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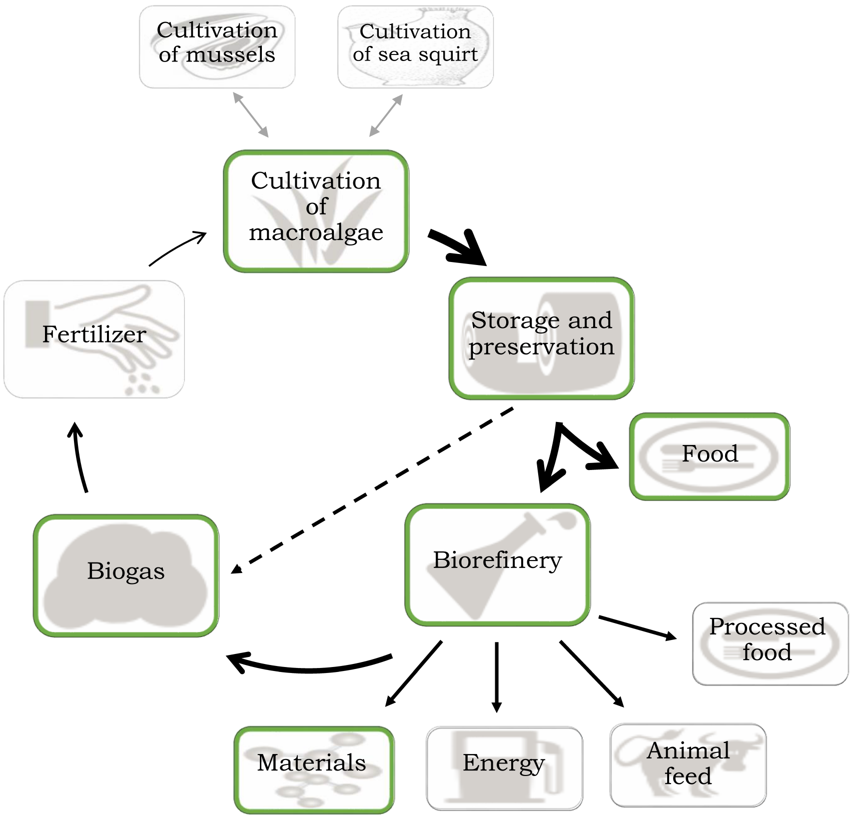

Macroalgae as a renewable resource for a fossil-independent region

Analysis of the innovation system of macroalgae in Western Sweden

Master's thesis in Innovative and Sustainable Chemical Engineering

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Gothenburg, Sweden 2017

Master's thesis 2017:NN

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Cover: Circular value chain of macroalgae as constructed by the research project *seafarm* with the focal system highlighted.

Abstract

Eutrophication [1] and the need to produce materials from renewable resources are sustainability challenges that we are currently presented with. One solution for these issues is the cultivation of algae, because it provides ecosystem-services such as mitigation of eutrophication and can be processed into a variety of inherently bio-based products. The opportunities for macroalgae cultivation that the long coastline on the Swedish West Coast offers have however hardly been seized. Therefore, this thesis aims at identifying the developments that have taken place and the factors that are hindering or promoting the development, resulting in a proposal of policy changes required for further development. The overarching aim of this thesis is to take on complex sustainability challenges in the setting of the Challenge Lab at Chalmers University of Technology. The identification of a sustainability challenge by using the backcasting approach is the first part of this thesis with the second part of finding a strategy towards closing the sustainability gap.

Opinions and insights from different stakeholders were the main source of information, gathered during ten interviews and one workshop. Complementary actions were researching existing publications and reports on the technology of macroalgae as well as identifying connected activities in Western Sweden. The data analysis was carried out based on the framework of the Technological Innovation System.

The study shows that the development of macroalgae is in an early stage, but emerging entrepreneurial activities and increasing knowledge development are moving the development forward. Additionally, the support from funding is what has been enabling the development and is necessary to generate incentives to induce new activities and to further advance the knowledge base. However, it is necessary to simplify the process to obtain a cultivation permit and to provide subsidies for ecosystem services to overcome the barriers that legislative issues pose. These are necessary changes in order for macroalgae to unfold its potential to develop into a noteworthy technology in Western Sweden.

Keywords: backcasting, macroalgae, stakeholders, technological innovation system, policies

[1] Excess of nutrients in the water, caused by human activities

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1
Introduction

A global challenge that humanity is currently presented with is the climate change, which because of its high complexity requires collaborative efforts in order to keep the global temperature rise in this century below 2°C compared to pre-industrial levels. This central aim of the Paris Agreement is necessary to limit dangerously disruptive climate impacts (*The Paris Agreement*, 2016). The issue of human perturbations that destabilize the conditions the earth is in was taken up by the framework of planetary boundaries, which indicate the condition of nine different critical processes. Whereas for the case of climate change, the condition is in the zone of uncertainty, biogeochemical flows of nitrogen and phosphorous are beyond the zone of uncertainty and pose a high risk that needs to be taken care of (Steffen et al., 2015)

Accordingly, the region of Västra Götaland has set an ambitious climate goal – to become a region that is independent of fossil resources by the year 2030. To reach this goal, the strategy for growth and development plans to reduce greenhouse gas emissions by 80%. Therefore, one focus lies on developing renewable and resource-efficient products and services with one strategy being the accomplishment of a greater market for bio-based materials and fuels (Lunder and Roupe, 2016). This aspect was taken up by the West Swedish Chemical and Material Cluster, who in collaboration with the Maritime Cluster is exploring the opportunities of marine and aquatic raw materials to be used in different applications as renewable resources.

1.1 Challenge Lab

The Challenge Lab was established in 2014 in order to address and solve complex sustainability problems, for which it is necessary that the industry, society and academia work together collaboratively. The aim is for students to facilitate this process as they are seen as non-threatening, but nonetheless challenging, giving them the ability to induce listening and trust. The collaboration between industry, society and academia, which is called the triple helix, was induced in Western Sweden by the identification and creation of five knowledge clusters. These are facilitated by the universities, due to their stable presence in the region. Additionally, the universities incorporate three elements: research, innovation and education, the knowledge triangle. Whereas research been in focus of the collaboration with the industry and society at Chalmers, the Areas of Advance were created to strengthen and integrate all elements of the knowledge triangle. The knowledge triangle is then connected with the other elements of the triple helix through the students of the Challenge Lab (see Figure 1.1) (Holmberg, 2014).

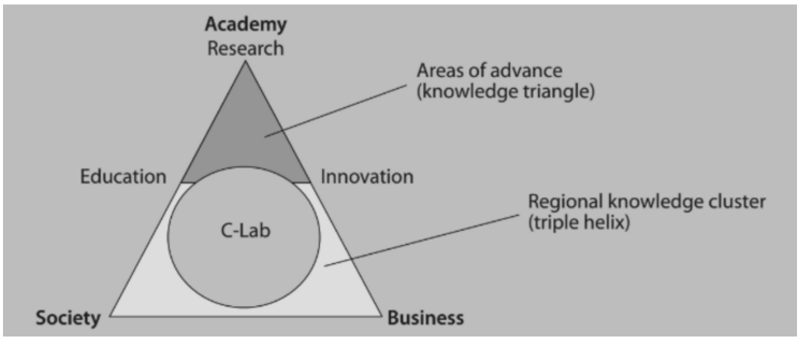

Figure 1.1: Challenge Lab in the centre of the regional knowledge cluster, from Holmberg (2014)

In the last study period before the start of the thesis, the preparatory course "Leadership for Sustainability Transitions" took place, where the method of backcasting and relevant tools to implement it were taught. The backcasting process was applied to the example of the 'sustainable campus', which introduced the students to the transformative and integrative processes in the Challenge Lab.

For this year's master theses, the group consists of 16 students from 11 different master programs. The process in the Challenge Lab is conducted in two phases. Phase 1 is characterized by the identification of regional sustainability challenges by conducting dialogues with stakeholders from the elements of the triple helix. As part of the approach of backcasting, the students create criteria for a sustainable future, which are used together with an identification of the present situation to identify sustainability gaps in the region. This is is the foundation for an iterative process on leverage points to intervene in the system, which ends with the formation of thesis pairs that explore a research question aiming at taking on regional sustainability issues. Phase 2 is then characterized by efforts to answer the posed research question and to find a way to close the identified sustainability gap.

1.2 Purpose and research question

During a stakeholder dialogue on the topic of circular products and services as part of the thesis process in the Challenge Lab, this project was presented by a representative from the West Swedish Chemical and Material Cluster. It was pointed out that there is currently an interest in this topic, because aquatic raw materials could support the transition from a linear to a circular economy. Additionally, they provide ecosystem services, which are beneficial effects from ecosystems to human well-being, e.g. air purification and removal of excess nutrients (Hattam et al., 2015). After connecting with the interdisciplinary Swedish research project on macroalgae, Seafarm (Gröndahl, 2014), we concluded that in particular macroalgae is a promising renewable resource for the future. Whereas the research project is researching how to carry out the different steps of the value chain, this thesis aims at evaluating the potential of macroalgae to take part in the transition.

This is achieved by identifying the innovation system surrounding the technological field of macroalgae within the later described scope. The goal is to have an understanding of the value chain and the stakeholders involved to understand the strengths, weaknesses and the state of development of the system. From this finding, a proposal can be made on which developments are necessary to foster the growth of the technological field and what barriers are hindering it. The research is guided by the following research-question:

Does macroalgae currently contribute to the transition towards a sustainable future in Western Sweden and how does the prospective potential look like?

The aim is to answer this question by evaluating the following two questions:

What are the actors, institutions, interactions and infrastructure that can be identified in the focal TIS and where are they found in the corresponding value chain?

What drives and what hinders the development of the focal TIS?

1.3 Scope and delimitations

The scope of the thesis is defined by three aspects: time-scale, geography and focus of attention. In this case, the time-scale of identifying the history of macroalgae of five years is set and the geography is narrowed down to the regional context of Western Sweden, based on the vision of the Challenge Lab to act on a local or regional level. As this thesis benefits from a broad geographical scope and benchmarking, the regional scale is a large limiting factor. The focus of attention is limited to the circular value chain of macroalgae production and its technological use, highlighting the case from cultivating macroalgae to the final product of high value compounds. Therefore, on-land cultivation of microalgae, as well as co-cultivation with other raw aquatic materials was excluded and other possible products neglected. These limitations are necessary to be able to write a thesis in the limited time given and attempt to ensure that the thesis has enough depth and is not only covering surface aspects. However, this results in the issue that the perspective is too narrow to accomplish meaningful findings and will not depict the system in its entirety. Additionally, the language barrier of being a non-native speaking person limits the understanding to mainly English literature.

1.4 Outline of the thesis

The thesis process is characterized by two phases: Phase 1 covers the process of applying the research methodology of backcasting to identify sustainability challenges in the region, from which the research question originates. Phase 2 continues with developing a strategy to answer the posed research question, which is in this thesis carried out by applying the Technological Innovation System framework to macroalgae.

Phase 1 includes the following text bodies:
Chapter 2 - Explanation of backcasting as a framework and relevant theory connected to the different steps
Chapter 3 - Description of the specific steps carried out to propose the research question
Chapter 4 - Presentation of the outcome of conducting backcasting, resulting in the research question

Phase 2 includes the following text bodies:
Chapter 5 - Presentation of relevant theory, namely the framework of Technological Innovation System (TIS) Analysis and a review of previous research
Chapter 6 - Introduction into the process from cultivating macroalgae to different applications
Chapter 7 - Description of the study approach and collection of data
Chapter 8 - Setting the scope of the focal TIS, followed by the structural and functional analysis
Chapter 9 - Identification of the phase phase of development and barriers and drivers
Chapter 10 - Concluding discussion with policy recommendations

Phase 1

2

Theory

The theory presented in this chapter consists of different tools, frameworks and approaches used during Phase 1 to identify the sustainability gap and to define the research question. They were utilized as tools to carry out the process of backcasting and are therefore structured according to their contribution to conduct the backcasting process.

