Navigating the Seaweed Biorefinery Value Chain

Implications for a Seaweed Farmer

Master's thesis in Management and Economics of Innovation & Quality and Operations Management

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Cover:
Seaweed harvesting from cultivation of brown macroalgae on the Swedish west coast used with permission from Nordic SeaFarm.

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SUMMARY

The food industry faces several issues as the demand increases with population growth, and current production is not sufficient to cover global nutrition needs. Blue foods could reduce the overall environmental pressure from food production since it requires significantly less fresh water and land use than terrestrial crops. Currently, oceans provide only 2% of global food production, highlighting the untapped potential of blue foods, including seaweed. To increase the use of seaweed in both food and non-food applications, it could be processed in biorefineries to produce a wide range of products. Nordic SeaFarm, a Swedish seaweed farmer, wishes to explore these possibilities. This thesis aims to investigate where, and how, Nordic SeaFarm could position itself in the emerging value chain of products from seaweed biorefineries. This will be accomplished through an exploration of the technical and organisational resources within the resource network, including an analysis of the necessary collaborations, and an examination of the current situation.

An abductive approach was taken for this qualitative study, where seven interviews with European biorefineries were conducted. Furthermore, two interviews with food product developers were held as they are the next key actors in the food value chain. The study shows that the European seaweed industry faces several challenges that Nordic SeaFarm has to consider. These challenges include the scarcity of biomass, the premium price of European biomass, the ambiguity of the concept of sustainability, and the vast investments and costs associated with the development and operation of a biorefinery. While some believe that European seaweed cultivation will scale up as demand increases, the course of action for European biorefineries working with cultivated seaweed remains uncertain if it does not scale sufficiently or if large-scale offshore cultivation proves to be complicated.

Findings from the interviews show that most biorefineries primarily focus on high-value compounds for the pharmaceutical and cosmetics industries, to ensure viable business cases. However, the interviews indicate that there might be untapped potential in the side streams, which could possibly be further developed into food products. Based on the findings from the interviews three potential roles a seaweed farmer can undertake in the upstream value chain were explored. These roles are as a contractor-based supplier of seaweed, a consolidator of seaweed, or as a member of a seaweed cooperative. In addition, the possibility of undertaking a downstream role as a coordinator of the valorisation of side stream for food production is also analysed. These were later problematised in terms of feasibility and chronology, leading up to the recommendation of a combination of contractor-based collaboration with biorefineries and research partnerships to secure potential customers and the company's position in the value chain. The recommendation further includes testing and developing food products from the biorefinery side streams.

Keywords: Seaweed, biorefinery, resource network, network collaborations, value chain, business relationships, emerging industry

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Alva Leufstedt & Tilda Wenäll
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Definition of Terminology

Biorefinery: A range of new processes, technologies, and solutions that, together, create new conditions for valorising biomass to new green and climate-friendly products.

Cascading biorefinery: A processing facility that integrates multiple biomass valorisation pathways to produce value-added products, by letting biomass cascade through different extraction steps. The extraction steps can alter the biochemical composition, meaning that optimisation of extraction steps is needed. Mild processing preserves the biochemical composition of the side streams which is beneficial for subsequent extraction steps.

Fucoidan: Polysaccharide found in brown macroalgae. Antioxidant with anti-inflammatory properties. High-value compound.

Alginate: Polysaccharide found in brown macroalgae. Is commonly used in food and pharmaceuticals due to its gelling properties.

Protein isolate: In various concentrations, could be used in food or feed.

Fucoxanthin: Pigment in brown macroalgae with numerous health benefits.

Mycosporin: Amino acid with an UV absorbing compound, for use in cosmetics and nutraceuticals.

Beta-Glucan: A soluble fibre with health benefits, can be used in nutritional and cosmeceutical applications.

Kelp: A type of brown macroalgae, including the brown species Saccharina latissima (Sugar kelp), Laminaria hyperborea (Tangle) and Fucus vesiculosus (Bladderwrack).

Sargassum: A genus of brown macroalgae, creating floating islands in the Sargasso Sea which creates problems for habitants especially in the Caribbean when floating to shore.

Ulva fenestrata: A species of green macroalgae. Also called Sea lettuce.

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1 Introduction

The food industry is a large driver of environmental change, and more than a quarter of the global greenhouse gas emissions come from the production of food (Ritchie & Roser, 2022). Conventional food production requires fresh water, nutritious soil and energy and it experiences a significant increase in demand due to a growing population. Even though agriculture is taking up half of the world's habitual land and 70% of the world's freshwater withdrawals it is not sufficient to cover the global nutrition need, and 820 million people are suffering from a lack of nutrition (Gephart et al., 2021). The Swedish Government stresses the importance of sustainable food production in the National Food Strategy for Sweden (Ministry of Enterprise and Innovation, 2017) and in addition the need for viable domestic food production for national security.

Blue foods, foods from the oceans, have a large potential to reduce the overall environmental pressure from food production since it requires significantly less fresh water and land use. It is recognised as a crucial component of sustainable development and is a central element of the European Union's Green Deal initiative (Nilsson et al., 2022). Approximately only 2% of the food produced today comes from the oceans, drawing attention to blue foods, including seaweed, as one of the biggest untapped sources for food production to meet growing demands (Halfdanarson et al., 2019). Seaweed has the potential to be used in biorefineries to manufacture a diverse range of products, both for food and non-food applications (Nilsson et al., 2022). In addition, seaweeds have been demonstrated to possess high biomass productivity compared to many terrestrial crops, such as wheat, seeds, and soybeans (Stedt et al., 2022).

1.1 Case Company - Nordic SeaFarm

Nordic SeaFarm is a company based on the Swedish west coast working with the development of plant-based nutrition from the sea (Nordic SeaFarm, 2023). The business was founded in 2016 by two leading scientists with knowledge of seaweed and was commissioned to explore the potential of seaweed as a raw material. Nordic SeaFarm’s vision is *“... to contribute to the transition towards a greener world by making nutritious products from our healthy seas available.”* They currently grow the brown macroalgae Saccharina latissima (S. latissima) and the green seaweed Ulva fenestrata (U. fenestrata).

The company is currently in a developmental phase, focused on expanding cultivation in terms of both yield and scale. The current seaweed farm is located off the coast of Lysekil and Nordic SeaFarm's premises are located in Dingle, a town just over thirty kilometres northeast of Lysekil. Nordic SeaFarm is the biggest producer of seaweed in Sweden and had in 2021 two hectares of seaweed production, which quadrupled in 2022. Their aim is to increase the current production from around 100 tonnes to 500 tonnes by 2026 with the goal of reaching 10,000 tonnes within ten years. The seaweed is harvested in April for 2-3 weeks. Currently, Nordic SeaFarm offers a range of products under its brand, including seaweed crisp bread, dried seaweed flakes, spices, and organic plant nutrition. Additionally, they provide frozen and fresh seaweed, mainly for use in restaurants. Nordic SeaFarm is working on expanding its network by collaborating with customers and hosting events connecting actors in the blue food sector. They wish to keep their future products under their brand name and take a central part in the value chain, continuing to expand their role beyond cultivation.

Nordic SeaFarm has recently started looking into the possibilities for seaweed to be processed in biorefineries to produce high-value compounds for different industries, with a main focus on the food industry. Since this is an unexplored market for Nordic SeaFarm, relying on immature technologies rarely deployed on an industrial scale, it entails great uncertainties and the need for new collaborations. A challenge for Nordic SeaFarm is therefore to evaluate relevant biorefineries and the type of relationships required to create the essential network to facilitate their possible expansion in the future food value chain.

1.2 Aim

This thesis aims to investigate where Nordic SeaFarm could position themselves in the emerging value chain of high-value compounds from seaweed biorefineries. This is achieved by exploring the resource networks in the industry and what collaborations and types of relationships are required to facilitate Nordic SeaFarm’s possible expansion of scope, with a primary focus on the food industry.

2 Research Context - Introduction to Seaweed

Presently, most of the global seaweed production occurs in Asia; however, there is a discernible increase in interest and investment in seaweed cultivation in Europe. Seaweed can be utilised in biorefineries to manufacture a diverse range of products, both for food and non-food applications. In the following chapter, an introduction to the seaweed industry will be given, together with a brief description of the properties of seaweed, as well as a short introduction to seaweed biorefineries.

2.1 Properties of Seaweed

Macroalgae, or seaweeds, are classified as brown, green or red depending on their thallus colour (Jung et al., 2013). Macroalgae in general differ from land-based plants in their chemical composition as well as their physiological and morphological features. However, green macroalgae, are relatively similar to land-based plants in these aspects.

Macroalgae contain around 80–90% water and their dry weight basis contains around 50% carbohydrates, 1–3% lipids, and 7–38% minerals (El-Said & El-Sikaily, 2013). The protein content varies significantly between 10–47% with high proportions of essential amino acids. Due to the high level of nutrients (van Oirschot et al., 2017), seaweed is well suited for human consumption. In addition, the highly favourable amino acid profile makes it suited as a potential protein source (Stedt et al., 2022). This is especially true for red and green algae which contain higher amounts of protein than most terrestrial crops. Even though the lipids are found in relatively small contents, the lipid fraction contains bioactive components that have shown beneficial effects on human health (Susanto et al., 2016). The environment and temperature where seaweed grows affect its chemical composition, growth rate and size (Jung et al., 2013; Susanto et al., 2016). Since Nordic SeaFarm currently cultivates brown and green seaweed, the biochemical properties of these will be further presented in the following sections.

2.1.1 Brown algae

Worldwide, brown macroalgae are the most consumed species of algae and stand for around 66.5% of all consumption (Afonso et al., 2019). Brown macroalgae consist of around 70% (dry weight) polysaccharides and fibres which vary significantly depending on the species. Alginates, fucoidans and laminarins are the most representative of the polysaccharides found in brown algae. Fucoidans and their possible applications within pharmaceuticals have in recent years been widely researched, due to its anti-inflammatory, anti-tumour, anti-viral properties, among others.

Brown macroalgae have several potential areas of usage within the food segment as it in addition has an attractive umami taste which can be used as a flavour enhancer. The brown macroalgae S. latissima has high biomass productivity and is grown on a large scale today which makes it a promising candidate to be used in food (Trigo et al., 2023). However, the protein content of S. latissima is relatively low, with levels ranging from 3 to 14% on a dry weight basis, requiring extraction processes to enhance its protein concentration for it to be used as a protein. Further on, brown algae are often known to contain high levels of the micronutrient iodine and non-essential elements such as cadmium, lead, mercury, and inorganic arsenic which could be harmful to consume (Aakre et al., 2021). This has to be taken into consideration and levels of harmful elements have to be lowered or removed completely through processing.

2.1.2 Green algae

Green seaweed has high protein levels, constituting up to 33% of its dry mass (Seaweed Solutions, n.d.), which is significantly higher than brown seaweed (Steinhagen et al., 2022). Adding to this, it also has high calcium and iron levels, as well as cobalamin, vitamin B12, sodium, magnesium, potassium, among others. The potentially harmful high iodine content is lower in green algae than in red and brown (Aakre et al., 2021). The colour of green seaweed comes from chlorophyll, thus dependent on sunlight for survival (Jung et al., 2013). Therefore, green seaweeds grow close to the surface and do not have to compete with red or brown algae that grow deeper down.

The green macroalgae U. fenestrata, or sea lettuce, has high biomass productivity and would be possible to grow on a large scale (Steinhagen et al., 2022). Some studies show that U. fenestrata is a better dietary fibre than vegetables and fruits and that its polysaccharides have shown promising anti-inflammatory and analgesic properties (Seaweed Solutions, n.d.).

