, instead of giving it away for free it can be cured and made into a product which can be sold to both private persons and businesses as soil amendment. Champost is a well-known concept in other countries and could be spread here as well. The mushroom producers were interested in this opportunity but expressed doubt in consumer awareness of the product. This concepts will also demand an effort of the producers to make it viable.

8.3.3 Summary of the identified opportunities

The case study and the literature review led to various identified opportunities. Some were found inside the investigated system and others outside of it. In the following tables 8.3 and 8.4 all of the identified opportunities are summarised.

Of the identified symbioses the ones already performed within the investigated case studies are the ones considered to be the easiest to implement among the other stakeholders of the same industry. The reason for this is that they are aware of many of the things that their colleagues are doing which is believed to create trust in the performed symbioses since they can see that it works within their sector and region. However, it is evident that this is not enough since there are clear opportunities that are not implemented even though the knowledge and trust in the symbiosis is apparent.

Table 8.3: Summary of the identified opportunities for beer waste and by-products

By/Waste-product	Identified opportunity	Connected stakeholder	Case study diffusion (out of 7)
Spent grain	Animal feed Bread Energy bars	Farmer Bakery Energy bar company	6 - -
Waste water	Biogas Algae production	e.g. Cambrian Innovation Algae producer	- -
Yeast	Livestock feed Fish feed Nutritional brewer's yeast	Farmer Fish farm Nutritional supplements company	1 - -
Kieselguhr sludge	Soil amendment	Farmer	-
Containers for chemicals	Reused	Farmer	1
Woven plastic bags	Reused	Urban farmer	1

Table 8.4: Summary of the identified opportunities for mushroom waste and by-products

By/Waste-product	Identified opportunity	Connected stakeholder	Case study diffusion (out of 4)
SMC	Soil amendment	Farmer	2
Mushroom leftovers	Mushroom soy Animal Feed	Mushroom soy producer Farmer	1 -

The barriers for these untapped opportunities vary, some practical and some more inherent. The practical barriers are often related to the location of the production facility i.e. that it is located in a too central part of the city to be feasible for a stakeholder from the rural parts to partner. Another barrier is problems related to the storing of by-products in order to be able to donate or sell it later on. This could for example be that a container is needed to store the yeast but it could also be space limitations as is in the case with one of the mushroom producers who is not able to cure and then sell the SMC at the current location. However, if the right stakeholder is found, these practicalities might not be a problem. If the mushroom producer is connected with a nearby farmer who would see a value with this waste and collect it instead of the mushroom producer having to pay a waste handling company to do it. The same thing goes for the barrier with the location, there might be stakeholders interested in symbiotic partnerships where the location is not a crucial factor because the free resource is worth the added effort. This is strengthened by the findings from Jensen et al. (2011), where it is shown that the median distance for symbiotic material exchanges was 32.6 km in their project in the UK. This is long enough for even the most centrally located stakeholders to reach the rural area of the region.

The stakeholders also mentioned that the time and effort required to build a network in order to find a symbiosis partner can be a barrier for it to happen. The location barrier does also seem to be closer related to network creation than the physical location. Thereby this is something that could be provided through an information exchange platform since it would display the resource to a wider audience as well as suggest opportunities that might not be thought of.

Two inherent barriers are lack of knowledge as well as a need to change the mindset of that waste and by-products can have a value within other industries. There is also no explicit incentive for some of the identified opportunities since there are no direct economical gains from creating a symbiotic relationship with e.g. the spent yeast. Though it might lead to long term economic gain from reduced maintenance costs as well as being beneficial from a holistic perspective in order to lower the BOD of the wastewater. Another waste flow that is not considered to be of value is the malt bags which are reaching relatively high amounts when all of the region's breweries are accounted for. These are not thought of as a resource but discarded as waste and has not been thoroughly explored in the literature. However, there are opportunities with the malt bags that could be uncovered by a change of mindset.

One clearly expressed barrier is the risk related to that the symbiotic exchange will not be as effortless and trustworthy as their existing solution. That the spent grain will not be collected is the major concern of the brewery who is not in a symbiotic relationship with a farm regarding this by-product. This risk was removed by Carlsberg's brewery in Falkenberg, Sweden, by employing a farmer who coordinates the pick-up of the spent grain and delivers it to the symbiotic partners (Carlsberg Sverige, 2017). In this way the nutrients of the spent grain comes to use and risk of the waste not being removed from the brewery is minimised. Coordinating the pick-up in order to remove this risk can be done with other by-products as well.