Backcasting is a planning method that is applicable to approach problems of high complexity and uncertainty, which is given for many sustainability challenges. It resulted from the problem that solutions were too reliant on the present situation when approached with forecasting. In contrast to forecasting, which is done by trend extrapolation, backcasting is carried out by first creating sustainability criteria of a desirable future and going backwards from there, thus preventing possible lock-ins in today's situation (Holmberg and Robert, 2000). With the aim of the Challenge lab to address challenge-driven sustainability transitions, backcasting is the core method used, complemented with relevant tools to carry out the different steps (Holmberg, 2014). The approach of backcasting is divided into four steps, starting with defining a framework for sustainability, followed by describing the current situation in relation to the framework. Adjoining with envisioning a future situation, the last step includes finding strategies for sustainability (Holmberg and Robert, 2000).

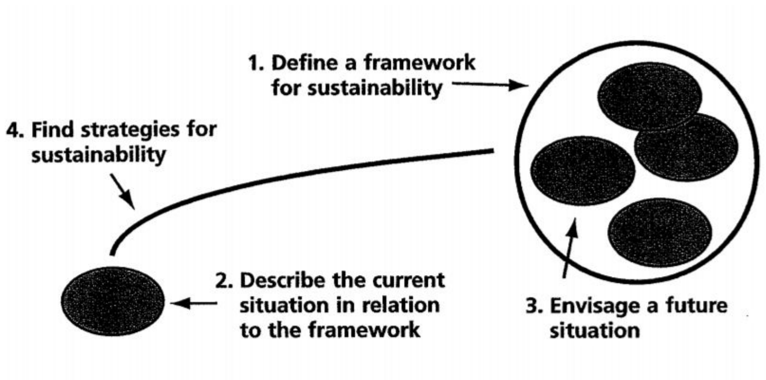

Figure 2.1: Steps in strategic planning for sustainability, from Holmberg (1998).

Each step is then approached by two different perspectives: the outside-in perspective with the aim to analyze the system by taking a global perspective, as well as the inside-out perspective that is concentrating on the individual and includes self-leadership dialogue tools (Holmberg, 2014). The theory for the four steps, including the different perspectives, is presented in the following paragraphs.

2.1 Defining criteria for sustainability

The first step in backcasting is to define criteria for sustainability, which is a process that involves acquiring self-leadership skills and has as a result a common vision of a sustainable future.

Outside-in

The starting point is to understand the conditions that need to be met in a sustainable future, thus a sustainability framework is developed for the dimensions well-being, society, economy and nature. The dimensions relate to each other in a way where the ecological criteria (nature) are the foundation for the dimensions of society and economy. When combined, they form the conditions to guarantee the well-being in the future (Holmberg, 2015).

The necessity to have a vision of a sustainable future also arises from the fact that the global demands for natural resources are increasing due to global population growth, ever growing economies, and increasing resource intensity per service. This is met with a decreasing supply capacity of natural resources, caused by increasing resource, assimilation, and land area restrictions. Combining the increasing global demand of natural resources with the decreasing supply capacity, the space to act within becomes smaller, which can be visualized as a time-dependent (resource) funnel that becomes more narrow as time goes on. With the decreasing resource potential, it is then even more pressing to move towards a sustainable future (Holmberg, 1998).

Inside-out

Holmberg (2014) argues that it is necessary to supply students with leadership skills that enable them to induce co-creative processes and to challenge prevailing perceptions that individuals have on the way that certain systems function. This type of leadership requires knowing ones values and strengths, which form the foundation of self-leadership. Moreover, knowing ones values and strengths, empowers students to identify their vision. Being aware of theses aspects gives the students the opportunity to connect to their intrinsic motivation, which is helpful for the transformation of complex systems (Stewart et al., 2011). As this is the goal of the Challenge Lab, there is an emphasis on gaining self-leadership skills.

2.2 Understanding the present system

The second step consists of understanding today's situation to be able to describe the present situation in relation to the criteria for sustainability. This is done by mapping the system with the aim to result in the identification of a gap between the envisioned future and the present.

Outside-in

The outside-in perspective in this step is used to understand the dynamics of the existing system. In order to map the system, different tools can be applied, in particular system thinking and multi-level perspective.

System thinking addresses the issue that problems are often cut into smaller pieces, which has as a result that the big picture becomes unclear and efforts made to put the pieces back together do not result in depicting the original situation. Consequently, Flood (1998) describes the core of system thinking in a review of Senge's *Fifth Discipline* that it "Explores things as wholes [. . .] they are all interconnected" (p.260) . Gathering knowledge of certain small reoccurring patterns, so called systems archetypes, helps to gain awareness of underlying processes to be able to make sense of the complexity. When using backcasting, the ability of systems thinking helps find holistic solutions, as sustainability issues are often multifarious and often interconnected. If a too narrow mindset is applied, improving a certain aspect, can lead to a worsening of others when important connections were not detected (ibid.).

The multi-level perspective, as described by Geels (2005), is an analytical framework that can be used to understand how innovations can be introduced into a system. Therefore, it distinguishes three different system levels: niche, regime and landscape that interact and influence each other. The regime refers to socio-technical systems that are formed by social groups that interact and influence each other and can be described by seven functions, as indicated in Figure 2.2. The technological niches offer opportunities for radical novelties to develop in a protected space. If they grow the ability to compete with prevailing solutions, they have the chance to alter the socio-technical systems and even to have an influence on the landscape development. The landscape refers is formed by the surrounding environment and influences the way socio-technical regimes are built up. It is the most rigid system level and thus the hardest to influence and change.

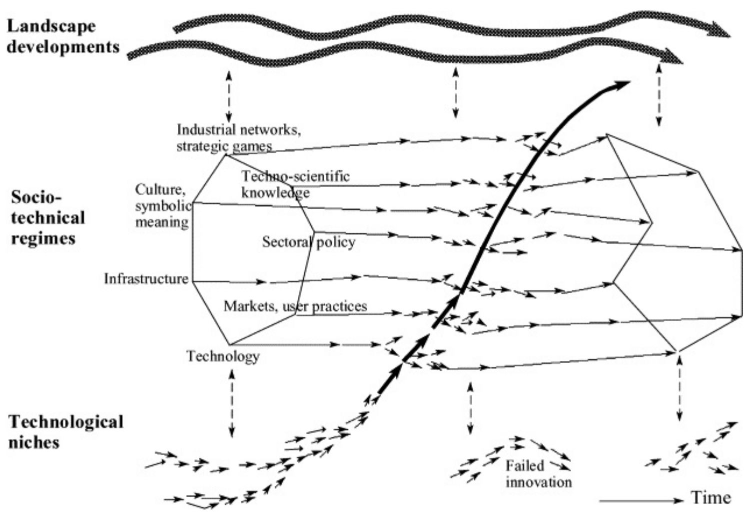

Figure 2.2: A dynamic multi-level perspective on system innovations (Geels, 2002).

Inside-out

The main tool used for the inside-out part is the conduction of dialogues to gather and mediate the opinions and insights of the different stakeholders on the present situation. According to Holmberg (2014), the ability to conduct a dialogue is thus essential in getting people to listen to each other and to be able to understand and appreciate different standpoints, especially when matters become complex. An important foundation to conduct a valuable dialogue is the ability to create trust. Jewell-Larsen and Sandow (1999) explain that it is listening and observing that lead to understanding, which is the foundation of collaboration. Collaboration then enhances listening, as well as increased participation. This then nourishes creativity and innovation and then leads to excitement and appreciation, which is the last step in closing the so called positive feedback loop with coming back to collaboration.

2.3 Envisioning future solutions

The third step includes the envisioning of solutions that fit within the sustainability framework that was created in the first step are envisioned, based on the evaluation of the present situation. Because the previous steps only set the general direction, there are various possible future solutions (Holmberg, 1998). A tool that can be used for this step is design thinking.

2.4 Finding strategies towards sustainability

To finish the backcasting process, the last step that needs to be taken is the identification of feasible ways to realize the envisioned future solutions. To find a holistic strategy, the following questions should be considered:

- "Will each measure (e.g. investment or product) 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 for humans and other species during the transition?" (Holmberg, 1998, p.39)

According to Holmberg (1998), these question are meant as guidance, resulting in a strategy with the largest possible impact only if all of them are combined

3

Method

Phase 1 was performed by carrying out the first and second step of backcasting, which resulted in the formulation of a research question as well as the formation of thesis pairs. The different steps taken are described in the following paragraphs.

3.1 Creating a shared mental model

Phase 1 began with the creation of a shared mental model, which was developed by both taking the outside-in perspective to investigate global sustainability aspects and the inside-out perspective to achieve self-awareness of each individual student.

Outside-in

The outside-in perspective was taken to develop criteria for a sustainable future of the four pillars (ecological, social, economical and well-being). Therefore, focus groups on each of the pillars were formed and in each focus group, the particular sustainability criteria were created by reviewing the material of previous courses and thesis groups, as well as literature. They were then presented to the entire group, discussed and decided upon. When an agreement was found, the criteria were registered and provided from thereon the framework for a sustainable future for the students to build the following processes and their thesis upon.

Inside-out

The first activity of the thesis process included taking an inside-out perspective by creating a "Coat of Arms" by drawing pictures to the following topics: This is me, Why I chose Challenge Lab, What makes me concerned, What makes me happy. The process of the creation of a shared mental model then finished with a day-long workshop on self-leadership skills, which involved the identification of the values of the individuals. These were subsequently communicated to other students in an active listening exercise to induce collaboration in the group by addressing the positive listening feedback loop, as explained in 2.2. Finally, a strength assessment was conducted, where the students identified their individual strengths and continued to describe the corresponding overdone strength, complementary strength and challenge in order to recognize how different strengths can collaborate to balance each other out. It finished with the identification of specific individual personality traits from which the students positioned themselves within the given characteristics.

3.2 Finding leverage points

The second step led to an understanding of the current situation in the region Västra Götaland, the identification of leverage points and the formulation of a research question.

Outside-in

As an introduction to the topic, representatives from the region presented their climate strategy to become a fossil-independent region by the year 2030. To reach this goal, the region developed four focus areas and climate actions of which three were adapted to the focus areas of the Challenge Lab, namely Circular Products and Services, Urban Futures, and Mobility (Lunder and Roupe, 2016). In addition to the information about the region's work with sustainability, Chalmers' Areas of Advances presented their strategy to get an understanding of our university's work. The synthesis of the dialogues, described in the inside-out perspective, was carried out using the multi-level perspective and system thinking (see Chapter 2.2). After each dialogue, the students met to discuss the topics that were brought up and clustered the results into sub-topics, from which the identification of leverage points followed. They were continuously iterated and finally assembled on one map that clustered and connected all leverage points identified during the different dialogues. Guiding questions for the iteration process were the following:

- What can Challenge Lab do? (Define a clear starting point.)
- Who are the stakeholders connected to this starting point?
- Which other leverage points is this leverage point connected to?

Inside-out

Stakeholder dialogues on the three focus areas were held in a fishbowl-setting to discuss sustainability challenges that the stakeholders saw and possible leverage points. They were prepared by conducting research on the topics, from which sustainability challenges were identified by the students beforehand, from which questions were formulated to be asked in the dialogue. Additionally, two facilitators were named, as well as a secretary and the final preparation included deciding who would take part in the inner circle and who would observe from the outer circle. The dialogue was then conducted based on the structure given by the facilitators. The table 3.1 below shows the background stakeholders that were present during the different transition dialogues.