2.2 Seaweed Production

Currently, both wild-harvested and cultivated seaweeds are used globally for a variety of purposes. The seaweed industry per se is mature and has primarily been focused on the extraction of hydrocolloids such as agar, alginate, and carrageenan (Filote et al., 2021). Hydrocolloids consist mainly of polysaccharides, and their gel-like structure makes them suitable for, and commonly used as, a thickening and stabilising component in food and pharmaceutical applications. Seaweed also continues to serve as a fertiliser in agriculture and as a source of food and feed. Additionally, seaweeds are being increasingly recognised as valuable ingredients for various sectors, including the pharmaceutical, cosmetic, and food industries (van Oirschot et al., 2017).

The global seaweed production was in 2019 almost 36 million tonnes of wet weight, heavily dominated by Asia, representing 97% of the total world production (FAO, 2021) as seen in Figure 1. In the same year, Europe produced 0.29 million wet tonnes, 0.8% of total world production. The high volumes produced in Asia lead to cheap imports to Europe, leaving premium-priced European seaweed farming under highly competitive pressure (Barbier et al., 2019). As Figure 1 shows, green seaweeds stand for only 0.3% of the total seaweed cultivation (excluding microalgae) in Europe while brown seaweed stands for 95.9% of the total European cultivation (FAO, 2021).

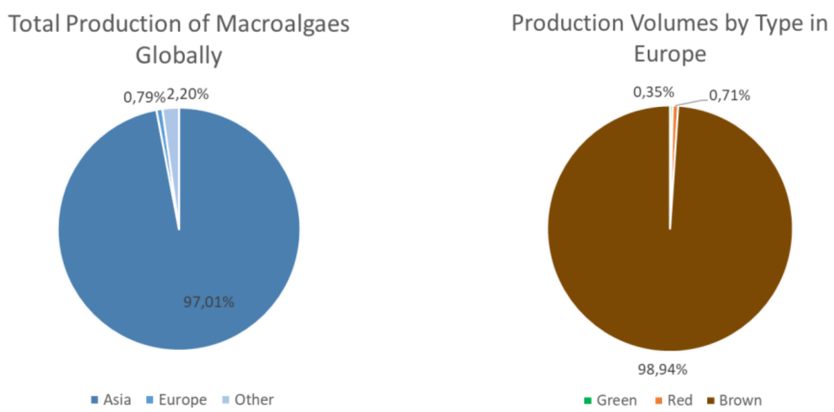

Figure 1. *Total production of macroalgae globally and production volume by type in Europe (FAO, 2021).*

Out of the total world production, almost 97% was generated through cultivation (FAO, 2021), despite this, the predominant method of obtaining seaweed in Europe is through wild harvesting (van Oirschot et al., 2017). The European seaweed cultivation was only

11 thousand tonnes in 2019 (FAO, 2021). However, in light of environmental concerns, there has been a substantial decrease in wild harvesting practices over the past decade (Mac Monagail et al., 2017). However, there are arguments suggesting that wild harvest can be carried out sustainably due to the high growth rate of macroalgae (Scottish Government, 2016). The main countries in Europe currently harvesting wild seaweed for commercial purposes are Ireland, Norway, and France (Filote et al., 2021). Nevertheless, large-scale wild harvesting could also have harmful effects on the ecological function of important habitats as well as the ecosystem services macroalgae beds provide. Consequently, there is a growing effort to meet the rising demand for seaweed by transitioning towards cultivation methods as an alternative means of production.

The EU has set a target to increase production via mass cultivation to eight million tonnes by 2030 (European Commission, 2022). However, the boom in cultivated seaweed comes with several challenges as well (Brakel et al., 2021). Firstly, the cultivation has to compete for ocean space with tourism, fishing grounds, and the growth of other native species (Cottier-Cook et al., 2021). Secondly, seaweed cultivation is exposed to a wide variety of hazards including reduced biodiversity and disease outbreaks (ibid). Policies and guidelines are needed to resolve conflicts over marine resources and to ensure the safe production of high-quality seaweeds.

2.3 Seaweed Biorefinery

There are many definitions of what a biorefinery is, a widely accepted characterisation is: *"A biorefinery is a facility, somewhat analogous to the petroleum refinery, which integrates biomass conversion processes and technologies to produce fuels, power, and chemicals"* (O'Callaghan, 2016). Originally, biorefineries were designed specifically for the production of these products, but over time, they have evolved to encompass a range of sustainable and synergistic technologies that convert biomass into a diverse array of valuable products, including food and feed, biopharmaceuticals, as well as nutraceuticals (Thongchul et al., 2022). A broader definition including these applications is, therefore, one from RISE Research Institutes of Sweden (RISE, 2020) stating that "*A biorefinery consists of a range of new processes, technologies, and solutions that, together, create new conditions for converting biomass to new green and* *climate-friendly products.".* A biorefinery approach itself thus entails that the processing of the biomass is done sustainably (Jung et al., 2013).

Adding to the definitions of biorefineries is the concept of an integrated, or cascading, biorefinery, which is defined as *"... a processing facility that integrates multiple biomass conversion pathways to produce value-added products."* (Ng et al., 2015). By letting the biomass cascade through different extraction steps in the biorefinery, multiple products can be extracted (Baghel, 2023). The integrated biorefinery thus has great potential to maximise the value of the biomass since it can permit making use of all contents in the seaweed, ideally leaving little to no waste (LUBIRC, 2021; RISE, 2020).

In the last decades, biorefineries focusing on the processing of seaweed have been widely researched and shown promising results for future applications (Baghel, 2023). Since seaweed has unique carbohydrates, the processes and technologies used on terrestrial plants are not directly applicable to macroalgae biomass, thus requiring novel technologies and processes (Jung et al., 2013). Even though the integrated processing of seaweed shows great potential, there are challenges and uncertainties to overcome before industrial scaling. Baghel (2023) presents four of them; lack of trustability, high transportation cost of fresh biomass, high ash content, and scarcity of biomass.

The lack of trustworthiness is a result of the fact that the processes are new, and testing has thus primarily been conducted on a laboratory scale, using limited quantities of biomass. The proof of economic feasibility, design, and functionality of the processes at large scale and actual product yield is therefore not yet confirmed. For a chance to be economically feasible, finding the right product combinations is essential (Filote et al., 2021). In turn, the choice of a specific seaweed for valorisation becomes of great importance due to the effect composition and stability has on product yields. Other researchers also raise concerns about the large quantity of biomass needed for the process to yield the desired output, due to the fact that seaweed is a highly water-dense crop (70-90%). For future large-scale biorefineries, this implies large cultivation areas in coastal regions which in turn could increase problems with cultivation as described in section 2.2 (Filote et al., 2021).

Due to increasing interest in seaweed and its applications in Europe, the EU has initiated many projects aiming to extend the use of seaweed together with biorefineries, seaweed farmers, and academia (European Commission, 2022).

3 Theoretical Framework

The following chapter is devoted to give a theoretical basis for analysing the studied issue. As the study aims to provide implications regarding the positioning of a seaweed supplier within the value chain of seaweed biorefining and the necessary relationships enabling such positioning, this section seeks to cover the background and theories relevant to the topic. The framework is based on the 4R model, which was chosen to enable the analysis and visualisation of an emerging value chain. To further facilitate analysis and fulfil the aim of the thesis, theories on resource interfaces and resource interactions and their effect on inter-organisational networks have been explored. Furthermore, theories regarding the degree of vertical integration and the characteristics this depends on are introduced. To further analyse what collaborations and types of relationships are needed in the emerging value chain, the framework also presents theories about value chain collaborations and the network's importance as well as different network ties. The theoretical framework leads up to the research problem and research questions of this thesis.

3.1 The 4R model

The 4R model developed by Håkansson and Waluszewski (2002) can be helpful for analysing a product development process that involves products and facilities within a network (Baraldi et al., 2012). This model will provide a basis for analysing resource interactions in the emerging value chain. According to Håkansson and Waluszewski (2002), four types of resource categories are central when technological development in a business network is carried out. These four categories are products, facilities, organisational units, and relationships. The 4R model can help map, classify, and analyse the processes of resource interaction between organisations in a network (Baraldi et al., 2012). In addition, it could represent the resource network of complex processes such as the development of innovations. The primary benefit of the four-part classification system is its ability to provide a thorough examination of the interactions between two or more resources. This form of analysis supports the efforts to alter the attributes of resources, thereby facilitating effective resource management.

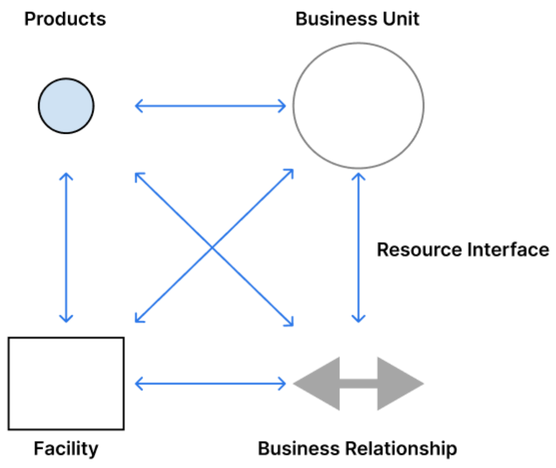

Figure 2. *An illustration of the 4R model, developed by Håkansson & Waluszewski (2002).*

3.2 Resource Interfaces

Resource interactions refer to the process of combining, re-combining, and co-developing resources through interaction among organisations (Baraldi et al., 2012). The concept of a resource relies on four assumptions; that both the producer and user could make use of the resource, that the resource is shaped by the network context, that the value of the resource depends on the combination with other resources, and that resources are open and variable. A key concept when discussing resource interaction in a business network is resource interface. Baraldi et al. (2012) state that resource interfaces are *"the contact points along which two specific resources interact or influence each other's technical, economic, and social features"* (p.267) and that the concept can be useful when formalising interactions between involved resources. There are technical interfaces concerning facilities and products, as well as organisational interfaces concerning relationships and organisational units. Adding to this, the combining of resources especially creates value via the so-called mixed interfaces, which are the connections between organisational and technical resources.

When two resources have been used in combination for an extended period of time, there is a greater probability that they have been more closely adapted through modifications made to one or both resources. As a result, a deeper, more specific, and stronger interface is formed, which can be difficult to break. The depth of an interface is dependent on the degree of mutual adaptation and the investments made in a particular resource combination, as per the findings of Baraldi & Waluszewski (2005) and Håkansson & Waluszewski (2002).

3.3 Vertical Integration

The number of vertical stages in an industry's value chain over which a firm has control and ownership is synonymous with the extent of vertical integration (Grant, 2018). Vertical integration could be upstream towards the supply side, or downstream towards the consumer side, and in addition, it could be full or partial. An example of partial vertical integration is when a firm's own produce is complemented by products from suppliers or when some of the products are sold through distributors and some by the firm itself.

Grant (2018) provides several implications as to when a firm should have a high level of vertical integration and what characteristics of the industry this depends on. One of these characteristics that would encourage vertical integration could for example be when a firm needs to invest in equipment or technology that is specific to the needs of another party in the value chain. Vertical integration can be a suitable alternative in cases where specialised processes require close technical collaboration and coordination among the involved parties. Another characteristic of the vertical relationship is how many firms are in the vertically adjacent activity, where the fewer the firms the more advantageous is vertical integration. Further on, vertical integration could entail advantages in terms of economies of scale and/or scope. On the other hand, vertical integration could also come with disadvantages when for example the difference in scope of the adjacent businesses is great or when the market demand is uncertain.