8.4 Method discussion

As it was stated in the purpose of this thesis we wanted to investigate how data could be collected to be used in an information exchange platform to support industrial symbiosis and evaluate the used method. This section includes an evaluation of the different parts of the method, which can be seen in table 7.1, and a discussion of how it could be improved.

8.4.1 Tools

The closed loop supply chain mapping was a useful tool to uncover connections between stakeholders in the system. Stakeholders that produce the same product will probably have similar by-products and waste flows which makes it easier to identify opportunities for many companies at the same time. The closed loop supply chain mapping is also useful if someone wants to expand and continue this work. Either the work can be continued with one of the studied supply chains or connected ones, or a different supply chain that seems promising for symbiosis opportunities.

The semi-structured interviews was a good tool to gather data from the stakeholders. The interviews gave a high quality data set but the drawback is that it is time consuming. It might be useful to conduct in person interviews in order to define what interesting resource flows that are occurring in a specific chain. When these are defined data regarding these flows could be collected through an interactive survey form, which would make it less time consuming. Nevertheless, it might be difficult to gather tacit knowledge through such a survey. In the research project in North Carolina they instead started with gathering data through a survey and then conducted interviews to clarify the survey answers (Kincaid and Overcash, 2001).

In this case the main focus of the opportunity identification was on mimicking other symbioses since that was considered easier to achieve. With this approach it was possible to identify already existing opportunities for turning waste into resources without having detailed knowledge about the waste flows. To be able to discover new processes and match input with output more detailed knowledge about the waste flows have to be acquired, like what it contains and what the requirements of the receiving side are.

8.4.2 Our approach

It was valuable with the two case studies to be able to evaluate the tools in regards to data collection on a real scenario. The choice of beer as one of the cases was because of the big momentum in the beer sector in Gothenburg and knowledge that some breweries had symbiotic relations connected to their waste flows. This also seemed to be an accessible sector with many small and micro companies open for collaborations. The idea of mushroom came when we heard that spent coffee grounds could be used for cultivation of mushrooms and substitute other raw material input. However, this turned out to not be applicable for the mushrooms producers in this region since they produce champignon mushrooms and buy ready made substrate for their production, which are not exchangeable with spent coffee grounds. Nevertheless, the mushroom producers in the region had large quantities of by-products with possibilities to create symbiosis around.

When scheduling the interviews it was beneficial to first contact the stakeholders through e-mail before calling them and refer to the e-mail. This lead to a positive response rate of 54% for beer producers and 83% for mushroom producers and the rejections were due to time limitations. For the breweries this is a very busy season with production and fairs, and it can be worth thinking of seasonal variations if planning to use this method for another case.

Our perception is that the interviews conducted face-to-face gave more extensive information, including the tacit knowledge. This might be because it is easier to create trust in that setting and to ask follow up questions when you can read the body language of the interviewee. What is also noticeable is the importance of interviewing the right person to get as much and accurate information out of the interview as possible. In this case, when only small and micro companies were contacted it was easy to get hold of the right person. If contacting larger companies it might be a good idea to do as Kincaid and Overcash (2001) and contact the environmental health and safety manager since they are likely to understand the purpose of the project.

The information gathered through the interviews was organised per stakeholder and step in the closed loop supply chain. It is also useful to know how often the flow occurs, the content and quality of the resource when finding possibilities for symbiosis. We have seen through this study that it is beneficial to collect as much information of the resource flows as possible but also to not focus on details before any opportunities are identified. Then it is possible to get back to the stakeholder for more information. It is more important to capture as many of the by-products and waste flows as possible and challenge the stakeholders to think of the non obvious, since they might be useful for someone else.

By using both the interviews and a literature review to identify opportunities for symbiosis we were able to find symbioses both inside and outside of the case studies. If only looking within the case studies opportunities would have been missed out, although the symbioses find within the system might be easier to mimic.