The iteration on the leverage points was carried out in a way that students had to choose two leverage points to further investigate and leverage points that had less than two interested students were taken away. Thus, a natural process emerged where students with common interests started to communicate with each other and started to form groups. This process was additionally guided by the supervisors from the Challenge Lab, who then gave support for the final formation of the thesis pairs.

Table 3.1: Stakeholders present during the three dialogues

Topic area	Institution
Circular products and services	West Swedish Chemical and Material Cluster Innovation and Chemistry industries in Sweden Chalmers - PhD Chalmers Industriteknik
Urban futures	Framtiden AB Göteborgs Stad, Kretslopp och vatten Chalmers - Docent Chalmers - Senior researcher Älvstranden AB Yes In My Backyard (YIMBY)
Mobility	RISE Victoria DenCity Yes In My Backyard (YIMBY) Trafikkontoret Göteborg Chalmers - PhD Area of Advance Transport - Chalmers Chalmers - Assistant professor

4

Results & Discussion

The results from the different activities that ranged from creating the coat of arms to identifying the research question are presented in this chapter.

4.1 Creating a shared mental model

The coats of arms was the first introduction to the inside-out perspective with the goal to get acquainted with the group and to start the collaborative process. It made us reflect on the purpose of being in the Challenge Lab to do our thesis and we presented who we are, instead of focusing on what we have done. The following three days were used to agree on criteria for a sustainable future, as proposed by Holmberg (2015). This task was harder than expected, because of having different cultural backgrounds, beliefs and education. Finally, we agreed on the following criteria for sustainable future:

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

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

Nature

- Substance* 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.

* A species of matter of definite chemical composition

Economy

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

- Resources* 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

*Resources include natural and man-made.

4.2 Finding leverage points

The procedure to identify challenges and leverage points was carried out and resulted in the identification of the leverage points and challenges presented in the following figures according to the three focus areas.

Circular Products and Services

Table 4.1: Challenges and leverage points identified during the Circular Products and Services dialogue

Challenge	Leverage point
Raw materials	Forest based bio-materials Algae
Reuse/Recycle (Mainly food, textiles, plastics)	Food waste Content declaration Excess heat for algae production Modular products How to recycle difficult end-use products?
Users	Consumer-based collaboration
Understanding the system	Connect and waste recycling
Business models	Bridge gap of profit vs. sustainability Advantage of circular market segment Questioning owner ship
Legislation/ Policies	-

Urban Futures

Table 4.2: Challenges and leverage points identified during the Urban Futures dialogue

Challenge	Leverage point
Use of Space	Density vs building in-between and connecting general plan Existing Stock: cost vs sustainable renovation Flexible Housing: ownership, growing housing demand
Environmental	RiverCity and the sea level rise Food production and resources independent cities, urban farming
Social	Social Space: Playful city and Empowerment and opportunity Gothenburg a sharing city. Change in consumption patterns
Understanding the system	Connect stakeholders and citizens' opinions Planning symbiosis (top-down vs. bottom-up)
Infrastructure/ Resources	Comparing Gothenburg and Malmö

Mobility

Table 4.3: Challenges and leverage points identified during the Mobility dialogue

Challenge	Leverage point
Private	UbiGo, why did it not succeeded Parking Norm
Infrastructure	Adaptability Data: Integration of different actors Use transportation structure for energy
Public	Barriers in the transportation system Multimodal: use of bikes and buses Pods/ platooning
Land Use	Use water as mean of mobility, integrating cargo/ human transportation
Environment	Noise and Vibration Water Pollution
Behaviour	Use transport to create trust

During the dialogue on circular products and services, it was pointed out by the representative from the West Swedish Chemical and Materials Cluster that algae as a renewable resource was an interesting material to be integrated into existing industrial processes. The cluster therefore was planning to explore the opportunities of marine and aquatic raw materials to be used in different applications as renewable resources. In collaboration with the Maritime cluster a seminar was held in March with different stakeholders to look for the opportunities in this field. This appeared to be a solid starting point for an interesting research field for me, as well as another student, which resulted in us forming a thesis pair that was later resolved into two individual research projects. After connecting with a supervisor with a background in analyzing innovation system, a research approach was set and the following research questions formulated:

Does macroalgae currently contribute to the transition towards a sustainable future in Western Sweden and how does the prospective potential look like?

The aim is to answer this question by evaluating the following two questions:

What are the actors, institutions, interactions and infrastructure that can be identified in the focal TIS and where are they found in the corresponding value chain?
What drives and what hinders the development of the focal TIS?

The starting point for this thesis was the seminar, with the main purpose to get a first overview over the situation in West Sweden and to connect with relevant stakeholders. It also revealed opportunities and challenges in different marine technologies. Macroalgae was a frequently discussed topic with a great interest in the field, which is why this thesis focuses on this specific strain of algae.

The aim is to analyze the system using the Technological Innovation System (TIS) framework, which was developed to explain why and how a technology has evolved and spread into a society, or on the contrary, failed to do so. The framework is integrated in the backcasting methodology as it approaches the fourth step, to find a strategy for sustainability transitions. The goal is to create recommendations on what is necessary to support the development of the focal TIS. It is finalized as a proposal for the clusters, and for the newcomers to the algae network.

Phase 2

5

Theory

During Phase 1, the approach of backcasting was used, resulting in the identification of the opportunity that macroalgae offers as a potential solution to close the identified sustainability gap. The task for Phase 2 is therefore to explore a feasible way to realize the envisioned future solution (forth step of backcasting) by using the Technological Innovation System (TIS) framework.

5.1 Analytical framework

The TIS framework is used to understand the processes and structures that foster or dampen the innovative processes surrounding a technology, formulated by Bergek et al. (2008), with the addition of different views and approaches from Wieczorek and Hekkert (2012) and Sanden and Hillman (2011). It is a practical scheme, divided in six steps, that was originally created as as an analytical framework to evaluate the performance of a technological system and to support policy makers in identifying key policy issues. The core part is the analysis of the key functions, in particular the processes that "have a direct and immediate impact on the development, diffusion and use of new technologies" (Bergek et al., 2008, p.409). In the following section, the six steps are presented.

5.1.1 The focal TIS

The scheme begins with setting the starting point by identifying the scope of the TIS that is to be analyzed. According to Bergek et al. (2008), three different aspects should be considered to describe the scope, with the first one being the focus of attention. Therefore, it has to be decided if the focus lays on a certain product or product group, e.g. solar cells, or if a technological knowledge field is to be evaluated.

Secondly, the breadth and depth of the analysis is defined by determining the level of aggregation and the range of applications. The level of aggregation requires a decision on the level of detail by choosing between aiming to get an overview of the broad picture or an insight into specific aspects. Moreover, the choice on the range of applications defines which actors, networks and institutions will be included in the second step of the analysis. Due to the uncertainty involved in setting a scope from the beginning in field that has an hitherto unknown structure, the focus can be adjusted over the course of the analysis when it is discovered that the initial focus is not appropriate anymore. Additionally, the socio-technical system can be expressed by depicting the elements of the value chain and by showing the relationship to other technologies (Sanden and Hillman, 2011).

The third aspect includes setting the spatial domain, which is the decision on the geographical context. The general tendency is that a global context should be used, because TISs generally have a global character, whereas it can sometimes be necessary to limit the analysis to a regional or local scope. This counteracts the need for an international component, which is important to have because "a spatially limited part of a global TIS can neither be understood, nor assessed, without a thorough understanding of the global context" (Bergek et al., 2008, p.413).

5.1.2 Structural components of the TIS

The definition of the starting point in the first step then leads to the identification and analysis of the structural components involved in the TIS. The structural components can be categorized into the following four categories: Actors, institutions, interactions and infrastructure (Wieczorek and Hekkert, 2012).

Actors in a TIS come from miscellaneous backgrounds and can be categorized depending on their role in the economic activity, according to Wieczorek and Hekkert (2012). The different categories are: civil society, companies (such as start-ups, small and medium-sized enterprises (SMEs), large firms), knowledge institutes (universities, technology institutes, research centres), government, non-governmental organizations and different parties that contribute to the TIS.

Institutions include rules, norms and strategies, which shape and are shaped by common habits, expectations, routines and shared concepts generally embraced by humans. They are called hard institutions and soft institutions, respectively (Wieczorek and Hekkert, 2012). Hard institutions on one hand define how actors should behave and are defined by regulations (controlled by juridical systems), as well as norms and attitudes, which are controlled by social systems. Soft institutions on the other hand reflect on the reality by pointing out expectations, common habits, customs and traditions, as well as routines and shared concepts. Going beyond the scope of expressing the present situation, they also convey beliefs about the future performance of systems (Sanden and Hillman, 2011).

Interactions can be carried out either at the level of networks or on an individual level. Especially for developments in early stages, mostly interpersonal relationships exist that could later be developed into networks. (Wieczorek and Hekkert, 2012).

Infrastructure includes elements that have not been introduced in the previous structural components: physical, knowledge and financial infrastructure, as proposed by Wieczorek and Hekkert (2012). Physical infrastructure is necessary to ensure the establishment of a new technology and shapes the direction of the technological trajectories. It includes elements, for instance building, roads, but also existing technologies such as instruments and machines. The importance of including physical artifacts is also emphasized by Sanden and Hillman (2011), who use the term "material dimension" instead. Moreover, knowledge infrastructure includes e.g. universities and libraries by emphasizing on the skills, expertise and know-how it provides and contains. Finally, financial infrastructure includes subsidies, financial programs, as well as grants to support the development of the TIS.

A summary of the elements that are part of the different structural components can be found in Table 5.1

Table 5.1: Structural components and their elements of TISs, adopted from Wieczorek and Hekkert (2012))

Components	Subcategories
Actors:	• Civil society • Companies: start-ups, SMEs, large firms, multinational companies • Knowledge institutes: universities, technology institutes, research centres • Government • NGOs • Other parties: legal and financial organizations, intermediaries, consultants
Institutions:	• Hard: rules, laws, regulations, instructions • Soft: customs, common habits, routines, established practices, traditions, norms, expectations
Interactions:	• At level of networks • At level of individual contacts
Infrastructure:	• Physical: artifacts, instruments, machines, roads, buildings, bridges, harbours • Knowledge: knowledge, expertise, know-how, strategic information • Financial: subsidies, financial programs, grants etc.

5.1.3 Functions of innovation systems

The identification of the structural components is the foundation for analyzing the system in functional terms. The aim is to determine how the TIS behaves in terms of different functions and key processes. The functional pattern of a TIS can differ from others, will most likely be modified over time and is composed by the judgment of the analyst based on collected qualitative and quantitative data. The functions that Hekkert et al. (2007) identified are explained in the following paragraphs and summarized in Table 5.2.

Entrepreneurial Activities

Trying out new technologies and applications to expand, e.g. into other markets is necessary for a TIS to develop. Therefore, entrepreneurial activities contribute to reduce the uncertainty inherent to the technological development. By evaluating the number of new entrants and new applications, as well as the diversification of established firms, the degree of activity of entrepreneurs in the focal TIS can be measured (Bergek et al., 2008).

Knowledge Development

According to Hekkert et al. (2007), the development of knowledge is the core of innovation processes and can come from different sources, namely 'learning by searching' and 'learning by doing'. This function therefore aims to capture the breadth and depth of the knowledge base of the TIS in global and local terms by compiling different types of knowledge, such as scientific, technological. The status of this function can be measured by different indicators, e.g. by a bibliometric analysis.