3.4 Value Chain Collaboration

In relation to vertical integration, the theory regarding horizontal collaboration puts emphasis on the value of cooperation between organisations working on the same level in the supply chain (Palmieri et al., 2019). Horizontal collaboration is about finding synergies between companies, where openness and trust lead to shared risks and rewards, and a competitive advantage that is greater than what the individual companies could achieve on their own. Adding to this, horizontal collaboration can also be beneficial in regard to sustainability, as well as for the customer. These benefits include increased visibility and more efficient transportation, made possible through infrastructure collaboration such as transport consolidation as well as synergies in processing equipment and similar.

Horizontal collaboration in logistics comes with many challenges, due to the complexity of inter-firm integration (Palmieri et al., 2019). Palmieri et al. (2019) put forward several enabling factors for successful horizontal collaboration, one being a relatively low level of competition between the actors at the supply chain level. Low competition indicates that actors can share resources and be associated with their competitors in logistic matters without harming their position in the value chain. Another enabling factor for horizontal collaboration addressed by Palmieri et al (2019) is if the costs of logistics present a large percentage of the total costs.

One example of horizontal collaboration within agriculture is the formation of farmer organisations, also known as agricultural cooperatives (Zakić et al., 2014). According to Coltrain et al (2000), a cooperative is defined as "*a business operated primarily to provide benefits to members through marketing transactions and through the distribution of earnings from these transactions*" (p.2). The cooperatives can help small-scale farmers build close linkages needed with different stakeholders, for the efficient coordination of supply and demand (Zakić et al., 2014). The collective action made possible through these cooperatives is described as a strategic choice in order to strengthen the participation of small-scale farmers in emerging markets. Through the cooperatives, the farmers can take advantage of an opportunity jointly as opposed to alone, sharing R&D costs and risks, as well as strengthening negotiating power. Cooperatives can also increase efficient communication with other actors in the value chain, due to the single contact point. The success of a cooperative depends on many factors, and it requires ongoing efforts from all members, thus only creating a cooperative is not enough.

Another common way of collaborating, aiming to link farmers with other important actors in the value chain, is contract farming (FAO, 2001). According to FAO (2001), contract farming can be defined as "*an agreement between farmers and processing* *and/or marketing firms for the production and supply of agricultural products under forward agreements, frequently at predetermined prices*" (p.2). This type of contract can offer numerous benefits for small farmers where reduced price-risk, advantageous production services offered by the investor, and exposure to new technologies and skills are a few of them. If not managed properly, there is a risk of exploitation of small-scale farmers, being the weaker party involved.

3.5 Network ties

To foster both horizontal and vertical collaborations and partnerships, it is important to evaluate inter-organisational relationships. For a start-up, business relationships are crucial to be embedded in a business network (Landqvist & Lind, 2019). These relationships, or network ties as they are also mentioned, improve the capacity of start-ups in fundamental entrepreneurial processes such as acquiring resources, gaining legitimacy, and spotting opportunities (Elfring & Hulsink, 2007). Granovetter (1973) defines these network ties as either strong or weak depending on four criteria; frequency of contact, the emotional intensity of the relationship, the degree of intensity, and the reciprocal commitments between the actors involved. Weak ties can provide access to novel information and industries, give connections to new business contacts, and through diversity provide access to various sources of new information and knowledge. Strong ties can bring similar actors together in intense and long-term relationships but could also "lock in" the actors in specific products or processes, potentially blinding them to new developments.

Elfring and Hulsink (2007) emphasise the importance of having both of these types of relationships and that they are valuable in different ways and at various stages of a company's development. In the early growth phase of organisations in emergent industries, the search for new opportunities is an extensive process and the role of weak ties is therefore of high importance. These could in later stages be dropped or further developed into strong ties. The interaction between strong and weak ties could improve the efficiency of resource searching by exploring weak ties among the strong ties already established. In addition, to gain legitimacy in emergent industries, newly developed strong ties are claimed to be beneficial for start-ups as well as weak ties which could later be strengthened as the organisation evolves.

3.6 Research Problem and Research Questions

The exploration of new markets and opportunities entails major challenges for any organisation, not the least regarding what role to develop in the value chain as well as what collaborations to initiate. Entering a nascent industry further adds complexity, as is the case for the industry connected to seaweed biorefining. The technologies involved have hardly ever been deployed at an industrial scale, indicating uncertainties regarding the potential for success.

To get an understanding of the emerging value chain, there is a need to investigate the technical and organisational resource features and how these affect the resource network. Further on, it is necessary to investigate the current situation, including what products and customer base biorefineries are currently developing their processes for. This enables analysis of where a seaweed farmer could position itself within the value chain. There is in addition a need to understand the effects the resource interfaces have on the future network to provide implications for the relationships and collaborations required in the emerging value chain. Additionally, the study will investigate the necessary collaborations and types of relationships needed in the emerging value chain through the lens of theories on value chain collaborations and the importance of networks and network ties.

The problems and uncertainties discussed above lead up to the following research questions (RQs):

RQ1: Where are the opportunities for a seaweed farmer to position itself in the resource network of high-value compounds from seaweed biorefineries in Europe?

RQ2: How do the resource features affect the strategy for a seaweed farmer regarding business relationships within the biorefining value chain?

RQ3: What collaborations and relationships are necessary for a seaweed farmer to successfully operate in a biorefinery network?

4 Method

This chapter will outline the method for this thesis and the reasoning behind the choices in the specific context. The chapter will address the research strategy, the research design, and data collection. Lastly, ethical considerations will be discussed, as well as a concluding reflection on the chosen method.

4.1 Research Strategy

The methodology used in this thesis was of a qualitative rather than a quantitative character (Bell et al., 2019). To complement the qualitative strategy, an abductive approach was taken. More specifically, the approach of systematic combining was used, as proposed by Dubois and Gadde (2002). Since the research topic at hand was relatively unexplored within academia, especially regarding the emerging value chain connected to the future seaweed industry, an abductive approach was preferred over a deductive or inductive. The reason for this lies in that abductive reasoning is characterised by iterative work between theory and data, and through this constant iteration, the researchers have been able to enhance their comprehension of both "worlds" (Dubois & Gadde, 2002). Observations through empirical data can lead to surprising but still related findings, and systematic combining opens up for continuous reorientation of the theoretical framework and research issues at hand, as new insights from empirical data emerge.

The abductive approach was further taken since it enabled the finding of valuable insights within network structures. For example, it facilitated the findings of interdependencies within the system that was not at first visible or deemed important for the researchers (Dubois & Gadde, 2002). The researchers have strived to stay open for new findings and possible deviations from initial preunderstandings and analyses. Further on, the abductive approach has been found suitable for case studies aiming at the development of new theories rather than testing existing ones, which was the case for this thesis (Bell et al., 2019).

4.2 Research Design

The research design of this thesis was a case study, which is a widely used research method in business research (Bell et al., 2019). More precisely, a single case study was performed to provide more depth rather than breadth, which allowed for a thorough examination of the specific setting (Bell et al., 2019; Dubois, 1999). Systematic combining, as described previously, can unlock the full potential of the case study approach. In line with theories presented by Dubois & Gadde (2002), the case analysis was performed simultaneously as the theoretical framework evolved and empirical data was gathered.

4.2.1 Literature Review

An extensive literature review was continuously carried out throughout the research process. Following the abductive reasoning previously described, empirical findings directed the literature search into new related fields. Databases that were used for the literature search were among others Scopus and Google Scholar. Search words were initially "biorefinery", "seaweed" and "protein extraction", for the researchers to gain a broad overview of the current state of the industry and technologies used. Search words were later refined and focused on business theory, such as "vertical integration", "resource combining", "horizontal collaboration" and "network ties" in different combinations. Given the scarcity of research conducted on the topic, the researchers adopted an interdisciplinary approach. This enabled the integration of knowledge from various fields to develop a comprehensive understanding of the case. An example of this is the theories presented regarding agriculture which have been used and applied to aquaculture as it is assumed that they are applicable to both industries.

4.2.2 Data Collection

The primary data for the research was collected through interviews with relevant actors for the emerging value chain of seaweed biorefineries. To gain a deep understanding of the seaweed biorefining industry, purposive sampling has been used, as proposed by Bell et al. (2019). This sampling method allows the researcher to select participants based on their likelihood of possessing relevant knowledge, experience, or representativeness of the group under investigation, thereby enhancing the quality and relevance of the collected data. Companies working within the field of biorefineries were primarily approached. Actors both within the biorefining of seaweed and terrestrial crops were interviewed, to gain the perspective from both industries and enable a comparison of a similar product resource network. The chosen actors within the area of biorefining of seaweed were mainly found through the database "Phyconomy Seaweed", which is a publicly available database tracking the development in the seaweed industry (Phyconomy, n.d.). Relevant companies were also found through recommendations from Nordic Seafarm and from Google searches within the field. Eleven European seaweed biorefineries found through "Phyconomy Seaweed" were contacted, and six chose to participate. One out of two biorefineries for terrestrial crops decided to participate. The participating company is the first company in Sweden that is extracting protein from crops, making it an interesting subject for comparison. From the interview with the biorefinery for terrestrial crops, it was found that the food developers play an important part in the value chain, and it was decided that it would be valuable to acquire their input as well. Therefore, two food developers were contacted of which both participated. Interviews were conducted in the language preferred by the interviewee, it being Swedish or English.

The interviews were semi-structured, following an interview guide but leaving room for flexible order of questions as well as follow-up questions (Bell et al., 2019). This allowed for flexibility while maintaining a structure that allowed for comparison between interviews. An interview guide was conducted before the interviews and was revised throughout the process to complement the questions as new knowledge was found. It was also adapted to fit the different types of interviewed actors. The questions in the interview guide for the biorefineries were designed to gain an understanding of their biorefinery process, their collaborations, as well as their progress to date. The interview guides can be found in Appendix 1.

The interviews were held on Zoom or Microsoft Teams, to enable interviews with actors located in different parts of Europe. After permission was granted from the interviewee, the interviews were recorded. The interviews were also transcribed, and key findings were summarised shortly after the interviews, to make sure no valuable insights were lost. The transcription allowed for a repeated and more thorough analysis of the answers, and the avoidance of biases based on initial interpretation of the answers (Bell et al., 2019). Both researchers were present during the interviews, one being responsible for asking questions and the other taking notes. Additionally, the participants had the opportunity to review the thesis before publication to verify the findings from the interview's accuracy and ensure credibility. Table 1 presents the different interviews in chronological order as they were held and includes the company name, the role of the interviewee in said company, and the selection method as well as the duration of the interview.