8.4.3 Output

If comparing this method with the five steps developed by Grant et al. (2010) presented in 6.1, we have performed the first two steps but are also elaborating upon the preceding step of data gathering which enables the opportunity identification. The third step is to remove barriers, which could be achieved through the information exchange platform, as indicated throughout this thesis. The fourth and fifth step could also be related to a platform for supporting symbiosis.

An information exchange platform can be seen as a facilitator of industrial symbiosis in itself but in the cases of NISP and Grøn industrisymbiose this platform is only used internally in the project and the organisation take the role of a mediator and network developers to support industrial symbiosis. It would be interesting to see if an information exchange platform could be used to facilitate IS on its own similarly to Loop Rocks. The stakeholders expressed that a symbiosis should be as effortless as possible for them to participate and in some cases that might demand a mediator or network developer but for some synergies it might be enough with a platform where waste streams can be visualised. If a mushroom producer would be able to show the amount of spent mushroom compost that is produced through an information exchange platform, we believe that would be enough to create a new symbiosis with for example a farmer.

9
Conclusion

This thesis has addressed the topic of industrial symbiosis and the possibility to support it through an information exchange platform. The research question that has been addressed is;

How can data be collected and organised for an information exchange platform to support bottom-up industrial symbiosis?

With the three objectives; (i) *What type of data needs to be collected?* (ii) *How can data be gathered and how can it be assured that the collected data is complete?* (iii) *What possibilities for symbiosis can be identified through this data collection?* The findings are split in two, where one part comprise of the results from the case studies where the method have been applied and the other part include the conclusion about the method itself.

9.1 Case study

The two case studies have been valuable to evaluate the method and to be able to answer the three objectives, and the third objective is concluded in this section. Opportunities for industrial symbiosis have been identified in the case of both beer and mushroom, through already existing symbioses found within and outside the case study.

For the beer production the by-product flows of spent grain and yeast were considered to be the most feasible symbioses opportunities. Disposal of spent grain through waste handling companies is expensive and hence, most breweries donate it as livestock feed instead. However, one of the breweries did not perform a symbiosis regarding their spent grain because of the effort required to find a partner willing to collect it in the centrally located brewery. The spent yeast is currently disposed of through the sewerage by all except for one of the breweries, who instead dispose of it as horse feed. This by-product does not have a direct economic incentive as the spent grain has but is a way of reducing the load of the sewerage as well as for good-will purposes. The knowledge about this symbiosis is not as widely spread as with the spent grain which might hinder it, also the lack of direct economical incentive seems to be hindering the breweries to find a partner themselves.

The most feasible opportunities for the mushroom producers regarded the SMC and the mushroom leftovers. Similarly to the spent grain, the SMC is also expensive to dispose of through waste handling companies and hence it is common to dispose of it for free as soil amendment in agriculture. However, two of the mushroom producers are still paying for their disposal and would benefit from having a symbiotic relation. The mushroom leftovers are disposed of together with the SMC at three of the producers, the last one refined this by-product into additional products such as mushroom soy instead. This by-product could be recirculated at a higher utility by refining it to additional products or as animal feed by the other producers as well.

9.2 Method

To be able to identify the industrial symbiosis possibilities in the two case studies, data regarding stakeholder, infrastructure and resources was gathered. The data included information about input, waste and by-products, possible contamination, amount, occurrence and current disposal. The location of the stakeholder is also useful data as well as the current cost for disposal.

The data regarding resources can be gathered through stakeholder interviews which in this case resulted in a comprehensive data set. When conducting several interviews they can be used for cross referencing and finding data gaps, to assure the completeness of data. In this case study the breweries had very similar waste and by-products when using similar production process, which could be used in the later interviews to make sure that all the resource flows were covered. This is an indication that a survey form could be used to gather the data when a baseline of the existing resource flows have been created through interviews.

The recommended steps to identify opportunities for and support bottom-up industrial symbiosis is concluded in the list below.

1. Collect data about stakeholders, infrastructure and resources in a product closed loop supply chain
    - interview
    - interactive survey form
2. Structure data in order to find the most promising opportunities
    - harmonise data
    - condense data
3. Identify opportunities for symbioses
    - new process discovery
    - input-output matching
    - mimicking
4. Investigate the feasibility of identified opportunities
5. Facilitate the found opportunities
    - communicate the opportunity
    - mediate the opportunity if needed

Step one to four have been conducted in this thesis but the fifth step was not in the scope of this study. An information exchange platform could be used as a facilitator to communicate the opportunities and reduce the effort to take part in industrial symbiosis.