Knowledge Diffusion

The diffusion of knowledge is necessary to enable 'learning by interacting', which is carried out by knowledge exchange within different networks. Through the combination of homogeneous and heterogeneous networks, knowledge is not only diffused within the research community, but also within governmental bodies, competitors and the market so that policy decisions are based upon the most recent technological insights. This can be analyzed by evaluating workshops and conferences related to the topic of the focal TIS and by mapping the networks and their previous development (Hekkert et al., 2007).

Guidance of the Search

The introduction of new entrants into the TIS needs to be ensured for a TIS to develop and is achieved by offering sufficient incentives and/or pressure for components to become part of the system. The mechanisms that influence the direction that the technology is being developed towards are characterized by this function. It is difficult to measure it quantifiably, as it expresses expectations, perceptions of visions of the different components, but can be indicated by the belief of the growth potential and an evaluation of relevant customer demands (Hekkert et al., 2007).

Market Formation

As explained in Section 2.2, technological niches offer opportunities for radical novelties to develop in a protected space that can enter the market when a certain level of maturity is reached. To support the development of a market, it is effective to supply technologies with a competitive advantage, such as tax reliefs. The strength of this function depends highly on the phase of development of the system. Indications for this function are the number of newly introduces niche markets, the way new technologies are treated by the tax system and how new environmental technologies are supported (Hekkert et al., 2007).

Resource Mobilization

The activities within a TIS rely on the supply of a variety of resources, namely human, financial and physical. Therefore, the strength of this function depends on amount of supplied funding, the number of components with relevant knowledge, etc. (Hekkert et al., 2007).

Creation of Legitimacy

To ensure the mobilization of resources, the technology needs to be seen as appropriate and desirable by relevant actors concerning social acceptance and conformity with relevant institutions. The competition of different TIS for the same market and the power of other interest groups are affecting this process. This function is analyzed by evaluation the level of alignment of this technology with relevant institutions, as well as social acceptance (Hekkert et al., 2007).

Table 5.2: Functions of technological innovation systems (Suurs et al., 2010)

Function	Description	Event types associated
Entrepreneurial Activities	At the core of any innovation system are the entrepreneurs. These risk takers exploit business opportunities and perform innovative commercial and/or practice oriented experiments	Projects with a commercial aim, demonstrations, portfolio expansions
Knowledge Development	Technological research and development (R&D) are a source of variation in the system and are therefore prerequisites for innovation processes to occur. Nontechnological knowledge is also of key importance	Studies, laboratory trials, pilots
Knowledge Diffusion	The typical organizational structure of an emergent innovation system is the knowledge network, primarily facilitating information exchange	Conferences, workshops, alliances
Guidance of the Search	This system function represents the selection processes necessary to facilitate a convergence in development	Expectations, promises, policy targets, standards, research outcomes
Market Formation	New technologies often cannot outperform established ones. In order to stimulate innovation it is necessary to facilitate the creation of (niche) markets, where new technologies have a possibility to grow	Market regulations, tax exemptions
Resource Mobilization	Financial, material and human factors are necessary inputs for all innovation system developments	Subsidies, investments
Creation of Legitimacy	The emergence of a new technology often leads to resistance from established actors. In order for an innovation system to develop, actors need to raise a political lobby that counteracts this inertia, and supports the new technology	Lobbies, advice

5.1.4 Phase of development and process goals

Following the description of how the system is functioning, carried out by mapping the functional patterns, a functionality assessment is performed with the aim to describe how well the system is functioning. An approach to express this is to describe the phase of development, which can range from a formative stage to a growth phase. Consequently, the state of system functions differ greatly depending on it and if the requirements of the phase of development is taken into account, the analysis can be carried out more significantly (Bergek et al., 2008).

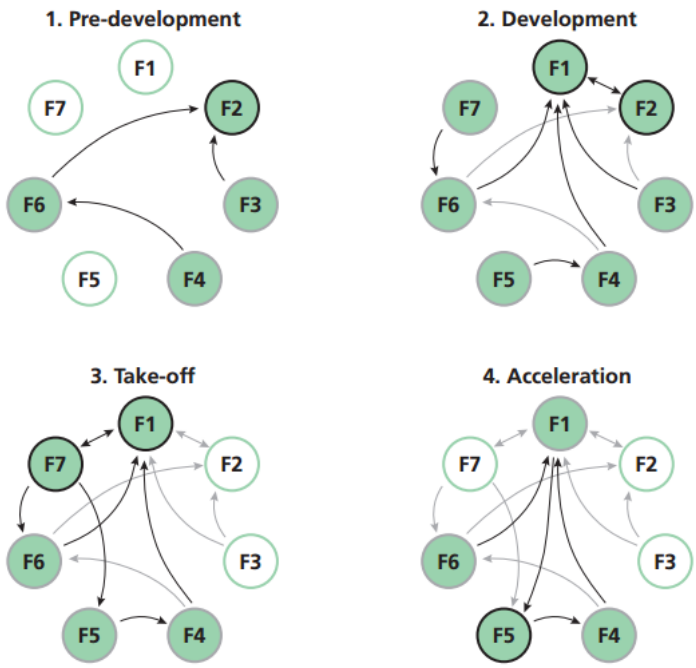

Figure 5.1: Functional pattern for the different stages of development (Hekkert et al., 2011)

In Figure 5.1, Hekkert et al. (2011) describe the relationship between the patterns for four different phases of development. In the earliest stage, which they call *pre-development*, the function of Knowledge Development is the most important for this stage, as it benefits from and depends on Knowledge Diffusion, as well as on Resource Mobilization, which is influenced by Guidance of the Search. As the influence from the other functions is rather low, an emphasis should be put on the analysis of the four mentioned functions. In the next phase, *development*, first pilot plants are set up, showing whether the innovation work in practice. There is a larger interdependency between the functions, with the most critical function being Entrepreneurial Activities, thus requiring a thorough analysis of all functions and interdependencies. The subsequent phase, *take-off*, Entrepreneurial Activities are again essential, but they should be in a further developed state and Creation of Legitimacy should become a strong function. Knowledge Development and Knowledge Diffusion are becoming less critical in this phase. *Acceleration* is the last phase, which is characterized by growing markets that cause the TIS to develop and diffuse. Market Formation is thus the strongest function, supported by Entrepreneurial Activities, Resource Mobilization and Guidance of the Search.

The evaluation of the phase of development gives an idea of what can be expected from the TIS in terms of a general, possible future development. From this, process goals of how the system should develop to reach higher functionality can be made. However, the high uncertainty concerning the long term development for systems in early phases, makes it unfeasible to set process goals for these systems.

The steps of describing the functional components as well as analyzing their strength is often carried out together, e.g. by (Hekkert et al., 2011), (Jacobsson and Karltorp, 2013) and (Andersen, 2014) and results in an integrated analysis, which makes the decision on the phase of development a mere result instead of requiring an isolated analysis to reach to this conclusion.

5.1.5 Inducement and blocking mechanisms

The previous analysis results in a description of the system functions that each inhibit certain strengths and weaknesses. However, the functions are inter-related and from this, the need arises to analyze the mechanisms that are driving or hindering the development of the functions in a more holistic manner. When identifying required policy changes, the blocking mechanisms are of peculiar interest, but it is useful to complement them with an evaluation of inducement mechanisms, as both mechanism are intertwined. Ana example of a blocking mechanism is the inability for structural components to achieve legitimation, because they were too weak to align certain institutions to the new technology. Another example are poorly connected networks that fail to support the new technology. However, if the networks are strongly connected, they can have a "lock-in" effect, preventing new entrants or further development (Bergek et al., 2008). The discussion of the inducement and blocking mechanisms is guided by the questions:

What is there driving the focal TIS?

What stands in the way/ is not existing/ needs to be created?

5.1.6 Key policy issues

The final step of the TIS analysis is to define key policy issues based on previously identified drivers and barriers. Consequently, by drawing conclusions on what they key policy issues are, blocking mechanisms of the focal TIS can effectively be eliminated.

5.2 Literature review

This section presents a background of the analytical framework of TIS discussed in the previous section and an overview of the previous literature on TIS and macroalgae.

Innovations are often seen as the main driver for economic growth and development and the need to understand the dynamics of innovation arose from the interest to be able to shape them to foster more efficient use of resources. Innovation systems have been recognized as the source for innovations and were traditionally described by the structure that they inhibited (Hekkert et al., 2007). However, this framework was not able to describe how well innovation system were functioning and led Bergek et al. (2008) and Hekkert et al. (2007) to define seven key processes, named system functions, that could reflect the dynamic nature of innovation systems. The direct impact of these processes on the development and diffusion of innovations makes it possible to identify necessary policy changes. Since then, authors like Wieczorek and Hekkert (2012) and Sanden and Hillman (2011) have added different perspectives on the structure of the TIS, but the initial idea of including a functional analysis has remained.

Previous TIS analyses were mainly carried out on specific, established technologies with different regional scopes. Jacobsson and Karltorp (2013) follow the approach from Bergek et al. (2008) with a detailed functional analysis on the European offshore wind energy, resulting in the identification of policy challenges from the functions resource mobilization, market formation and legitimation that they identified as weak. A different approach was taken by outlining the event history of the focal TIS, as proposed by Hekkert et al. (2007), which Suurs et al. (2010) applied to the development of Automotive Natural Gas from 1970 to 2007 in the Netherlands and Suurs et al. (2009) used to explain the build-up of the hydrogen and fuel cell technology from 1980 to 2007, also in the Netherlands. Additionally, Quitzow (2015) analyzed the historical development of solar voltaics in comparative study of Germany and China and pointed out that innovation dynamics go beyond national dynamics, advocating that spatially distinct systems can have strong interdependencies. Haase et al. (2013) contributed a TIS analysis on algae, more precisely algal biodiesel, in which they draw conclusions based on two case studies on first generation biodiesel (from vegetable oil) and solar photovoltaics. They concluded that the major barrier algal biodiesel is facing are the lacking federal subsidies.

Previous work on utilization of macroalgae as a renewable resource has mostly focused on researching specific topics in detail, e.g. Sterner and Edlund (2016) who developed a fractionation strategy to extract different components from the algal biomass by identifying the most beneficial extraction solution and pH-conditions. A broader perspective was taken by Pechsiri et al. (2016), who looked at the economic performance and greenhouse gas emissions of the value chain from cultivation to biogas production. Their approach included taking the system perspective by including the whole value chain and thus, they evaluated the performance within the existing system. However, there is a lack of studies that attempts to look at how the system needs to change to support the development of a technology, which is the perspective this thesis aims at.

6

Technology overview

Macroalgae, commonly referred to as seaweed, are a species of macroscopic, multicellular, marine algae that are producing biomass from sunlight, carbon dioxide and the extraction of nutrients from the sea (Laurens, 2017). They have a great variation in length from a few centimeters to several meters with growth rates ranging from slow growth for perennial algae to rapid growth for other species. They can be classified as green, red and brown in accordance with the different pigments used for photosynthesis that relate to their color. Macroalgae are the primary producer in the marine food chain, providing food and shelter to other marine organisms like fish and invertebrates. They pose an attractive solution to locally combat eutrophication as they bind nutrients and carbohydrates and assist at providing oxygen to their environment (Schultz-Zehden and Matczak, 2012).

The tradition to utilize macroalgae has been longstanding for several purposes like food and feed, as well as fertilizer and has especially in Asian countries been dating back as far as the fourth century. The global production of macroalgae in 2014 added up to 27.3 million tons wet weight with 80-90% of the production carried out in China, with a variety of appliances (Laurens, 2017). The steps to cultivate, harvest and preserve are necessary operations to obtain the macroalgae and can be summarized as upstream operations. The downstream operations are various, because of the several applications of macroalgae. Both operations are explained in the following steps.