Table 1. *Representation of the interviews held.*

Company	**Role**	**Field**	**Selection method**	**Duration**
Chalmers University of Technology	PhD Student in Chemical and Biological Engineering	Research on seaweed	Case Company	48 min
Alginor	R&D Manager	Seaweed biorefinery	Case Company	32 min
GOA Ventures	Biotechnology Laboratory Lead	Seaweed biorefinery	Phyconomy Seaweed	21 min
BioMara	Founder & CEO	Seaweed biorefinery	Phyconomy Seaweed	30 min
GroPro	Founder & CEO	Pea biorefinery	Google search	38 min
Oceanium	Co-founder & CTO	Seaweed biorefinery	Phyconomy Seaweed	36 min
Origin by Ocean	CEO	Seaweed biorefinery	Phyconomy Seaweed	44 min
Solina Sweden	Product & Application developer	Food Developer	Interviews	24 min
Seaweed Scaleup	Founding Partner	Seaweed biorefinery	Phyconomy Seaweed	45 min
Culinar	Head of Development	Food Developer	Case Company	21 min

4.2.3 Data Analysis

To capture key points early on, data analysis was made directly after each interview. The data from the interviews was also transcribed to be available for repeated analysis. The researchers both listened to the audio files and read the transcripts repeatedly throughout the project to ensure that the information was correctly understood. This also facilitated the abductive approach, where certain parts of the interviews became more relevant as the project progressed and findings from single interviews were put in perspective to the others, gradually unfolding the case.

After the interviews had been conducted the results were summarised and analysed. Three categories of biorefineries were distinguished based on their business plan, business scope, and intended position in the value chain. The categorisation was done in order to later draw more generalised conclusions on how a seaweed supplier can interact with different biorefineries depending on their offering and thus their category.

A summarising analysis regarding the value chain from the perspective of a biorefinery was thereafter conducted, as well as a thematic analysis regarding their view on vertical integration and what kind of collaborations they deemed important. Drawing on the 4R model, analysis was further done through the visualisation of relevant resources and their interfaces from the perspective of a biorefinery.

Due to the fact that the industry itself is in its infancy, working with hypothetical future scenarios was chosen as a relevant approach to evaluate different possibilities regarding where a seaweed farmer can position itself in the emerging value chain. With the base in the 4R model as well as the previously developed biorefinery categories, three hypothetical scenarios were explored. These scenarios were all developed from a seaweed farmers point of view.

4.2.4 Ethical Considerations

In the field of business research, Bell et al. (2019) emphasise the importance of incorporating ethical considerations, not only when treating the participants involved in the research but also in the selection of methods utilised by the researchers. Personal information of participants was protected by excluding any data that could potentially harm any interviewees, the companies involved, or others. Additionally, the interviews were recorded if consent was obtained. The interviewees also got the opportunity to read the final thesis before publication. By enacting these measures, it was expected that, participants would feel more at ease and be more willing to share information that would contribute to the research. Furthermore, the measures were intended to prevent any form of harm, infringement of privacy, or deception.

4.3 Reflections on the Methodology

To ensure that the outcome of the thesis met the quality criteria for business research, the researchers considered the study's reliability and took measures to overcome the subjective traits of qualitative research. Bell et al. (2019) clarify how this can be done by internal reliability meaning that the two observers agree on what is discerned both in interviews as well as in the literature analysis. The two researchers have continuously cross-checked findings with each other to achieve inter-observer consistency.

An important aspect to consider for this thesis is that it concerns a nascent industry, which has not yet been deployed at large scale in Europe. Therefore, it is difficult to draw firm conclusions regarding the future of the value chain. There is currently a surge in interest and investments in the seaweed industry, consequently providing new opportunities for development. However, the industry's development trajectory can rapidly shift based on the general interest and investments as the biorefineries all rely on funding from the EU and other sources. This poses a challenge in terms of research credibility as the case study investigates an industry that has yet to develop fully. New actors, technologies or regulations may potentially emerge and reshape the industry in the coming years. To increase the viability of the thesis, the aim of it is not to assess whether or not the industry itself will succeed, but rather aims to explore how the case company could act and interact in terms of value chain positioning.

5 Results

In the following sections, the empirical results from conducted interviews are presented along with relevant data sourced from the respective company's website. As mentioned in 4.2.3, the interviewed biorefineries have been divided into three categories depending on their business plan, business scope, and intended position in the value chain. These categories are: biorefinery with an in-house supply of biomass, operating biorefinery, and provider of biorefinery solutions. Each of the seven biorefineries is evaluated first on their technical resource features such as species of seaweed, end products, locational aspects of the biorefinery, and volume of seaweed required. Further on, the organisational resource features are presented, such as their relationships with customers and suppliers as well as end product industry. Lastly, the results from interviews with other relevant actors are presented. The contacted biorefineries along with their geographical location is presented in Figure 3.

Figure 3. A map showing activities in seaweed biorefining in Europe.

5.1 Biorefinery with an In-house Supply of Biomass

The category of biorefineries with an in-house supply of biomass includes Alginor and Seaweed Scaleup. These companies plan (or planned) fully own their first biorefinery, as well as supply it internally with wild-harvested or cultivated seaweed.

5.1.1 Alginor

Alginor is a Norwegian marine biotechnology company that is developing a value chain for brown seaweed with a vision to" *...be a large-scale manufacturer and supplier of high-quality and unique ingredients extracted from Laminaria hyperborea to a global customer base consisting mainly of end-user production companies spread over seven established market segments*". Alginor was established in 2014 with the aim to develop the first biorefinery for marine products in Europe (Alginor ASA, 2021). They are currently moving from their pilot plant into a plant of industrial scale, both located on the southwest coast of Norway.

Technical Resource Features

The species used is Laminaria hyperborea (L. hyperborea), due to its abundance on the Norwegian west coast. The harvest is carried out by Alginor through their subsidiary Alginor Hypomar. Furthermore, L. hyperborea grows relatively deep in comparison to other species. As a result, the harvesting process can target that specific species, making the chemical extraction process more effective. Alginor wants to primarily focus on only one species to be able to optimise their processes, concerning everything from harvesting, and cutting to chemical processing. Alginor will do tests on S. Latissima through a research project called CircAlgae which they are involved in together with Nordic SeaFarm, universities, research institutes, and other biotechnology companies in Europe (CircAlgae, n.d.). Green species like U. fenestrata which significantly differs from brown seaweed will not be tested unless required by the research project CircAlgae.

Alginor aims to produce alginate in their new plant of industrial scale in early 2023 and fucoidan will follow at a large scale later the same year. The plant is expected to process 5,000-30,000 tonnes of wet seaweed in the coming year. The volume depends on when the equipment will arrive and if the market is ready. In a future scenario where Alginor processes L. hyperborea at this scale, their estimation suggests that in order to introduce an additional species into their refining process, they would need a minimum of one week's production volume to achieve economic feasibility. This is due to a halt in their own production for cleaning purposes. One week of production volume would be equal to around one hundred tonnes of seaweed (wet weight). The quantities needed, however, depend significantly on the value of the products extracted. They further explain that due to the composition of L. hyperborea, they can produce high-priced alginate, which is not possible for S. latissima due to its inferior gelling strength. The properties of fucoidan, however, differ between species and can therefore have different application areas depending on the species used as an input. They see a potential in extracting fucoidan from other species in addition to L. hyperborea. Fucoidan has a much higher price than alginate and is extracted in mild processes keeping the biochemical compositions, meaning that the rest product can possibly be used in food. Alginor describes that fucoidan is a fairly stable compound, meaning that the seaweed can be processed some days after harvest without the compounds deteriorating.

Organisational Resource Features

In addition to Alginor Hypomar, Alginor ASA consists of three other subsidiaries including Alginor Biorefinery, which is their downstream function, OEWA which focuses on R&D, quality control, and consumer products as well as Alginor Industrial Estate (Alginor ASA, 2021).

Alginor targets seven different market segments, including pharmaceuticals, cosmetics, food, and textiles. They are also looking into producing biofertilisers from the side streams. Their fucoidan is going to be used primarily in the pharmaceutical and cosmetics industries. Alginor explains that they have a major customer which will purchase any quantities of alginate produced in the coming years. They are working closely with their customer to customise the products to their needs, stating that this is valuable also because they can get insights into what other customers in the same industry might want, stating that when developing the process "*... it might generally make more sense to produce it that way, not only for them.*". They see that in the future, less purified products will also be released without a confirmed buyer, but as much as possible will be developed together with customers.

They describe that there are many high-value products in seaweed, but that they continuously have to evaluate how costly it is to purify them and sell them as single products. Alginor describes that "...*there are a lot of calculations regarding what is best, purifying or not? If we purify, how much water would it take? How much energy would it take?*" and that "... *maybe it is better to take all the leftovers, combine them into a powder or liquid extract, and sell them for less than the purified one*".

5.1.2 Seaweed Scaleup

Seaweed Scaleup is a Dutch company founded in 2021 with the mission "*to grow a better tomorrow by sustainably supplying the world of high-value products based on macroalgae*". Their plan was to use a cascading process for the extraction of protein, fucoidan, and alginate. The products were to be used in the food industry to substitute meat consumption. However, their business plan recently changed drastically due to a lack of economic feasibility in the business case.

Technical Resource Features

Seaweed Scaleup aimed to use European cultivated seaweed in their facility. However, they found that the cost of producing seaweed in Europe, as well as the biorefinery process itself, is too expensive to reach economic viability. For the biorefining of seaweed to be economically feasible, they see that the cost of cultivation has to drop at least ten times through technological investments in the cultivation. The processes for biorefining also have to be further optimised to reach economic feasibility. They do not see this being feasible within the next 10-15 years.

The business case was built on their planned demo plant, which would have had the capacity to process up to 6,000 tonnes (wet weight) of seaweed per year. However, Seaweed Scaleup claims that larger volumes would not change the outcome of the case significantly. Another problem stressed was the complex biorefinery process due to the biochemical structure of seaweed. The cell structure is hard to break down and it is difficult to create a process for several products since extraction of high-quality alginate for example would also mean destroying the protein. They explain that optimising the process for more than one product adds severe complexity, since "...*one product gives about five parameters in your process. If you want two products, you have about 10* *parameters. If you have three products, you have about 15 process parameters you need to optimise*". In addition, several sustainability concerns connected to large-scale seaweed cultivation were presented, such as plastic pollution in the ocean, the extended usage of non-renewable fuels for offshore cultivation, and potential hazards such as diseases. Further on, there are also potential certifications and insurance costs that were not included in their business case. Another problem addressed by focusing on the food industry was that food producers require large volumes of products derived from seaweed, requiring biomass volumes not available in Europe today.

The way forward for Seaweed Scaleup is to import comparatively cheaper seaweed in its dry form from Asia and find a market for non-biorefined seaweed in meat replacement products. They highlight the problem that Europeans generally are not used to consuming seaweed and its taste. Partly due to this, they are shifting to red seaweed rather than brown due to the flavour characteristics which they believe could be easier accepted on the European market and has more suitable properties for non-processed consumption. They aim to first create a market for red seaweed as food in Europe starting with getting the customers and consumers used to seaweed as food. They see that the environmental impact of transporting dry seaweed is low due to its weight, which motivates the choice of importing seaweed to Europe. After confirming the market, they plan to go back to their original plan regarding farming their own seaweed, continuing their focus on red species.

Organisational Resource Features

Seaweed Scaleup was planning to farm seaweed to use as an input in their biorefinery and to cooperate with other farmers to get enough biomass. Due to Seaweed Scaleup's recent change of scope, no other organisational aspects connected to resource features were discussed during the interview.

5.2 Operating biorefineries

The category of operating biorefineries includes BioMara, Origin by Ocean and Oceanium. These companies plan to fully own and operate at least their first biorefinery. These companies will process sustainably sourced seaweed, but they do not aim to cultivate their own. BioMara is researching what process to use in their pilot plant, Origin by Ocean is looking into scaling up their production and Oceanium is operating a biorefinery today.