9.3 Possibilities for future research

To continue the effort of this thesis, it is suggested that further research is done to evaluate if this method is applicable to other closed loop supply chains as well. This will ensure that the method is a useful tool for supporting industrial symbiosis not only for the investigated supply chains. It would be beneficial to further investigate if an interactive survey form also would be able to acquire the required data to identify opportunities.

As could be seen in the results, it was possible to identify opportunities for symbioses in the two case studies through the gathered data. However, we did not have the possibility to try if this data could be implemented and utilised in an information exchange platform to support industrial symbiosis. To proceed, an information exchange platform could be developed in order to cover step five, facilitate the found opportunities, of the suggested method. This would evaluate if the first steps are useful for collecting data for such a platform. The outcome would demonstrate if this could support bottom-up industrial symbiosis by removing barriers connected to recirculation of resources.

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A

Appendix 1

A.1 Data

In this section the data is presented in its entirety, starting with the beer data then followed by the mushroom data.

Company information	Brewery 1			Brewery 2			Brewery 3			Brewery 4			Brewery 5			Brewery 6			Brewery 7		
Yearly production [l]	500 000			400 000			400 000			350 000			300 000			100 000			60 000		
Employees	9			Unknown			5			7			7			3			1.5		
Sourcing	**Brewery 1**			**Brewery 2**			**Brewery 3**			**Brewery 4**			**Brewery 5**			**Brewery 6**			**Brewery 7**		
Main raw materials	**Amount**	**Occurrence**	**Source**	**Amount**	**Occurrence**	**Source**	**Amount**	**Occurrence**	**Source**	**Amount**	**Occurrence**	**Source**	**Amount**	**Occurrence**	**Source**	**Amount**	**Occurrence**	**Source**	**Amount**	**Occurrence**	**Source**
Malt [tonnes]	2,5	weekly		2,5	weekly		2	weekly		1,5	weekly		1,5	weekly		0,8	weekly		0,5	weekly	
Hops [kg]	50-500	weekly		x			50	weekly		x			35	weekly		10	wekly		40	weekly	
Yeast	20-40 l	weekly		x			0,5 kg	weekly		x			1	weekly		2 kg	weekly		x		
Water	x			x			5:1			x			x			x			x		
Carbonic acid	x			x			x			x			x			x			x		
Auxiliary raw materials																					
Flavours e.g. coffee, orange	x																				
Water adjustment, salts [kg]	1-2	weekly					3	weekly		x			x						x		
Water adjustment, formic acid [kg]	2-4	weekly					4	weekly													
Clarifying agent	x						8	weekly													
Filter	-												x								
kieselguhr [kg]	-			-			15	weekly													
glycol acid [kg]							15	weekly													
Maintenance																					
Ozon	x																				
Lye [l]	30	weekly					15-20	weekly		x			x			x			x		
Methanesulfonic acid	x																				
Nitric acid																x					
Peracetic acid																x					
Packaging																					
Caps	x			x			x			x			x			x			x		
Bottles	x			x			x			x			x			x			x		
Labels	x			x			x			x			x			x			x		
Cartons	x			x			x			x			x			x			x		
Plastic kegs	x						x			x						x			x		
Metal kegs							x						x								
Energy & water																					
Heat	x			x			x			x			x			x			x		
Cooling	x			x						x			x			x			x		
Other																					
Chlorine							10 kg	weekly					x								
Production	**Brewery 1**			**Brewery 2**			**Brewery 3**			**Brewery 4**			**Brewery 5**			**Brewery 6**			**Brewery 7**		
By-products	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**