Upstream operations

The cultivation of macroalgae can be carried out either in systems that are open or half-open, which is done in open ponds or long-lines or in closed systems, so called photobioreactor systems (Sternberg et al., 2014). The long-line production is of interest for this thesis and starts with the collection of fertile specimens from previously cultivated algae in the wintertime. The seedlings are sown onto nylon strings and grown in hatcheries until they are a couple of millimeters in size. Subsequently, they are wound onto thicker ropes, so called long-lines in the kelp farm, which is situated in the sea (Schultz-Zehden and Matczak, 2012). In late summer, the algae can be harvested. The cultivation process is depicted in Figure A.1. After the algae is cultivated, it has to be taken out of the sea. The harvesting is currently carried out by hand from a fishing boat, but more advanced technologies are under development. The preservation is necessary, because algae break down quickly in the air and besides freezing and drying, less energy consuming procedures are developed, such as silage (Gröndahl, 2014).

Downstream operations

As Figure 6.1 shows, a variety of applications of macroalgae is possible, of which a few will be further explained in this section. Utilizing macroalgae as food has been a long tradition in Asia and the interest in Europe has been growing, because it is recognized as a healthy nutritional source that is low in calories and rich in vitamins and minerals. The high contents of minerals, trace elements and vitamins is why macroalgae are readily utilized as animal feed. Additionally, the extraction of high value compounds from macroalgae offers broad market opportunities, with the most common being the extraction of phycocolloids (algal colloids). These substances can be used to stabilize emulsions and dispersions and find their application in different industries, e.g. as dairy products, textiles, cosmetics and pharmaceuticals. The phycocolloid mainly extracted from brown macroalgae is alginate (Schultz-Zehden and Matczak, 2012).

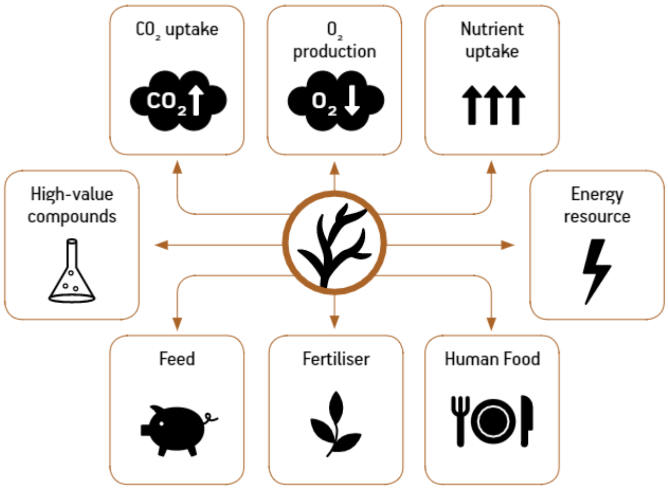

Figure 6.1: Possible applications of macroalgae harvesting and cultivation (Schultz-Zehden and Matczak, 2012)

7
Method

The starting point for the thesis was an interest by the West Swedish Chemical and Material Cluster to explore opportunities of marine and aquatic raw materials, which they carried out in a seminar in collaboration with the Marine Cluster and interested stakeholders. To prepare for the seminar, which was held seven weeks after the start of the thesis, data on TIS and macroalgae was gathered. The research project was then presented in the seminar, where contacts to relevant stakeholders were made that were subsequently interviewed. The collected data was then analyzed according to the TIS framework, resulting in the identification of barriers and drivers, as well as policy recommendations, as shown in Figure 7.1.

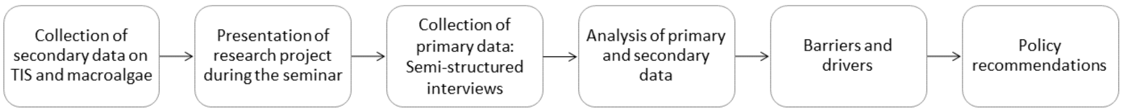

Figure 7.1: Research process

7.1 Study approach

Depending on the nature of a study, it can have a quantitative or qualitative approach. For a quantitative approach, meanings are derived from numbers and the analysis is conducted through the use of diagrams, as well as statistics. A qualitative approach is on the contrary characterized by meanings that are expressed through words and an analysis carried out through the use of conceptualization (Saunders et al., 2009). The main approach chosen for conducting the TIS analysis was qualitative data collected through interviews. To support the validity of the analysis, quantitative data was used when available to ensure a greater diversity.

7.2 Data collection

The approach for data collection included a combination of secondary and primary sources. Secondary data was used to get an overview of the TIS and of events that had occurred by an initial literature review. However, as there was a shortage in scientific articles concerning the system perspective of macroalgae in Sweden, the main source of secondary data came from reports from conferences and seminars, such as the Nordic Algae Network and different research networks, which are covered in Chapter 8.2. The information gathered from the attendance of the seminar on the opportunities of marine and aquatic raw materials could also be classified as secondary data, because we relied on receiving translated transcripts from a native Swedish speaker.

To gather primary data, interviews were chosen to collect the opinions and insights of different stakeholders. Therefore, a choice between the possible interview styles, namely unstructured, semi-structured or a structured had to be made. Whereas structured interviews aim at collecting quantifiable data and use questionnaires with predetermined questions, unstructured interviews aim at an in-depth understanding of a certain topic, which is done by letting the interviewee talk freely without posing a predetermined list of questions. In semi-structured interviews, a combined approach is taken by posing both structured questions, as well as giving the interviewee the opportunity to develop the conversation in a certain direction (Saunders et al., 2009). The opportunity that semi-structured interviews offered was chosen and an interview template with mainly open questions created to guide and document the conversations, which can be found in Material for conducting the TIS.

The interviews were generally conducted during a physical meeting, otherwise conducted through a video call and lasted approximately one hour. As the amount of directly involved stakeholders was rather small, most of the ones that agreed to a meeting came from a research background. To achieve a greater diversity, effort was put into conducting interviews with stakeholders from differing backgrounds. The respondents are listed in Table 7.1. Different tools were used to identify stakeholders, namely bibliometric analysis and "snowballing". To conduct the bibliometric analysis, SCOPUS was used to research publications and citations in published papers written on the topic of macroalgae in Sweden. This served as a first overview of the main contributors to the topic of macroalgae and gave a first historic background. To further identify relevant actors, respondents of interviews might point to other actors, a process that can be described as "snowballing". This process is then carried out until no further names are brought up, which is an indicator that all relevant actors are identified.

Table 7.1: Respondents with type and name of organization and their position

Organization	Name of organization	Position	Respondent
University	Chalmers	Researcher	A
University	Chalmers Industriteknik	Researcher	B
University	Gothenburg University	Researcher	C
University	KTH Royal Institute of Technology	PhD student	D
University	Gothenburg School of Business, Economics and Law	PhD student	E
Start-up	Swedish Algae Factory AB	CEO	F
		Chairman	G
Start-up	Marin Biogas AB	Manager	G
Small enterprise	Tångbrödsspecialisten Grebbestad Bageri AB	Boardmember	H
Emerging start-up	KosterAlg AB	Chairman of the board	I

8

Results

The completion of several interviews and attendance of the seminar on opportunities of marine and aquatic raw materials led to the results by first setting the scope of the focal TIS, continued by a structural analysis, which included mapping the structural components connected to the value chain of macroalgae in Western Sweden. A functional analysis followed with the aim to capture the dynamic aspects of the system, from which barriers and drivers were identified. Finally, policy recommendations were made to support the development to overcome the barriers.

8.1 The focal TIS

The scope of the TIS was previously defined in Chapter 1 by these three aspects: time-scale, geographical context and focus of attention. The time-scale for identifying the history of macroalgae was set to five years and the geographical scope selected for the TIS limited to the Western Swedish region. The focus of attention was limited to brown macroalgae and its technological use, excluding green and red species. Moreover, the socio-technical system in focus (see Chapter 5.1.1) was described by a value chain in accordance with the approach from Sanden and Hillman (2011). The elements of the value chain of macro algae that were analyzed in this study are shown and highlighted in Figure 8.1.

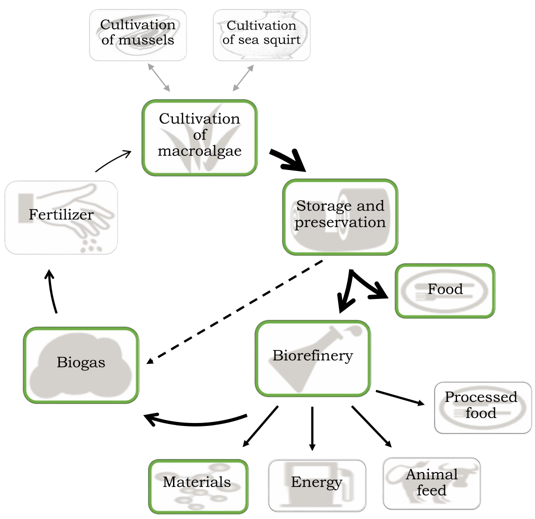

Figure 8.1: The value chain of macroalgae, from Gröndahl (2014)

The initial step of the value chain is the cultivation of macroalgae, followed by storing and preserving the algae, preventing the otherwise imminent decomposition. The algae can be directly used as food in its raw form or as an ingredient. For the technological application, two possible paths can be chosen. Although the simpler, traditional approach uses biomass provided by algae to produce biogas, it proved to be beneficial according to Gröndahl (2014) to add one step before the biogas production to process the biomass in a biorefinery to produce materials of higher value and to subsequently pass the residues on to the biogas production. Fertilizer is a residue from the biogas production and to close the loop into a circular system, its nutritious effect can be used to ensure a continuous algae production that does not deteriorate nature. In Figure 8.1, it is also shown that the value chain at the step of cultivating macroalgae interacts with cultivation of mussels and sea-squirt, because the infrastructure required for those processes is similar and interests to form common networks exist. Additionally, symbiotic effects occur when those species are co-cultivated together. Because of time being the limiting factor, it was decided to exclude the co-cultivation with other raw aquatic materials from the TIS in focus and to concentrate on the highlighted value chain, but to include references when it proved to be valuable.

8.2 Structural analysis

The seminar on the opportunities for the technological use of marine and aquatic raw materials was the starting point for the analysis of the structural components, where directly involved actors and representatives from other components met. This setting allowed to get an insight on the interaction between them and into the most pressing issues, as well as the setup of first contacts to interview. The process of mapping the different components according to their position in the value chain resulted in the following Figure 8.2, which is followed by a more detailed discussion in the subsequent paragraphs. It is distinctive for this system that the majority of greatly diverse structural components were found in the first step of the value chain, the cultivation. In the following steps, the amount of components and their diversity decreased.