5.2.1 BioMara

BioMara is a Scottish start-up company founded in early 2022, developing a biorefinery technology for the production of high-value products from seaweed. Their aim is "*to positively impact the world by leading in excellent science as they seek to realise the full industrial potential of kelp to address globally important challenges related to nutrition, healthcare, medicine, sustainability, and food security*." (BioMara Ltd, 2022). BioMara is in an early research phase, aiming to have done pilot testing in a year, and possibly a demonstration-scale biorefinery within three years.

Technical Resource Features

BioMara will use farmed Scottish native brown algae and is currently testing processes for several different species, researching extraction and purification methods. They aim to be able to adapt the process so it can operate on a range of species. As for now, the main focus product for extraction is fucoidan. They aim to focus on only one product rather than all the products from the cascading process but since fucoidan is only a small part of the algae, they are also looking into what can be done to make use of side streams. However, the process will be optimised for the extraction and purification of fucoidan.

Since BioMara is in an early development stage, they have not set a required volume for the biorefinery yet. They express that the volume required to reach profitability will depend a lot on the product, product price, extraction costs, and potential customers, parameters that are all uncertain as of now. They are currently looking into the refining of dry seaweed but state that this might change in the future.

Organisational Resource Features

BioMara does not aim to cultivate any seaweed and acknowledges the need for tight partnerships with farmers to ensure a high and consistent quality of the feedstock. They state that since farming is relatively easy to set up, the volumes of produced seaweed will grow as demand grows and the farmed seaweed could then be cheaper due to economies of scale. They have also chosen to focus on cultivated seaweed since they see a larger potential in scaling up that production without harming the ecosystem. In addition, they mention the fragility of wild harvest in terms of legislation, stating that: *"There's always the possibility in certain countries like the UK, that the government just shuts down wild harvesting, for example, or really restrains it. That could happen at any moment in the next five years in any country".*

BioMara sees that there will also be close customer collaborations, envisioning that products will be co-developed with customers or that the technology could even be licensed from them. They describe that they "*have to be led by the customer"*, through the presentation of samples which later determines the whole direction of the business. They are currently seeking to be the link between farmers and end product developers which are likely to be large corporations, thus only working business to business. The end product industry is yet to be decided, and the company is talking to potential customers in the cosmetic and pharmaceutical industries, among others.

5.2.2 Origin by Ocean

Origin by Ocean is a Finnish company founded in 2019 with the mission to "*make the chemical industry run on algae*". They currently have a pilot plant operated by a partner company and aim to have their first own plant of industrial scale running by the end of 2026. The first end product with an ingredient from Origin by Ocean will be released in spring 2023 and will be a home and personal care product.

Technical Resource Features

Origin by Ocean has developed a patented cascading biorefinery process that can operate on all types of brown seaweed, with small alterations to the process depending on the composition of the species. Currently, they are processing the invasive species Sargassum imported from the Caribbean as well as the farmed brown seaweeds kelp and bladderwrack (Fucus vesiculosus). Origin by Ocean is in the R&D phase focusing on industrialising their process which will be producing alginate, mycosporin, fucoxanthin, and fucoidan.

They describe that the cosmetic industry is deemed suitable initially, given the feasibility of handling smaller volumes and batches before large scale production is available. In later stages, they will potentially also extract laminarin and phycobilin. The six products have possible usages in industries such as pharmaceuticals, cosmetics, food, agriculture, packaging, and textiles. The side stream is currently used by a partner company for feed production but might be used for other applications in the future, such as protein for food.

Origin by Ocean’s pilot plant in Finland is processing tens of tonnes of Sargassum from the Caribbean annually, as well as European brown seaweeds such as kelp and bladderwrack. They aim to have their first own plant running by the end of 2026, with the ability to process any type of brown seaweed at a feedstock volume of at least 20,000 tonnes/year. The seaweed will go through the process wet, and they mention that transportation and storing it for at least 6 months is not a problem with their storing and preservative methods. Production will be done all year around, so to ensure biomass availability as well as maintain the biochemical composition these storing methods are crucial. For the future, they want to use only locally sourced seaweed, but there is not enough biomass in Europe for that yet. They aim for the coming plants to be located where there are vast amounts of seaweed, with a production of 100,000 tonnes/year. When processing wild harvested seaweed, the company will only use invasive species, thus “cleaning the ocean”. For other species, they will use sustainably cultivated seaweed.

Organisational Resource Features

Origin by Ocean describes that they work closely with their customers when developing their products and processes, describing it as being “*the same as in any chemical sales*”. They are offering formulation services for their functional ingredients, describing that the relationship to the customer is similar no matter the end industry. They had initiated relationships with customers in the early stages of the company’s development and describe that their first sample sent to a potential customer gave valuable information about the customers need and “*based on that information you go back into your process and start to think how it could be developed to be even better*”.

Origin by Ocean describes that they also aim to have close partnerships with suppliers of seaweed and that they do not aim to cultivate their own. However, they see that vertical integration is needed in the beginning since the value chain does not exist yet. They have established partnerships with suppliers in the Caribbean, as well as with European farmers about future local supply to build up long-term partnerships with common goals in the supply chain.

Origin by Ocean currently sees itself as the operator and owner of the plants to be established. They also state that "*... there are different kinds of financial structure possibilities*". However, as of now, they do not envision licensing the technology due to the costly and complicated IP strategy that would entail. Co-branding products is an option and Origin by Ocean believes that this can create added value for their customers due to their sustainable brand identity.

5.2.3 Oceanium

Oceanium is a Scottish company founded in 2018, with the purpose "*to enable the emerging seaweed industry by creating demand for sustainably farmed seaweed*". This is done through the development of a biorefinery technology to produce seaweed-based products. The original idea for the company was to produce bio packaging, an idea that was further evolved to include several high-value products to maximise the value of seaweed and ensure commercial viability. In recent years, Oceanium has conducted pilot-scale testing in a contractor's biorefinery facility, they intend to set up their own industrial demonstration-scale production facility within the next year.

Technical Resource Features

The biorefinery process is currently developed for manufacturing four products. These are the two bioactives fucoidan and beta-glucan for the cosmetic and nutraceutical industries, as well as functional fibre and protein concentrate for the production of food.

Oceanium mentions that bioactives are of high value ranging between 100-500$ per kilo. Food ingredients are in the low to medium value segment of 5-20$ per kilo and due to the low cost of plastic polymers of around 1-2$ per kilo packaging is of the lowest value. This means that only working with bio packaging would not be enough even if cultivated seaweed will be cheaper in the future. On the material side, they have moved from packaging to focusing on other applications, such as materials that can be used for clothing or footwear. The food ingredients produced have a certain colour and taste which some customers like and others do not. However, this is not a concern from Oceanium's point of view since the taste and smell are suitable for, for example, meat substitutes which is a sufficiently large market. Nevertheless, they are developing versions of the food ingredients with reduced colour and flavour similar to products used in the food industry today in order to maximise the market opportunity.

Oceanium's biorefinery process is flexible and can process several types of brown seaweed, and the process is proven for five species today. Recently they have entirely focused on S. latissima, due to the relatively high availability of biomass in Europe in comparison to other species. They are also looking into refining other species grown in Asia or on the US Pacific Coast to reduce the uncertainty of supply in Europe. Oceanium also sees potential in the green seaweed U. fenestrata because of the high protein content, but as of today, it is an expensive feedstock compared to the other species, and in addition, the supply is uncertain since there is no large-scale cultivation. They have started a project looking into the development of a biorefinery process for this type of seaweed, possibly using the feedstock from so-called green tides. In general, they want to use cultivated seaweed to ensure long-term and large-scale sustainability.

Oceanium envisions that a full-scale production plant would process 20,000 wet tonnes annually. During 2023, 100 tonnes will be processed, and in the upcoming year at least 350 tonnes, possibly more, depending on feedstock availability. Oceanium describes that they are already a significant buyer of seaweed in Europe, coming in at the right time and creating demand for feedstock. Despite this, they expect a shortfall in supply in the coming years but anticipate that the farmers will scale up when demand rises.

The long-term goal is to use as much wet seaweed as possible for the biorefinery, but the process also works for dry seaweed. Since Oceanium currently and in the near future has to work with many suppliers distributed over Europe to gather enough feedstock, it has to be dried or frozen due to logistical reasons. The possibility to use dry seaweed enables less challenging logistics regarding the transportation of biomass.

Organisational Resource Features

Oceanium strives to develop partnerships with seaweed farmers since they see that a tight collaboration is needed to ensure consistent quality of the biomass. The quality of the dry matter can vary depending on growth conditions, season, and location. Thus, they want to change the traditional view that seaweed is sold in wet weight since it is the amount and quality of the dry matter that is of value for them. They describe that they recently have developed a supplier package, ensuring that what is agreed is delivered in terms of components of the biomass, sustainability, and compliance matters. This is necessary since some seaweed is not economically viable for Oceanium to process as it does not contain enough desirable properties. Oceanium describes that this is a difficult conversation to have with the farmers, but that it is necessary since different applications pose different requirements on the properties of the seaweed. It also helps the suppliers to understand their product and for what industry it is suitable.

Although its main business model is to sell dry powders extracted from seaweed, Oceanium describes itself as not being solely a processing company. They also work with end product development, e.g., recipe development, in order to show potential customers what can be done with the ingredients. Oceanium is currently working closely with potential customers through sampling, discussions, and sharing experiences regarding the use of the products. They want to work with partner customers that are willing to have their brand on their products, for the end customer to "*get the seaweed sustainability story*". Bigger brands tend to not want to work like that, leading Oceanium to mainly work with SMEs at the moment.

Oceanium does not see itself having its own cultivation in the near future. They had the thought when starting up but took the decision early on that it would be too challenging both financially and in terms of staff required. In the long term, upstream vertical integration into additional parts of the value chain is seen as a likely scenario. For the future, Oceanium would like to prove the biorefinery at scale, and then replicate it in factories located where there is enough seaweed supply. They see that licensing the technology is the way forward for expansion, developing partnerships in different locations to work as an enabler of the industry and the whole value chain both in Europe and in North America and Asia. The product portfolio would then differ slightly depending on the seaweed species, but the technology would be similar, and the process would in large produce the same product categories. The technology could also be developed to fit existing refineries producing hydrocolloids from seaweed and could then extend the product portfolio as well as reduce waste from such refineries. However, these producers are large established firms and are not likely to switch from wild-harvested seaweed to the more expensive cultivated seaweed in the near future.

5.3 Provider of Biorefinery Solutions

In the following chapter the findings from the interview with a provider of biorefinery solutions, GOA Ventures, are presented. A provider of biorefinery solutions intends to neither farm seaweed nor operate a biorefinery but to provide solutions for farmers or other actors who want to develop a biorefinery for seaweed.

5.3.1 GOA Ventures

GOA Ventures (GOA) is a Dutch company founded in 2016 with the aim to produce and sell turnkey seaweed biorefinery facilities with its patented processing technique. Their ambition is "*to be the best scalable solution for sustainable seaweed valorisation*.". They are currently starting up a laboratory where their process will be researched at a lab scale, research that in parallel includes plant designs as well as the large-scale production processes of the biorefineries.

Technical Resource Features

GOA's biorefinery process will extract functional protein and make use of the side streams by producing biogas. The protein is to be used for food applications since GOA deems it to be the application with the highest value and most environmental urgency. The protein content in the isolate extracted from their processes could vary between 40-90% and will be altered depending on what the buyer of the biorefinery wants. Important to note is that the energy intensity increases as the purity increases.