spent grains [tonnes]	5	weekly	Livestock feed	5	weekly	Municipal waste handling	2	weekly	Livestock feed	3	weekly	Game feed	3	weekly	Livestock feed	1,6	weekly	Game feed	1	weekly	Livestock feed
yeast [l]	400	weekly	Reuse and municipal sewerage	x	weekly	Municipal sewerage	200	weekly	Municipal sewerage	x			30	weekly	Horse feed	40	weekly	Municipal sewerage	10-20	weekly	Municipal sewerage
yeast/hops sludge [l]	1250	weekly	Municipal sewerage	x	weekly	Municipal sewerage	100	weekly	Municipal sewerage	250-100	weekly	Municipal sewerage				100	weekly	Municipal sewerage	x		Municipal sewerage
kieselguhr sludge [kg]	-			-			>15	weekly	Municipal sewerage												
Waste products																					
plastic around pallets	x						>100 kg	monthly	Sold to another company	x		Recycling	x		Recycling	x			x		Recycling
woven plastic bags for malt	x			x			7 pcs	weekly	Municipla waste handling	x		Recycling	x		Municipal waste handling	x			x		Recycling
paper for labels	x																				
glass (production error/waste)	3-5%	weekly	Recycling				x		Recycling	Small amount		Recycling	<1%		Recycling	<1 %		Recycling			
carton							>100 kg	monthly	Sold to another company	x						x			x		Recycling
pallet							x			x		Return system	x		Return system				x		Reused them
containers for chemicals																			x		Same farmer as spent grains
Energy & Water																					
Water	x		Municipal sewerage	x		Municipal sewerage	5:1		Municipal sewerage	x		Municipal sewerage	x		Municipal sewerage	x		Municipal sewerage	x		Municipal sewerage
Other																					
Logistics	**Brewery 1**			**Brewery 2**			**Brewery 3**			**Brewery 4**			**Brewery 5**			**Brewery 6**			**Brewery 7**		
Waste products	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**
Other																					
Warehouse (cooling, size, time...?)	**Amount**	**How long**	**Who warehouses?**	**Amount**	**How long**	**Who warehouses?**	**Amount**	**How long**	**Who warehouses?**	**Amount**	**How long**	**Who warehouses?**	**Amount**	**How long**	**Who warehouses?**	**Amount**	**How long**	**Who warehouses?**	**Amount**	**How long**	**Who warehouses?**
Storing	x	Varying	Themselves				x		Themselves	x		Distributioncenter	x		Themselves	x		Themselves	x		Themselves
Transport of product	**Amount**	**How often?**	**Who transports?**	**Amount**	**How often?**	**Who transports?**	**Amount**	**How often?**	**Who transports?**	**Amount**	**How often?**	**Who transports?**	**Amount**	**How often?**	**Who transports?**	**Amount**	**How often?**	**Who transports?**	**Amount**	**How often?**	**Who transports?**
Truck	x	Varying	Logistics companies							x		Logistics companies									
Van							x		Themselves and logistics				x		Themselves and logistics	x	2 times/week	Themselves	x		Themselves
Consumption	**Brewery 1**			**Brewery 2**			**Brewery 3**			**Brewery 4**			**Brewery 5**			**Brewery 6**			**Brewery 7**		
Reseller	**Amount**	**Waste/bypro**	**Comments**	**Amount**	**Waste/bypro**	**Comments**	**Amount**	**Waste/bypro**	**Comments**	**Amount**	**Waste/bypro**	**Comments**	**Amount**	**Waste/bypro**	**Comments**	**Amount**	**Waste/bypro**	**Comments**	**Amount**	**Waste/byproduc**	**Comments**
Systembolaget	x						x			x			x			x					
Bars and restaurants	x						x			x			x			x			x		
Export	x									x			x								
End of Life	**Brewery 1**			**Brewery 2**			**Brewery 3**			**Brewery 4**			**Brewery 5**			**Brewery 6**			**Brewery 7**		
Waste products	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**
Plastic kegs	x						x			x		Recycling				x			x		Recycling
Metal kegs							x		Return system				x		Return system						
Bottles	x		Recycling				x		Recycling	x		Recycling				x		Recycling	x		Recycling
Other																					