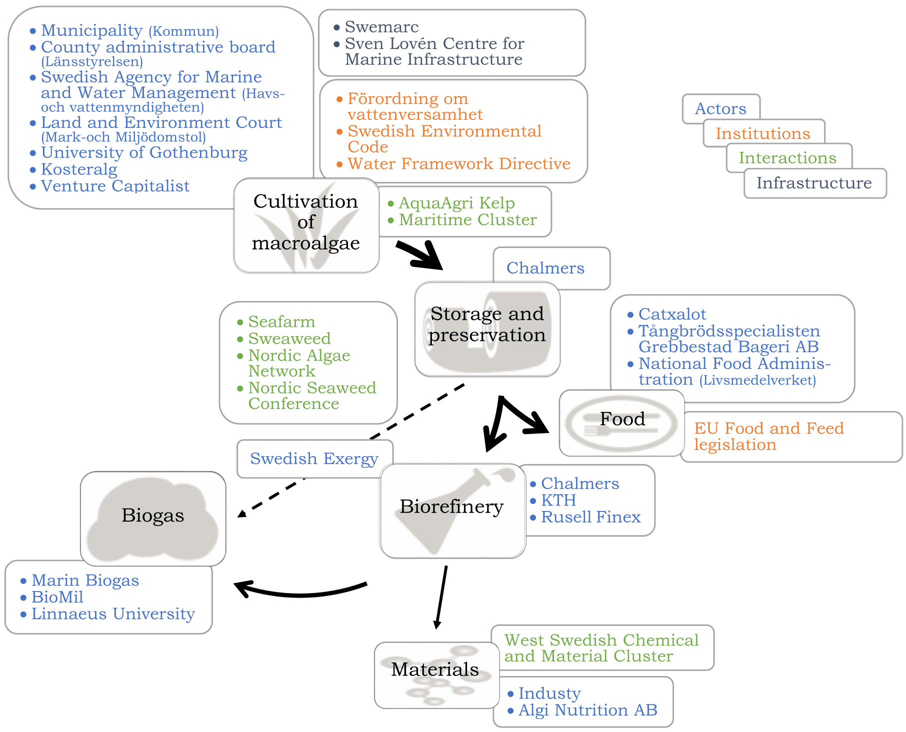

Figure 8.2: The value chain of macroalgae with the structural components

Actors

Actors constitute the majority of structural components and were present in every step of the value chain with most of them connected to the cultivation of macroalgae. For the step of cultivation, the actors came mainly from the government (municipality, county administrative board, Swedish Agency for Marine and Water Management, Land and Environment Court), as well as the University of Gothenburg as the main knowledge institute. Further stakeholders were a start-up company planning for large scale cultivation of macroalgae (Kosteralg) in collaboration with a local food producer (Tångbrödsspecialisten Grebbestad Bageri) and a venture capitalist, who has been investing into business opportunities in aquatic raw materials.

The actors found in the following stages were mainly universities carrying out fundamental research and companies that transferred the knowledge gained from their primary operations to support the development of technologies suited for macroalgae (Swedish Exergy, Rusell Finex, Marin Biogas, BioMil). Additionally, enterprises that found a niche to operate within (Catxalot and Tångbrödsspecialisten) were identified, as well as industrial enterprises as a group that had a large interest in materials produced from the biorefinery. Finally, the National Food Administration acted as the supervisory authority for matters relating to food.

Institutions

The institutions shown in Figure 8.2 are regulations and thus hard institutions. When the Swedish Environmental Code was adopted 18 years ago, macroalgae, in contrast to fish, mussels or crustaceans, was not included in the regulations concerning cultivation of marine and aquatic raw materials within Chapter 9 (Environmentally hazardous activities and health protection), simply because it was not in practice at that time. Therefore, only Chapter 11 (Water operations) applies, which states that setting up any water operative requires permission from the county administrative board. The ordinance on water-related work (Förordning om vattenverksamhet) then specifies that a case only has to be tried by court if the requested area is bigger than 3000 sqm, otherwise an application is to be handed in to the municipality, which is granted if the municipality does not object within six weeks. Furthermore, the European Union's Water Framework directive (WFD) applies for coastal areas within one nautical mile and aims at protecting all waters (surface and groundwater) to achieve a "good status" for all waters.

Concerning the soft institutions, a dichotomy between different expectations concerning the future of macroalgae in West Sweden was observed during the seminar. The enthusiasm came mainly from actors that were not directly involved in developing the value chain, but came from organizations that had an interest in the results of an operational scale-up. Actors that were directly involved in the application process for cultivation (of mussel) voiced that their optimism was dampened due to regulatory obstacles that did not favor industrial growth. However, the strong financial support that macroalgae research is currently experiencing, shows the strong belief in its growth potential to become a technology that will be able to perform independently.

Interactions

Interactions exist in the form of research networks, either for algae and specifically macroalgae, or as part of a greater organization. To strengthen the communication between algae researchers of different fields throughout the Scandinavian countries, multinational networks (Nordic Algae Network, Nordic Seaweed Conference) were created. Other networks exist on a national level, where either a general approach towards the whole value chain is taken or they are specifically aiming at carrying out one step of the value chain. For the first category, Seafarm is an example for taken a holistic approach by connecting the different steps with each other, as well as introducing enterprises to test the industrial application. Sweaweed on the other hand is solely research based and aims at identifying an algae production system with high-quality applications. AgraAgri Kelp falls in the latter category, because it is only focused at cultivation. One additional interaction that does not fall in the previous categories is the collaboration between Tångbrödsspecialisten Grebbestad Bageri and Kosteralg in which the former holds a permit for cultivation and provided this area to the latter, which utilized it to do a cultivation test run. Finally, the cultivated algae was then purchased from the former.

In order to develop cross-boundary collaborations, the region of West Sweden introduced five clusters (Kullendorff, 2012), of which the Maritime Cluster with its aim to increase innovation and business development offers a support network for macroalgae cultivation and the Chemicals & Materials Cluster with its goal of promoting sustainable chemistry has an interest in the products from the biorefinery.

Infrastructure

Structural components that were not expressed in the previous three categories are summarized under physical, knowledge and financial infrastructure, of which only the former is depicted in the Figure 8.2. Physical infrastructure is provided by the possibility of sharing logistical elements, such as boats, harvesting machines and warehouses. These opportunities are a result of the close connection between the mussel farming industry and research as well the macroalgae research. This caused an interdisciplinary knowledge infrastructure to form, which is characterized by research projects that focus on the development of sustainable marine aquaculture (Swemarc) and two research stations on the Swedish West Coast that conduct extensive experimental work on marine sciences (Sven Lovén Centre for Marine Infrastructure). As most of the structural components are research based, they are heavily relying on financial support, which is provided from different research foundations and institutes (The Swedish Foundation For Strategic Environmental Research (Mistra), The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas), Lantmännen Research Foundation, Swedish Foundation for Strategic Research (SSF), Local water conservation projects (Lova)). Moreover,funding is also supplied from the regions, municipalities and some companies, as well as support in the form of know-how for starting and developing a business (Business Region Gothenburg, Chalmers Ventures e.g.).

8.3 Functional analysis

Entrepreneurial Activities

Entrepreneurial activities have occurred in two parts of the value chain in the form of rather established activities on a small scale connected to food and as an emerging enterprise for cultivation. When Respondent H talked about his involvement with algae, it dated back to the 1980s where he experimented on implementing hand harvested algae into bread together. In 2011, trials to cultivate different kinds of algae were carried out in collaboration with a Danish company, but lacking availability of knowledge on the cultivation the caused the trials to be unsuccessful. The required permits for the cultivation on two sites adding up to 6000 sqm were issued after going through the difficult legal process explained in the section Institutions. In 2016, Respondent C, who researches cultivation, co-founded KosterAlg after making an agreement with Gothenburg University to utilize the surplus of algae cultivated for research purposes commercially that would need to be disposed otherwise. As he had the know-how and Respondent H had the permit for areas to cultivate algae, they collaborated to be able to carry out the cultivation. Some of the algae has already been harvested and purchased by Respondent H from Respondent C. The current capacity to be sold was estimated to 10-12 tons (wet weight) by Respondent I. In addition, the company Catxalot found a market niche to offer tours to harvest wild seaweed, as well as workshops and lectures about seaweed. In addition, they sell seaweed in a raw or processed form as "artisan and maritime food". As the wild harvesting falls under the ‘right to roam’ (allemansrätt), they do not have the legislative struggles connected to the cultivation, according to Respondent H.

Knowledge Development

Europe is currently the region with the largest involvement concerning the development of the global knowledge base on macroalgae cultivation and conversion (in terms of published literature, studies and projects). The majority of activities are aiming at lowering the cost and improving the efficiency of cultivation, as well as increasing rate, yield and biomass quality. In Asia on the other hand, large scale operations have already been built up because of available knowledge, resulting in a lower need for development (Laurens, 2017).

In Sweden, the development in knowledge has been a growing process from 1980 to 2003 until it reached a rather steady state during the time period from 2004 to 2016. This was implied by a bibliometric analysis that was done on publications about macroalgae in Sweden, which is shown in Figure A.2. Moreover A.3 shows that the majority of publications came from the University of Stockholm and University of Gothenburg, which concentrate on marine biology, thus the first step of the value chain. The low research activities from the technical universities imply that only small efforts were made towards biotechnological aspects, which relate to later parts of the value chain. Albers (2013) agrees that marine biology has rather strong research activities, wheres algal biotechnology is carried out in small and distributed research groups. The bibliometric analysis for recent years showed that the involvement of technical universities in macroalgae research had only emerged, which is why the development of the steps that follow the cultivation is less developed.

In the focus area of Western Sweden, Gothenburg University researches on cultivation and Chalmers on biotechnological aspects like storage, preservation and the production of chemicals and materials (biorefinery), thus covering different research aspects. Additionally to the research development through research, entrepreneurial knowledge in terms of applied expertise has also been developed by small business initiatives, which was further explained in the function Entrepreneurial Activities. This development of the past years was made possible because of the funding supplied from different sides. It provided the opportunity to complement the research on cultivation with research on ways to process the algae into different products. From the conducted interviews, the impression was created that in order to make the value chain feasible, the execution of each step has to be further developed for the system to function. This requires a diverse set of researchers that have to investigate the details of each step, while communicating what they are working with to previous and subsequent steps.

Knowledge Diffusion

The creation of the Nordic Algae Network put efforts into increasing collaboration of researchers within Scandinavia and to advance their position in the field of algae (Nikolajsen and Bech, 2014). Additionally, the implementation of the research project seafarm established a network between researchers themselves and small business owners with an involvement in algae in Sweden. This was possible because of the limited number of actors involved and caused a small community to emerge that in the case of the Nordic Algae Network persisted even after the project was over, according to Respondent A. Furthermore, the annual recurring event of the Nordic Seaweed Conference provides the opportunity to continuously exchange knowledge and know-how.

The marine sector has been characterized by a strong connection between different fields (e.g. fishing and mussel farming) due to shared infrastructure. Additionally, collaborative research is carried out in marine sciences, e.g. in the Sven Lovén Centre for Marine Infrastructure, which caused a network to grow between the value chains involved in cultivating material in the sea. Especially because co-cultivation of species is an option, as mentioned by Respondent C, this existing network could be of value when the technology becomes more developed.

The main efforts for the development and diffusion of knowledge come from research and the small businesses, which indicates that the process of knowledge development is currently not demand driven. The government with their incentive to become fossil-independent offers research grants and has recognized the legislative issue, but has not been able to ease the process of getting a permission to grow algae as their focus for marine resources lies rather on fish or other marine fauna (Schultz-Zehden and Matczak, 2012). The interested industry plays a rather passive role with a general interest in business opportunities, but without the ambition to pay 'premium prices' for the ecosystem services provided by sustainably produced products, such as algae. In addition, it was also noted by Respondent B that there is a lack of obvious industry to turn to, due to the variety in possible products.

Guidance of the Search

During the seminar, one conclusion was that there is a great interest from different sides in developing products from marine resources, especially because many saw Western Sweden as a "sustainable region". Ideas on how to achieve this vision were however quite diverse, depending on the intensity of direct involvement and can be summarized in three different views.

The establishment of seafarm brought researchers from different disciplines together to work on developing a value chain for macroalgae. They took inspiration from initiatives launched in other countries that were further advanced and showed that what they set out to do was possible, according to Respondent A, which gave them a common vision on what kind of system to create. In the conducted interviews, they explained that under the current legislation, the technology needs to be further developed to be able to compete with existing solutions. For the case of biogas production from macroalgae, the technology exists, but Pechsiri et al. (2016) concluded that commercial viability could not be reached, even in an upscaled calculation for a basic commercial scale, though this case performed better. Therefore, these actors are aiming at achieving a viable value chain within the existing system conditions without counting for system changes.