The biorefinery process has for now been tested on 8 different species spanning over all three major seaweed types, brown, red, and green. All have shown promising results but with different protein yields. The extracted protein is in a powder form and is salty with a rich umami taste and has been tested in for example a miso-broth, but it also has gelling properties so it could be used as a thickening agent as well. Depending on what species is used, there might also be other valuable substances that can be extracted, if that extraction is compatible with the production process of protein and biogas. A quote from the interview supports this as: *"... for now we don't have a specific species that we're basing the biorefining process on, once the customer comes with the specific species, we can look at the composition of that species and align our process to the customer's needs".*

In the future, the company aims to sell production facilities for the processing of cultivated seaweed in case wild harvest is found to be harmful to the ecosystem. As for now, GOA is looking into the processing of the brown floating algae Sargassum, which is currently causing problems on beaches in the Caribbean and is now being burnt. The intended volume for an economically viable seaweed biorefinery is around 0,5-1 million wet tonnes per year, but to break even the required amount would be around 10,000-30,000 tonnes per annum (wet weight). It is physically possible to produce biorefineries for smaller-scale production, but GOA sees it as difficult to achieve economic viability.

Since the seaweed will enter the biorefinery fresh, there is a need for the production plant to be located so that fresh seaweed can easily and fast be transported to the facility. This is due to the fact that the protein starts to deteriorate within hours from harvest and has to be transported in seawater to keep it stable for longer. The need to keep the functionality of the proteins is of great importance in this case since the production is for human food. As a result of this, GOA Ventures is primarily looking for their first customers to be based in Asia or the Caribbean to enable adequate logistics while ensuring biomass availability. They are now in contact with potential customers in both locations with the aim for a facility to be up and running within 2-3 years.

Organisational Resource Features

GOA plans to work solely as a producer of biorefinery production facilities and not cultivate their own seaweed, nor sell or produce any ingredients Their strategic plan entails focusing solely on essential research and development (R&D) activities aimed at the development and optimisation of the processes intended for sale. GOA intends to establish close collaboration with its customers and tailor the production site to accommodate their specific seaweed species and desired end products.

In terms of competence required for the buyer of the biorefinery, GOA mentions that the buyer should find suitable offtake partners, with assistance from GOA if needed. Additionally, the buyer should possess an understanding of the intended application of the extracted product in the end product and the desired biochemical properties associated with it. The buyer also must have a solid supply of seaweed, and all other knowledge of seaweed is welcome. GOA will take care of the whole set-up of the turnkey plant, and they also plan to provide training in operating the machines if necessary.

5.3 Other Actors

In the following section, the findings from the interview with a biorefinery of terrestrial crops is presented. In addition, the results from the interviews with the two food developers Solina Sweden and Culinar are summarised.

5.3.1 GroPro

GroPro is a company based in the south of Sweden (GroPro, n.d.). It was founded in 2021 with the idea to *"...make high-quality protein and starch concentrates for the food industry with a unique, environmentally friendly and climate-smart technology"*. The production is located within the facility of Foodhills Fastigheter which aims to create a cluster of large and small food companies where the focus is mainly on sustainable food production and activities in related areas of interest (Foodhills Fastigheter, n.d.).

Technical Resource Features

GroPro is currently producing protein flour from yellow, dried peas through a completely dry biorefinery process. GroPro is working with dried peas because it simplifies the logistics primarily because it is storable, which consequently enables all-year-around production. They chose to focus on the protein flour as a product ingredient, and thus to solely undertake one role in the value chain. The reasoning behind this was to limit the investments to production and not expand to end-product development and distribution. Their process requires around 20% of the energy of more traditional processing and with no harmful chemicals. The main side stream is currently used as feed, and the peels are sold as an ingredient in probiotics. GroPro recognises that the most effective approach for a biorefinery is to initially focus on optimising the process for a single product, then gradually develop more advanced products from the side streams.

Organisational Resource Features

GroPro works with the supplier Foodhills, a company aiming to facilitate pea farming in the south of Sweden. They help interested farmers by supplying seeds, contributing with their expertise, and are responsible for and administering the harvest (Foodhills, n.d.). After the harvest, the peas are transported to the Foodhills production facility in Bjuv where they are quality checked, pre-treated, and packed.

The degree of customer involvement in the ingredient development differs depending on what industry the ingredient will be used in. When the end industry is food, GroPro works closely with their customers (food developers) to develop recipes and in addition, their customer's customers (food producers) to make sure that there is a market need. The food producers are the recipients of the recipes, and they turn them into products, market, and sell them. Furthermore, GroPro is in contact with the food distributors to create a market demand for product development from that side, as well as to ensure that they satisfy the distributor's high standards for energy efficiency and ecological sustainability. In contrast, when the end industry is nutritional supplements, they solely collaborate with their customers due to the lower complexity of the recipes. The most important actors in the initiation of the company were the investors, the CEO’s network within academia, as well as the food producers. GroPro often takes the role of initiating collaborations due to its extensive network.

5.3.2 Solina Sweden

Solina Sweden (Solina) is a part of the global company Solina Group, working business to business with developing future food products by selling spices and functional food ingredients. In the business area of future food and vegetarian products, they tailor dry mixtures for customers with a comprehensive approach to product development. They have the possibility to develop products from start to finish depending on the customer's needs. Solina buys ingredients for use in their production and recipe development, for example, protein isolate. They develop the production process in their pilot plant, to later help implement the production process in the food producer's plant since knowledge about handling this type of new food is lacking in the industry.

Solina describes that the collaboration differs between small companies and big corporations, where Solina often function as the whole R&D department in the first case. Small companies often initiate contact with Solina when they have a raw material which they want help with understanding what types of products and application areas it would fit in. Since large corporations have their own R&D resources and experience in working on projects, they often generate a more refined vision of the product they intend to develop. Furthermore, large corporations most often have their own production plant, while smaller and newly started businesses do not. In these cases, Solina can suggest suitable producers and coordinate the value chain, since they have a large network within the industry.

Solina describes that in general, projects are initiated through the sales department at Solina. When working with start-ups and smaller companies, however, projects can be initiated more organically through the food developers. The product developer and the existing customer often develops a close relationship due to their frequent contact, and further projects can thus be initiated there as well.

5.3.3 Culinar

Culinar is a Swedish food company that offers flavouring to the food industry including product development of customised flavourings and ingredients for the food industry in the Nordic market (Culinar, n.d.). They work solely business to business and develop unique recipes for each customer. Around 80% of their sales are made up of dry blends used for flavouring and function in various foods, and the recipe remains held by Culinar. They collaborate closely with their customers and the development of a new recipe is a collaborative development process. They have about 900-1,000 ingredients in their portfolio and evaluate around 200 new ingredients a year to continually develop the portfolio and service offering.

The customers are food-producing companies and projects are initiated by customers through Culinar's sales department, and they are also collaborating with research institutes like RISE and Vinnova for long-term innovation products. They work closely with their suppliers and have high standards in terms of corporate social responsibility and environmental sustainability.

Culinar is currently working with some seaweed products and has for example developed products together with Nordic SeaFarm. It is possible to incorporate seaweed in their blends as long as the ingredient complies with their high-quality standards and has been approved as a product through their supplier approval process.

6 Analysis

Findings show that there seems to be a predominant focus on the extraction of high-value compounds from seaweed biorefineries. The reason for this is the requirement for economic feasibility, which appears to only be achievable through the extraction of high-value compounds, such as fucoidan. Furthermore, there seems to be a primary interest in going into the pharmaceutical and cosmetics industries with these products, since the product is more suitable for these higher-priced markets.

It was also concluded from the interviews that biorefining as a process varies greatly depending on the substances extracted. Further on, a pure product requires significantly more energy to produce since the process has more sequential steps compared to a less pure product. Most of the seaweed processed today is dry but due to the high energy consumption of drying seaweed, most new generation biorefineries focus on wet seaweed in the long term, awaiting sufficient local supply. For some use cases, essential properties of the seaweed are also lost in the drying process, which can further motivate the use of wet seaweed. However, the use of wet seaweed increases logistical complexity as most biorefineries then need to process the seaweed shortly after harvesting. The time pressure primarily revolves around proteins, as they deteriorate within hours, other compounds like fucoidan over the course of days. However, it is important to note that the specific time constraints vary significantly depending on the biorefinery process and the storing methods employed as well as the intended use in the end products.

All biorefineries express that from an economical as well as a sustainability perspective, they intend to use all components from the biomass in a way that creates as much value as possible. The long-term plan is in most cases to make use of the entire seaweed through a cascading biorefinery process. Due to economic constraints as well as the significant variation in scope between products and customers in different industries, prioritisation is essential when commencing operations. This generally makes biorefineries focus on optimising the process for fewer high-value products initially, to then add products gradually to the portfolio. These high-value products only constitute a small part of the processed seaweed, and when extracting these pure high-value compounds most of the output becomes side streams. Findings from the interviews thus indicate that there is unlocked potential for further development in these side streams. Based on these findings, the following sections will provide further analysis of the results in relation to the theoretical framework presented in Chapter 3.

6.1 Biorefinery Value Chain: From Seaweed to Products

Based on information obtained from the interviews, a general view of the value chain from the perspective of a biorefinery is presented in Figure 4. The value chain starts with the biomass producer supplying the biorefinery with seaweed, according to the specifications made by the biorefinery. The biorefinery processes the seaweed according to the specifications developed with the specific customer or customers. The customer then takes ownership of the products, to process and develop them further either alone or together with the customers' customer. What might complicate the value chain is the extraction of several products which leads to a customer base spanning several industries. This thus leads to the need to understand and be present in several industries and manage a wide range of customer needs. Since the products are developed together with the customer there is also a need to balance the optimisation of the process for the different products according to the different customer needs, which further complexifies the development process. The extraction of additional products from the side streams introduces an added layer of complexity, as it would necessitate expanding the customer base and optimising multiple product streams.

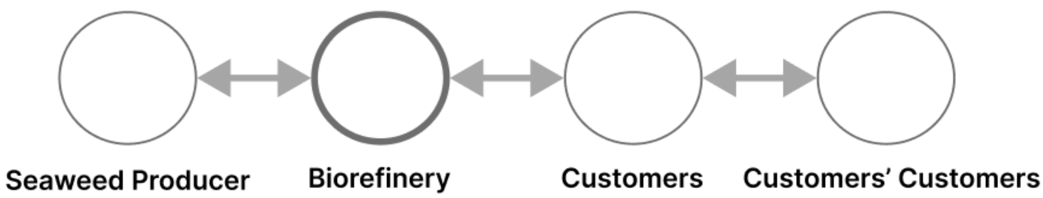

Figure 4. *Representation of the value chain from the point of view of a biorefinery as a production facility.*

In the case of food products, essential actors in the value chain are the food developers and third-party food producers, who both take a crucial part in value-adding activities. For food products, there is also a need to get input from customers' customers (food retailers) as concluded from the interview with GroPro, increasing the complexity further.

6.1.1 Variation in Vertical Integration

The level of upstream vertical integration differs between the different biorefineries ranging from biorefineries that have an in-house supply of seaweed to biorefineries solely focusing on biorefining operations. Biorefineries with an in-house supply of biomass have a high degree of upstream vertical integration. This is supported by the literature on vertical integration since there are relatively few actors working with supplying seaweed, compared to the demand from a biorefinery. In addition, there needs to be a high degree of coordination between activities such as farming and the specialised biorefinery process. This entails close technical collaboration as well as investments in specific equipment making a high degree of vertical integration a suitable option.