Figure A.1: *The gathered data from the breweries.*

Company information	Mushroom producer 1			Mushroom producer 2			Mushroom producer 3			Mushroom producer 4		
Employees	4,5			2,5			3			1		
Production [ton/week]	2			1,2			0,8			0,025		
Sourcing	**Mushroom producer 1**			**Mushroom producer 2**			**Mushroom producer 3**			**Mushroom producer 4**		
Main raw material	**Amount**	**Occurrence**	**Source**	**Amount**	**Occurrence**	**Source**	**Amount**	**Occurrence**	**Source**	**Amount**	**Occurrence**	**Source**
Compost (hay, horse/chicken manure, chalk)	7,5 tonnes	weekly	Germany	7,5 tonnes	weekly	Germany	7,5 tonnes	weekly	Germany			
Sawdust										60 kg	weekly	
Cutter shavings (woodchips)										33 kg	weekly	
Wheat										5 kg	weekly	
Rape										2 kg	weekly	
Mycelium										3,3 l	weekly	
Chalk										x	weekly	
Plasticbags										33 pcs	weekly	
Mushroom trays	x			x						x		
Plastic packaging							~2000 pcs	yearly				
Plastic gloves	x						x					
Paper towels							x					
Labels							x					
Packaging for refined products (eg glass bottles)							x					
Water	x			x			x			x		
heating/cooling	x			x			x			x		
Production	**Mushroom producer 1**			**Mushroom producer 2**			**Mushroom producer 3**			**Mushroom producer 4**		
Salt				x								
Dried mushroom				x								
Mushroom	2	weekly		1,2 ton	weekly		0,8 ton	weekly		0,025	weekly	
Mushroom ketchup							x					
Mushroom soy				x			x					
Type of waste	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**
Plastic from substrate	x		Municipal waste handling	x			x		Municipal waste handling	35 pcs	weekly	Municipal waste handling
SMC [ton]	7,5	weekly	Waste handling company	7,5	weekly	Farmer	7,5	weekly	Farmer	0,1	weekly	Municipal waste handling
Mushroom waste [kg]	500	weekly	Waste handling company	<100		Additional products	200	weekly	Farmer	2		
Plastic gloves	x		Municipal waste handling	x			x		Municipal waste handling			
Logistics	**Mushroom producer 1**			**Mushroom producer 2**			**Mushroom producer 3**			**Mushroom producer 4**		
Warehouse (cooling, size, time...?)	**Amount**	**How long?**	**Who warehouses?**	**Amount**	**How long?**	**Who warehouses?**	**Amount**	**How long?**	**Who warehouses?**	**Amount**	**How long?**	**Who warehouses?**
Cooling-room mushrooms				x	2-3 days		x	1-4 days	Own storage		1 day	Own storage
Transport of product	**Amount**	**Occurence**	**Who transports?**	**Amount**	**Occurence**	**Who transports?**	**Amount**	**Occurence**	**Who transports?**	**Amount**	**Occurence**	**Who transports?**
Van	x		Themselves	x			x	3x/week	Themselves			
Bike/Tram										x	2x/week	Themselves
Consumption	**Mushroom producer 1**			**Mushroom producer 2**			**Mushroom producer 3**			**Mushroom producer 4**		
Reseller	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**
Retailers e.g. ICA and Coop	x			x			x					
Restaurants										x		
Smaller stores							x			x		
End of Life	**Mushroom producer 1**			**Mushroom producer 2**			**Mushroom producer 3**			**Mushroom producer 4**		
Waste	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**	**Amount**	**Occurrence**	**Current disposal**

Figure A.2: *The gathered data from the mushroom producers.*

B

Appendix 2

Table B.1 is a way of structuring the resources that is useful for identifying possible synergies.

Table B.1: *Needed information to identify possible synergies for stakeholders in a closed loop supply chain. Sourcing is the input for production*

Stakeholder 1					
Contact: Location: Employees:					
Product	Amount	Occurrence		Comment	
Sourcing	Amount	Occurrence	Source	Cost	Comment
Main raw material					
Auxiliary raw material					
Maintenance material					
Packaging material					
Energy & water					
Other					
Production	Amount	Occurrence	Current disposal	Cost	Comment
By-products					
Waste products					
Energy & Water					
Other					
Logistics	Amount	Occurrence	Current disposal	Cost	Comment
Waste products					
Other					
Consumption	Amount	Occurrence	Current disposal	Cost	Comment
Waste products					
Other					
End of Life	Amount	Occurrence	Current disposal	Cost	Comment
Waste products					
Other					