Actors involved in the cultivation of (mainly other) marine material however demanded a regulatory change, stating that "sea-farmers need agricultural conditions" during the seminar. This issue was also taken up by Respondent G, who mentioned that in order to compete with established products, systems need to generate revenue from putting value into society. Therefore, it is necessary to transform the ecological benefit into an economical benefit and he continued that subsidies would be one powerful tool to achieve this transformation.

As described as part of the section Institutions, actors that were not directly involved in the value, but had an interest in a successful realization of the value chain, were optimistic about future performance. However, it was pointed out by directly involved actors that decision-making is a slow process in Sweden, caused by a fear of making mistakes (Nikolajsen and Bech, 2014).

Everyone agreed in the seminar that there is a need for networks and common project to “bridge the gap between innovation and the market”. Even though there is no unified vision between all stakeholders, the strong vision to evaluate the opportunities that macroalgae poses motivated a strong actor group to gather funding for the seafarm project. Therefore, guidance of search can be identified as one of the motors for the development of an innovation system based on macroalgae.

Market Formation

The efforts put into research to achieve feasibility and ways to implement the value chain have not translated in the formation of a market yet. The current market for macroalgae is related to food, where wild harvested algae is sold in its raw form or used as a food ingredient. However, Respondent D mentioned that this market only has a limited capacity, which is why it is necessary to develop further applications for macroalgae.

The market opportunities for macroalgae were identified as promising by Nikolajsen and Bech (2014), because of the strong Scandinavian brand on the international market, the solid technical sector that exists in Sweden and the pronounced environmental thinking of Swedes. Moreover, macroalgae is considered a particularly promising alternative feedstock for the production of commodities, such as food, feed, chemicals and biofuels with the additional benefit of providing ecosystem services. Resulting from the seminar and interviews, three potential market opportunities were identified. The first one is to produce existing products, such as platform chemicals. Even though a large market for these products exists, it is characterized by competitive prices and large volumes. It was concluded in the seminar that in order to reach such a level, extensive basic research as well as on up-scaling the operation is required. Secondly, the industry for blue biotechnology (which is the application of biotechnology on marine resources) is emerging at the time and most of the activities are focused on research and development (Schultz-Zehden and Matczak, 2012). This offers the possibility of finding market niches for new products to be developed from macroalgae. Finally, the ability to mitigate eutrophication and to lower green house gases in the atmosphere poses an opportunity that has yet to find a market niche to operate within.

The development of the Swedish Algae Factory is an example how to form a market niche for an emerging technology. Respondent F explained the process the business underwent from the initial plan to only remove nutrients from waste streams over trying to compete with existing products (biofuels), it resulted in an economically feasible business when a technological niche was found by producing a high-value low-volume compound. Even though this business is based on microalgae, it showed that it is possible to enter a non-existing market with continuous entrepreneurial experimentation, which could be seen as a benchmarking case for macroalgae. The struggles of not having a clear market to turn to and the nondemand driven development proved to be possible to overcome.

Resource Mobilization

The existence of the different research projects shows that there is an interest to finance research aimed at evaluating and developing circular products and services. In the region of Western Sweden, several financing possibilities, as well as other support exist (see 8.2). During the seminar, many stakeholders voiced the need for a pilot plant to evaluate upscaling of the process whereas Respondent B described a different approach, which includes connecting the entrepreneurs in a network to form a common value chain. It was said that both of the ideas would hit a barrier when it comes to funding when trying to industrialize the process, because it was likelier to get funding for novel ideas than for the final upscaling of a process. To conclude, the question if there are sufficient financial resources can not be clearly answered, especially concerning the development to mature the industry.

Human resources are available in the form of highly specialized researchers, as well as know-how from companies that can be transferred to a certain step of the value chain, but in both of the categories, only a small number of actors exist. So far, only a reluctant number of actors with interdisciplinary knowledge are available. In the case of Swedish Algae Factory, the diversified education of Respondent F in biotechnical engineering combined entrepreneurship was the largest enabler for the development of the start-up. Thus, the human resources require some diversification as well as expansion.

As mentioned in the section Infrastructure, physical resources can be used from other value chains. In the case of cultivation, machines from mussel farming can be transferred and for the processing of the biomass, equipment and knowledge used for other types of biomass can be utilized. However, the need for development of equipment for the specific application on macroalgae is existing.

Creation of Legitimacy

The creation of legitimacy requires both social acceptance, as well as recognition from relevant institutions, such as the legislation and investors. An issue related to social acceptance was mentioned by Respondent G. Even though there is a general interest for sustainable solutions in the general population, societal problems might arise when the technology becomes mature and a larger amount of cultivation area is required. As the view over the water is something many residents appreciate, they could prevent the issuing of permits in order to keep the view from being altered by a cultivation site.

Moreover, no clear statement can be made concerning the question if an investment in macroalgae can be seen as a legitimate decision, as the technology is only in the process of being developed and entrepreneurial activities are low. The current funding situation implies that it is, but there are many obstacles that need to be overcome in order to build up a business. Even though there is no resistance against the development of the TIS, the legislation, as explained in Institutions is not in favor of macroalgae cultivation and the ecosystem services that the cultivation of marine resources offer are not subsidized. In order to change the latter, Respondent G is lobbying to receive subsidies for providing these ecosystem services. However, the lobbying power is rather small and has only impacted in a way that awareness has been raised. This low creation of legitimacy can be related to the weak mobilization of human resources.

9

Discussion

Following the definition of the focal TIS, the structural and functional analysis, this section includes the interpretation of the results by first identifying the phase of the development and subsequently pointing out the drivers and barriers with their influence on the different functions.

9.1 Phase of development

The functional analysis showed that besides knowledge development as a considerably strong function, supported by knowledge diffusion and guidance of the search, as well as entrepreneurial activities, the other four functions were rather insignificantly contributing to the development of the TIS. When comparing this analysis with the phases of development described by Hekkert et al. (2011) in Chapter 5.1.4, the conclusion is that this TIS is in the pre-development stage. Similar conclusions have been found by Andersson et al. (2017), who studied the immature technology of marine energy in Sweden. However, it appeared that the focal TIS of macroalgae is characterized by a much stronger and unified vision of the research community.

9.2 Barriers and Drivers

The identified drivers and barriers can be found in Figure 9.1 with the influence they have on the different system functions. Driving the development are the cooperation within the focal TIS, the *entrepreneurial spirit* [1], funding for the development of fossil-independent resources and the shared infrastructure and interaction with other marine sectors.

The cooperation between researchers and entrepreneurs was seen as a strong driver for the development of knowledge, for example in the case of the cultivation of macroalgae as part of the seafarm project, which could be realized because one enterprise was holding the cultivation permit. The enterprise then benefited in terms of gained knowledge and cultivated macroalgae. In order to obtain funding for this research project, different researchers created a common vision of developing a value chain for macroalgae, resulting in a strong direction of the search. This project then increased the strength of their network, because it connected their individual

[1] We decided to name the entrepreneurial initiatives that emerged in niches without existing knowledge to rely on *entrepreneurial spirit*

research into a bigger initiative and resulted in diffusion of knowledge within the research community.

It appears that the second driver, *entrepreneurial spirit*, is an exceptional attribute of the focal TIS. Over the last ten years, enterprises working with macroalgae as a source a food successfully emerged in market niches by developing expertise through learning by doing to gain underlying knowledge. Those niches were originally related to marketing algae as food, but they eventually contributed to developing businesses in new niches focusing on the cultivation of macroalgae.

The current favorable funding opportunities for novel technologies that contribute to the production fossil-independent resource is what enabled the resource mobilization of researchers to facilitate knowledge development on a research level. Such opportunities for financial support are known to the research community and influence the guidance of search. It seems that researchers align their research proposition to what is supported by the funding organizations.

Finally, shared infrastructure and networks with other marine sectors is enabling the development of the focal TIS. Research is carried out in a collaborative manner and especially because co-cultivation of species is an option, knowledge on macroalgae can be developed by benefiting from the diffusion of knowledge developed on other marine species. Shared physical resources between interacting value chains, e.g. machines for mussel farming and equipment for processing of different types of biomass, are facilitating the development of the value chain of macroalgae.

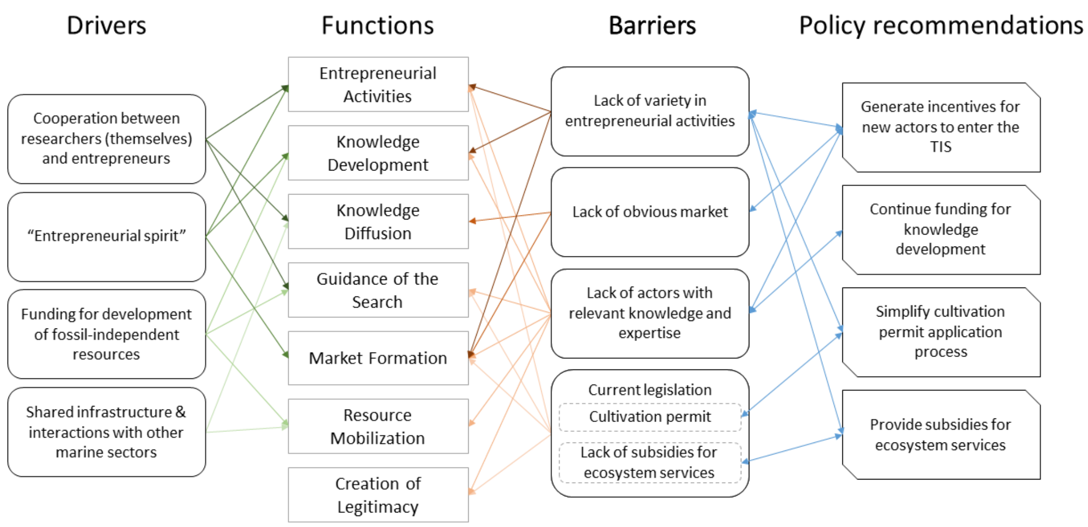

Figure 9.1: Identified drivers and barriers as well as policy recommendations (covered in Chapter 10)

The main barriers are the lack of variety in entrepreneurial activities, obvious market, components with relevant knowledge and expertise as well as the current legislation.

It appears that the only noteworthy entrepreneurial activities are carried out in the market niche of marketing algae as food. This market has however a limited capacity, so there is a need to diversify the product range.

Another barrier that this development encounters is that there are no Swedish actors on the market for cultivated macroalgae and that there is no obvious market to turn to for enterprises wanting to enter the market. This results from the variety of applications that was described in the section 8.3. The industry plays are passive role in the focal TIS, which is why the knowledge diffusion is not demand driven, but rather originates from efforts made the research community.

Because the focal TIS is only in the phase of pre-development, lack of components with relevant knowledge is the barrier that is affecting the development of most of the functions. It originates from guidance of search, because the technology requires further development to be able to compete with existing solutions. Thus, knowledge development is necessary to increase the economic feasibility as well as human resources with relevant knowledge and expertise. Because the components with relevant knowledge are limited, this TIS has only experienced small lobbying efforts

According to actors involved in marine activities, the current legislation is standing in the way of the development of the TIS. Legislative issues, explained in the section 8.2 are making it difficult for actors to obtain permits for cultivation, which is hindering entrepreneurial activities and obstructing market formation for actors aiming to cultivate macroalgae. The actors are therefore lobbying to simplify the process to obtain a cultivation permit as well as to receive subsidies for the ecosystem services that the cultivation of marine resources offer, which exist for conventional agriculture. The absence of these subsidies makes macroalgae cultivation less feasible. This was also the major barrier that Haase et al. (2013) identified for the TIS of algal biofuels in the USA.