However, biorefineries outside of the category of in-house supply have stated that increasing upstream vertical integration through in-house cultivation is too broad in scope and too costly for a newly started biorefinery. Seaweed Scaleup intended to cultivate their own seaweed but deemed it to be non-profitable which is in line with the statements from the other biorefineries. Further on, as the industry is new and market demand might still be uncertain, a full vertical integration might entail too much risk. Among the interviewed biorefineries planning for an in-house supply of seaweed, the plan is to use wild-harvested seaweed. In the case of wild harvest, a high degree of upstream vertical integration can be deemed possible due to the less advanced processes compared to cultivation, as well as less costly investments. Wild harvesting can therefore be seen as less of an economic risk than owning large cultivations. Nevertheless, there is a risk that wild-harvested seaweed could become strictly regulated in the future, making it more difficult for biorefineries with an in-house supply to scale up further.

Developing a biorefinery is heavily research focused with a different scope than the cultivation of seaweed, which motivates less vertical integration. However, one interesting aspect is that all biorefineries highlight the scarcity of biomass available in Europe. Enabling biomass availability for the biorefinery could be seen as a reason for wanting to go into farming simultaneously with biorefining. Nevertheless, the operating biorefineries see that the biorefining of seaweed first must be proven at an industrial scale and that large-scale European cultivation will follow the demand the biorefineries will create. Origin by Ocean sees that some sort of vertical integration can be essential in the early phase of initiating their supply chain, while Oceanium sees that a higher degree of vertical integration is likely to be favourable in later development stages to reduce the uncertainty of biomass availability.

The downstream vertical integration varies as some biorefineries are developing their own products while some leave the product development to their customers. However, no biorefineries observed in this study have their own production of end products. This could be explained by the significant difference in scope between operating a biorefinery and producing end products.

6.1.2 Strong Ties and Collaborations: Key to Biorefinery Success

Due to the specific needs of both the biorefineries and their customers, the relationships with the seaweed suppliers are of great importance. Several aspects of the relationships between biorefineries and seaweed suppliers in the network indicate that strong ties are being developed. One of these indications is the wording used by several biorefineries to describe the current or desired relationship as a “partnership,” indicating a certain level of commitment between the parties in the network. These strong ties are maintained due to the specific requirements posed on the seaweed in terms of species and quality, as well as the varying need for biomass freshness for each specific biorefinery. One way to further establish reciprocal commitments and trust is through standardised supplier packages, which Oceanium has recently set up. Furthermore, the importance of a well-functioning supplier relationships is highlighted by Oceanium, when expressing that the conversations needed with some suppliers that do not live up to the requirements are difficult to handle.

Further on, the biorefineries describe the importance of close customer collaborations. They describe current and future scenarios where co-development, customer-led development, customer partnerships, and offering formulation services dominate product development. Adding to this, their established feedback loops with customers regarding samples, early prototypes, and demonstration of how to use the products in recipes and formulas indicate strong ties with frequent interactions and reciprocal commitments. The ties between the biorefineries and their customers are also strengthened by the need to co-create these relatively new markets for seaweed products to create end customer demand. This co-development and co-creation of products further indicate that working with several customer market segments could be complex and entail organisational difficulties. According to Seaweed Scaleup, increasing the number of products derived from the biorefinery process complicates the process of optimisation. Additionally, if these products are intended for different customers and sectors this could lead to the need to prioritise products and consequently customers. This further enhances the complexity of handling several products. Further on, GroPro and BioMara suggest that focusing on optimising the process for one specific product and initially treating the side streams as a single product may be more manageable.

No evidence of horizontal collaboration was found through the interviews, not in regard to upstream collaboration between farmers nor collaboration between biorefineries in the biorefinery development. This could imply that there are potential missed opportunities to take advantage of the synergies within the value chain, including sustainability benefits for suppliers and reduced R&D costs for biorefineries. The literature suggests that horizontal collaboration may be advantageous for example when transport expenses constitute a significant portion of overall costs, which is the case with the transportation of fresh seaweed.

6.1.3 Supply Scarcity Affecting the Industry

Based on the analysis of vertical integration as well as the need for co–development, there are several implications that the actors in a seaweed value chain must take into consideration regarding their placement in the value chain, specifically in terms of the seaweed supply. It is noticeable that the scarcity of biomass supply in Europe today significantly impacts the decisions made by biorefineries and consequently, how the industry takes shape. The decisions in question encompass a variety of factors such as the selection of the type of seaweed to be processed, determining the sourcing location, specifying the necessary quantity of suppliers, and in some cases, indicating the preferred form of the seaweed, whether it be wet or dry. Currently, the biorefineries are opting to process species of which they can obtain sufficient supply, from the locations where it is available, and from enough suppliers that meet their requirements. These decisions will affect the business and processes of the biorefineries in the long term and could potentially alter their business scope. The decisions being made today, due to the scarcity of seaweed biomass and the uncertainties surrounding it, could thus shape the whole industry long term.

However, the scarcity of biomass implies that seaweed suppliers are in a position to take part in shaping the future of the industry. As the biorefinery companies aim to establish their facilities in proximity to the seaweed production, the availability of an adequate supply could impact both the location and the selection of seaweed species for the biorefinery. Thus, a collaboration between seaweed farmers may provide greater power to influence the establishment of biorefineries, compared to individual efforts. As the literature suggests, an adapted interface between resources (seaweed species and the biorefinery) can be formed that might be difficult to change if they have been combined for an extended period of time. This underscores the importance of influencing the establishment and the adaptations needed early on.

The uncertainties regarding the availability of biomass could increase the probability of biorefineries seeking a higher degree of upstream vertical integration with in-house cultivation. In turn, this poses a future risk where seaweed suppliers get replaced by in-house production of seaweed if the biorefineries expand their scope to go more towards upstream vertical integration in the coming years. To reduce this risk, not only would the total volumes of seaweed need to increase but potentially also the level of cooperation between farmers in terms of species and quality.

As most farms are comparatively small-scale in relation to the volume required by a biorefinery, it is assumed that there is a relatively low level of competition on the farming side, at least until European cultivation advances as the expected demand from the biorefineries increases. Following the presented theories regarding horizontal collaboration, the low level of competition and potential synergies in relation to biorefineries could enable cooperation between farmers. For efficient handling of supply and demand via many farmers, some sort of consolidation of biomass would then be favourable for the supply chain, in terms of communication, transportation, and storage. Another possibility to increase horizontal collaboration among farmers could be through the establishment of a seaweed cooperative. A cooperative could strengthen the individual farmer’s position in the probable scenario that European cultivation rapidly expands. Further on, the total production of larger volumes could motivate the setting of industry standards for seaweed in Europe, through certifications and quality assurance measures. Regarding food products, these standards could potentially help seaweed become a more accepted part of European food consumption.

6.2 Key Resource Features and Interfaces

Drawing on the 4R model, together with the presented results and analysis of the value chain, some critical resource features and interfaces have been identified. Key resource features of seaweed are volume, form (wet or dry), species, and quality, which are also related to how fresh the seaweed needs to be. These features are critical since they enable efficient and economical processing of seaweed in the key production facility, the biorefinery. The technical features of the biorefinery are all adjusted to fit the seaweed, as well as to extract the desired products. The identified technical resource features for the biorefineries as well as for Nordic SeaFarm is presented in Table 2. Other key resource features in the value chain are the features of the business relationships. These relationships are characterised by collaborations and interdependencies. Of particular significance are the connections between the biorefinery and its customers, given that the biorefinery process is contingent on this relationship, and is determined by the specifications of the product that the customer desires.

Table 2. *Key technical resource features for the biorefineries and Nordic SeaFarm.*

Company	Current volume[1]	Long term volume [1]	Species	Form	Cultiv.[3]/ Wild H.[4]	Biorefinery Product Focus	Primary end products
Nordic SeaFarm	100	10,000	Sugar kelp, Sea lettuce	N/A	Cultiv.	N/A	Food
Alginor	5000-30,000	X[2]	Tangle	Wet	Wild H.	Alginate, fucoidan, protein	Pharmaceuticals, cosmetics
Goa Ventures	N/A	0.5-1 million	TBD	Wet	Cultiv.	Protein, biogas	Food
BioMara	N/A	TBD	TBD	Dry	Cultiv.	Fucoidan	TBD
Origin by Ocean	100s	100,000	Brown species	Wet	Cultiv.	Alginate, fucoxanthin, fucoidan, mycosporin	Pharmaceuticals, cosmetics, food, textiles, packaging, agriculture
Oceanium	100-350	20,000	Brown species	Wet	Cultiv.	Fucoidan, beta-glucan, fibre, protein	Cosmetics, nutraceuticals, food
Seaweed Scaleup[5]	6000	X[2]	Brown species	Wet	Cultiv.	Alginate, protein, fucoidan	Food

[1]*Volume: Wet tonnes*
[2]*X: Not concluded from the interviews.*
[3]*Cultiv.: Cultivated seaweed*
[4]*Wild H.: Wild harvested seaweed*
[5]*The scope of Seaweed Scaleup recently changed, due to economic infeasibility in their business case. The data in the table is based on their business case.*

Resources and resource interfaces that are crucial to be able to take part in the network are presented in Figure 5 and later analysed in the text. The key concerns of the food developers have been incorporated into the model, as well as the notions made by the pea biorefinery.

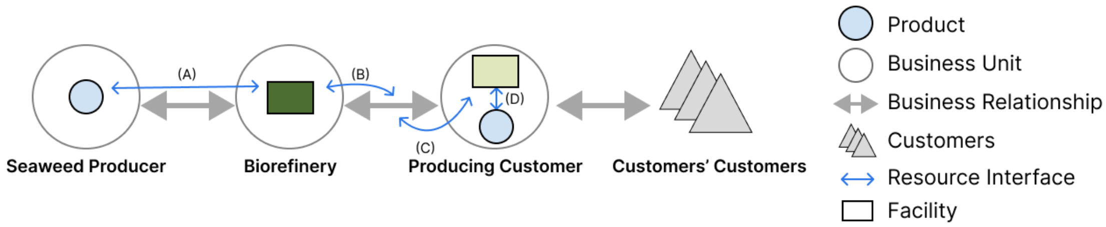

Figure 5. *A model representing key resource interactions from the perspective of a biorefinery.*

(A) The resource interface has several features: The species of seaweed, the volume, and the quality of the seaweed. These features all determine the success of the biorefinery process as a producing resource and the output from it. This interface is also dependent on requirements on freshness of the seaweed. This, in turn, depends on where the seaweed grows, as well as the distance between the biomass harvest and the biorefinery.

(B) The output products from the biorefinery and their biochemical properties are determined by the biorefinery process. The process is in turn determined by the biorefining company in collaboration with its customers.

(C) The business relationship between the biorefining company and its customers also decides the molecular properties of the products since it affects what end products the customer can produce. In addition, this depends on the customer's production facilities and their capacity, as well as what type of industry the customer is in and what they want to produce.

(D) The end product depends on the technical aspects of the production facility as a producing resource, such as capacity, and what other input products are used.

7 Discussion

In the following chapter three potential roles that Nordic SeaFarm can take on in the upstream value chain will be presented and discussed. These roles are as a contractor-based supplier of seaweed, a consolidator of seaweed, or as a member of a seaweed cooperative. An additional possibility of undertaking a role downstream in the value chain, as a developer of side streams or protein from a biorefinery, for the production of food, is thereafter presented. The potential roles are thereafter discussed and compared in terms of feasibility and chronology. Thereafter, the strategic partnerships that would become important for the different roles are discussed, as well as the identified overarching challenges and uncertainties of the industry.