9.3 Validity, reliability and generalizability

It is important in qualitative research to reflect on the three aspects of validity, reliability and generalizability. Whereas validity describes how appropriate the tools, processes, and data used to obtain the results were, reliability questions the consistency of the different sources and how well the findings can be reproduced. Finally, generalizability expresses whether the findings are applicable to other research settings (Leung, 2015).

For this research setting, it was necessary to gather primary data from involved stakeholders, because of the lack of relevant secondary data, especially on the geographical scope of Western Sweden. Therefore, the seminar gave a good overall impression of the situation and stakeholders from various backgrounds were contacted to conduct more in-depth interviews with. However, many of them were not interested for reasons unknown, so that most of the interviews were conducted with respondents from similar backgrounds, as they were either algae researchers or entrepreneurs. Choosing semi-structured interviews proved valuable, because the respondents had the opportunity to direct the conversation topic they perceived as important. Additionally, further respondents were identified after the first interviews by the "snowballing" method, which possibly hindered to development of a more diverse respondent base. Because the respondents had similar interests and ideas how the system should develop, we faced difficulties to acquire results that were taking into account all the different opinions. Therefore, this study might rather express the opinions of stakeholders that felt most passionately about the TIS while neglecting others not as involved.

To ensure reliability, different sources of data were utilized to ensure that the findings were not relying on the statement of a single source, but were supported from different sides, such as the interviews, published articles or reports. Unfortunately, the lack of secondary data, especially on the regional scope, caused this study to be heavily relying on primary data. In order to achieve reliability, statements made by one respondent were brought up in subsequent interviews to evaluate whether they supported them or had opposing opinions. By not anonymizing the respondents, the aim was to increase the transparency to be able to reproduce the collection of primary data.

The findings seem to be quite specific to the chosen geographical scope, especially because the interaction with other value chains was relevant and the physical infrastructure supported the development. Because this might not be the case in other regions, these results can hardly be transferred to other Swedish regions. Moreover, the difficult legislation was a major barrier in the focal TIS, but might not be relevant in other countries.

10

Conclusion

Guided by the climate goal that the region of Västra Götaland set with a focus on the development of renewable and resource-efficient products and services, this thesis explored the current and prospective contribution of brown macroalgae to the transition towards a sustainable future in Western Sweden. To answer the overarching research question, it seemed necessary to map the network of components involved in macroalgae to be able to understand the mechanisms that influenced previous and future development. For this approach, the chosen Technological Innovation System (TIS) framework proved to be suitable. The TIS in focus was expressed by a value chain including the steps from the production of macroalgae to its application as food and high value compounds with residual biogas production.

The identification of the structure of the value chain of macroalgae suggested that the highest diversity of actors was found connected the cultivation with a decreasing number of components further down the value chain. Several interactions within the TIS and with connected value chains were found, mainly originating from shared infrastructure. Moreover, the hard and soft institutions revealed difficulties in the cultivation permit application process and revealed strongly differing expectations concerning the future of the focal TIS.

Through our analysis of the dynamic processes that occur in the focal TIS, we were able to identify the most significant drivers that were cooperation between researchers (themselves) and entrepreneurs, *entrepreneurial spirit*, funding for development of fossil-independent resources and shared infrastructure & interactions with other marine sectors. The factors standing in the way of the development were identified as lack of variety in entrepreneurial activities, obvious market and thirdly actors with relevant knowledge and expertise, as well as legislative issues (cultivation permit and lack of subsidies for ecosystem services)

These results suggested that the current contribution of macroalgae to the sustainability transition is negligible in terms of quantifiably contributing to the market for bio-based products, because required knowledge is only being developed for all steps of the value chain. The small established enterprises however play a role in raising awareness for locally produced, bio-based food and the emerging enterprises that aim to industrially cultivate macroalgae give rise to a positive outlook on the future contribution.

The prospective role that macroalgae could play in Western Sweden depends on how the policy issues shown in Figure 9.1 will be taken care of, especially concerning the strong demand for legislative changes. One of the key policy recommendation we suggest would be to simplify the cultivation permit application process, e.g. by including macroalgae in the 9th Chapter of the Swedish Environmental Code. This barrier in the current legislative framework does not only stand in the way of developing the first step of the value chain, but also impairs the progress of the development of downstream technologies. The lack of subsidies for ecosystem services is not only affecting cultivators of algae but also other marine species. Their statement "sea-farmers need agricultural conditions" highlights the legal disadvantage they face, which unites them in lobbying for legislative changes. These legislative changes would encourage entrepreneurial activities and could therefore remove the barrier of lacking variety in entrepreneurial activities. Besides the legislative changes, two other policy recommendations aim at supporting the development of the TIS. Generating incentives for new actors to enter the TIS would have a positive impact on the first three barriers in Figure 9.1 by inducing a larger variety of entrepreneurs and incentivize growth of relevant knowledge and expertise, as well as fostering the development of a market, possibly by directly aiming incentives at certain industries. The continuation of funding appears to be necessary to increase the number of actors that have relevant knowledge.

The TIS in focus of this study would benefit if the governmental awareness was coupled with the implementation of the above described policy recommendations and continuous support. Addressing the blocking mechanisms and inducing the existing drivers is crucial for the future success of macroalgae as a renewable resource.

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A

Material for conducting the TIS

A.1 Interviews

A.1.1 Questionnaire template

Ask about time frame & recording
Tell him/her what we are doing in the C-Lab
Focus on West Sweden, maybe benchmarking from outside but not all Nordic overview.

Questions about specific project
How did the idea for ... arise?
What is the state of the project?
What struggles have you been facing?
Is there anything hindering your development?
How well did the financing work?
Was there existing research to rely on?

Questions regarding the Technical Innovation System
Explain our perspective from TISA

Are you connected to other actors, institutions,... in the algae field?
Is there anyone we should connect with?
What does the market look like? (Is this technology easily to implement?)
Are there any supporting or restraining policies?
Is there any other momentum besides Swedish Algae Factory, and/or Marine BioGas, or in other places like Nordic countries?
What opportunities do you see for the Western Swedish region to develop more in the technological field of algae?
Is there a vision on how the industry should develop?

A.1.2 List of interviewed stakeholders

Table A.1: Respondents with type and name of organization, their position and name

Organization	Name of organization	Position	Respondent
University	Chalmers	Researcher	Eva Albers
University	Chalmers Industriteknik	Researcher	Jenny Veide Vilg
University	Gothenburg University	Researcher	Göran Nylund
University	KTH Royal Institute of Technology	PhD student	Martin Sterner
University	Gothenburg School of Business, Economics and Law	PhD student	Jonas Nilsson
Start-up	Swedish Algae Factory	CEO	Sofie Allert
		Chairman	Olle Stenberg
Start-up	Marin Biogas AB	Manager	Olle Stenberg
Small enterprise	Tångbrödsspecialisten Grebbestad Bageri AB	Boardmember	Ola Dahlman

A.2 Cultivation process

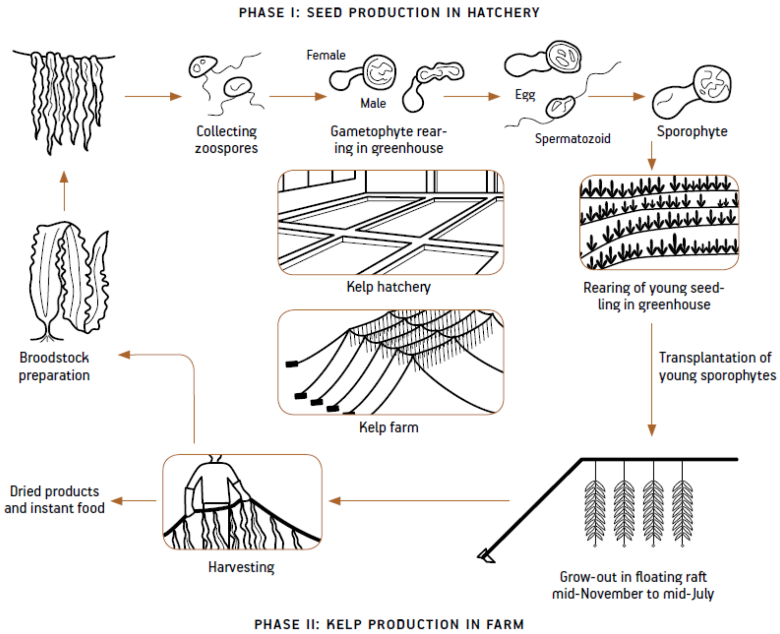

Figure A.1: Cultivation process via macroalgae hatchery and farm (Schultz-Zehden and Matczak, 2012)

A.3 Bibliometric analysis

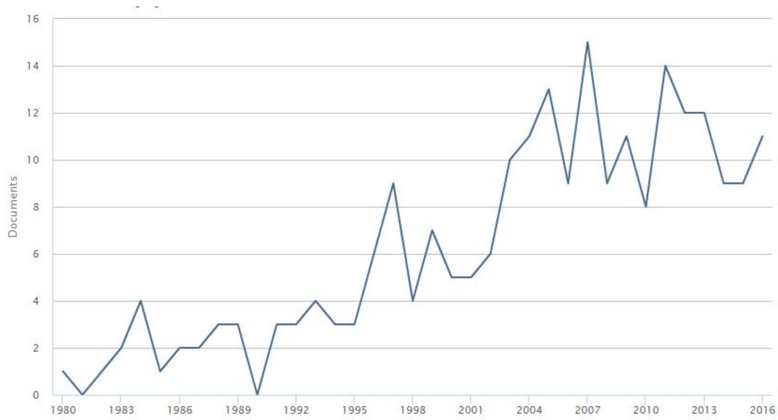

Figure A.2: Number of publications with the keywords macroalgae, macro algae, seaweed or kelp over the years 1980-2016 in Sweden

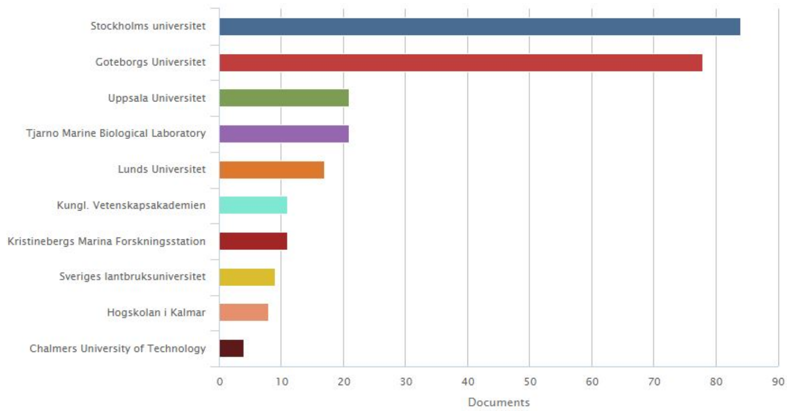

Figure A.3: Number of publications with the keywords macroalgae, macro algae, seaweed or kelp in Sweden over the years 1980-2016 in Sweden, categorized by affiliation

B

Contribution report

Responsibilities

The responsibilities were mainly shared. Anali's experience in planning proved valuable when conducting the first long term plan for the thesis process, whereas the weekly planning was a collaborative process. The information collection, selection of methods and implementation of interviews was also a collaborative process. Communication was loosely separated in written communication carried out by me and phone calls carried out by Anali. However, as the written communication proved to have a greater extent, this was also partly covered by Anali. Interviews were carried out together, except for two interviews that were carried out one by me and one by Anali.

Lead authors

It was decided that sections written by only one author was only to be used by her and thus solely collaboratively written sections to be used in the thesis. These included:

Phase I

Abstract

Results: Step 2

Phase II

Analytical framework: Functions of innovation systems (Introduction and the first two functions)

Results: Identifying the TIS in focus