7.1 Nordic SeaFarm's Potential Roles in the Value Chain

Based on the analysis, three potential roles that Nordic SeaFarm can take on in the upstream value chain have been analysed. The roles have been developed to fit one out of the three biorefinery categories previously discussed. Further on, the scenarios were developed with a base in Nordic SeaFarm's vision of not simply becoming a biomass supplier but taking on a greater role in the value chain. Taking on a greater role upstream could potentially limit the threat of biorefineries engaging in cultivation activities, as a result of uncertainties regarding biomass supply. However, taking on several parts of the value chain would require vast investments, as per learnings from GroPro. Partial integration can be an alternative for less complexity as well as less investment if Nordic SeaFarm continues to be interested in owning the end products.

With a base in the 4R model, three hypothetical future scenarios for upstream value chain engagement have been constructed, where Nordic SeaFarm takes one of three fundamentally different roles in the supply chain. The role depends on the scope of the biorefinery and could be categorised as a contractor-based supplier of seaweed, as a consolidator of seaweed, or as a member of a seaweed cooperative. The presented models are to be viewed as exceptional cases, highlighting the fundamental differences between the roles. Further on, a hypothetical future scenario where Nordic SeaFarm undertakes a downstream role as a developer of side streams or protein from a biorefinery, for the production of food, is presented. The models have been generalised to fit a future scenario where new players have entered the market. Hypothetical interfaces, business relationships, and business units are represented in the models by dashed lines, and the ones already in place today are represented by solid lines.

7.1.1 Contractor-based Seaweed Supplier

The way Nordic SeaFarm can be incorporated into the resource network of a biorefinery with an in-house supply of biomass is based on the premise that S. latissima is found to have equal or superior properties over the in-house supply regarding high-value products. In addition, Nordic SeaFarm would need to produce sufficient volumes as biorefineries suggestibly require a minimum of 100 tonnes for a single week of production. Nordic SeaFarm's current annual production is 100 tonnes annually, while their long-term objective is a scale of 10,000 tonnes. Given these considerations, Nordic SeaFarm could supply the biorefinery with S. latissima in a contractor-based capacity. This scenario would require establishing a relationship with a biorefinery for exploring new opportunities and participating in the resource network, with continuous interaction needed to adapt the biorefinery process, cultivation, and harvesting. The future possibility where Nordic SeaFarm is a contractor-based supplier is presented in Figure 6, with connected resource interfaces described below.

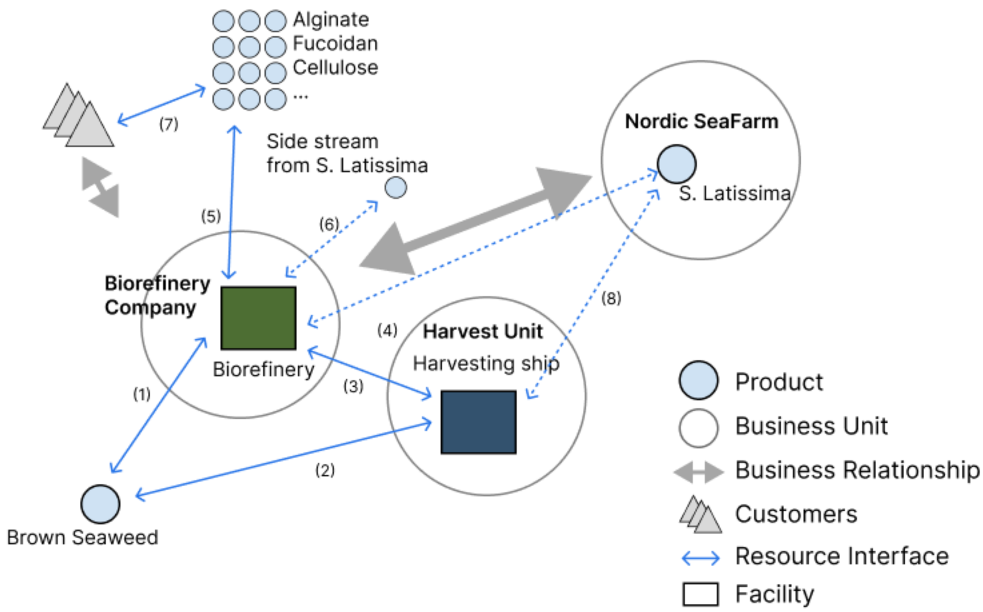

Figure 6. *A model representing a resource network with Nordic SeaFarm as a contractor-based seaweed supplier.*

(1 & 4) Brown seaweed is in this case referring to one specific species, which might differ depending on the biorefining company. Depending on if the biorefining company focuses on wild harvest or cultivated seaweed the seaweed as a product would be in or outside of the business unit. In **(4)** there is also an organisational aspect to consider since the biorefinery process could need to be adjusted for the species S. Latissima.

(2, 3 & 8) The harvesting unit affects the technical features of volume and freshness since it needs to be coordinated with the harvesting period of the seaweed and the technical aspects of for example the speed of the vessel as well as how much seaweed one vessel can carry.

(5 & 6) As previously stated in section 6.2 the type of products and their properties are determined by the biorefinery process. **(7)** The customers take part in deciding the molecular properties of the products and the product volumes affect which end products can be produced to ensure economic viability. **(6)** The biorefinery process also determines the volume of side streams, and properties such as flavour, texture, purity and if it is edible.

7.1.2 Consolidator of Seaweed

The most direct approach for Nordic SeaFarm to work with an operating biorefinery would be to function as one of several seaweed suppliers, which can also be seen as the most immediate option. However, the need for large volumes of biomass and in consequence many seaweed suppliers per operating biorefinery entails logistic challenges. The volume suggested is a minimum of 20,000 wet tonnes per year, which is more than Nordic SeaFarm long term goal of 10,000 wet tonnes per year. The large volumes suggests that an upstream intermediator, who could function as a consolidator of supply as well as a single point of contact connecting farmers and biorefineries would be beneficial for an efficient value chain. As mentioned in section 3.3, when market demand is uncertain, there is a risk to have a high level of vertical integration. It may then be more appropriate to act as a consolidator rather than owning and operating extensive farming activities. To facilitate an expansion of scope and become more than a commodity supplier, Nordic SeaFarm could potentially undertake the role of a seaweed consolidator. This role would be similar to the role of GroPro’s supplier of peas, Foodhills, which also works towards building a cluster for the development of future foods. The role would thus include building a cooperative organisation, consolidating volume from other farmers as well as cultivating their own seaweed. Establishing a consolidator role for Nordic SeaFarm would require an efficient collaboration with other seaweed farmers, necessitating networking to explore the feasibility and new opportunities. Successful implementation could create a local seaweed cluster, facilitating further development and attracting new actors to the area.

This scenario is built with the background of Nordic SeaFarm aiming to be a central part of the value chain and a facilitator for the growing seaweed industry. An additional advantage of this scenario is that they could potentially help form certifications for seaweed. This could in turn be advantageous since they could then take part in setting standards and influencing the industry. Further on, the consolidator role could entail setting up contract farming with other seaweed farmers. In this scenario, Nordic SeaFarm could be a buyer of the side stream from the biorefinery, for the production of food, which will be discussed in 7.1.4. The future possibility where Nordic SeaFarm is a biomass consolidator is presented in Figure 7, with connected resource interfaces described below. The model has many aspects in common with the previously presented model for contractor-based supply (Figure 6), and only the differing aspects will thus be discussed in this section.

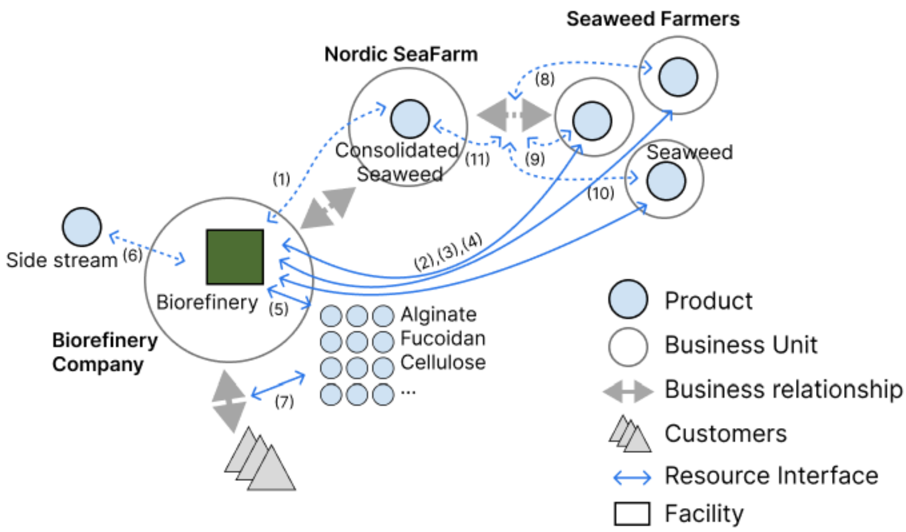

Figure 7. *A model representing the resource network with Nordic SeaFarm as a consolidator of seaweed.*

(2-4) As of today, the seaweed is sourced from multiple farmers since there is currently no large-scale cultivation in the EU and scaling up wild harvest could lead to environmental sustainability issues. The properties for the technical interfaces suggested by the two further progressed biorefineries are a minimum volume of 20,000 wet tonnes, several to all types of brown seaweed, and preferably the processing of wet seaweed. These technical features of seaweed are essential for the efficient processing of the product in the key production facility, the biorefinery. Efficient processing also requires several organisational features such as coordination of the different farms to produce high-quality seaweed and seaweed that is similar enough to not require adaptation of the biorefinery process. In addition, the transportation of the seaweed and the logistics affect both the freshness and volume. In the future scenario of Nordic SeaFarm taking the role of a biomass consolidator, the interfaces **(2-4)** are replaced by the consolidated seaweed supply, **(1)**.

(8-11) The coordination of the cultivated seaweed would be done by Nordic SeaFarm, working as a consolidator for the seaweed supplied to the biorefinery. The role of a consolidator requires the coordination of the farmers, the species produced, and the quality of the seaweed. Another possible role could be to contribute towards the certification of seaweed and collaborate with the biorefining company to establish quality standards. The properties of the seaweed all depend on what is decided through the business relationship between Nordic SeaFarm and the other farmers, through supplier packages and similar contracts.

7.1.3 Member of a Seaweed Cooperative

Several types of biorefineries mention that setting up new biorefineries through partnerships at locations where there is enough biomass is a goal for the future. However, high-value products for pharmaceuticals and cosmetic industries are deemed to be out of the scope of Nordic SeaFarm. Therefore, only a biorefinery producing protein for food is considered in this scenario. The biomass volume required for an economically viable biorefinery of this type is suggested to be 0.5 million wet tonnes per year, which is significantly more than Nordic SeaFarm's long term goal of 10,000 tonnes. Given the large biomass volumes required, the establishment of a hypothetical business unit, "Seaweed Cooperative", can be seen as a future scenario. The seaweed cooperative would involve a partnership among farmers to acquire the required volume of biomass as well as to secure the substantial investments needed to procure a biorefinery from a biorefinery solutions provider. A successful establishment of a seaweed cooperative would require tight collaboration between its members, as well as a collaborative partnership with a biorefinery provider, to enable the procurement and development of a viable biorefinery.

In this scenario, Nordic SeaFarm could be a buyer of protein from the biorefinery for food production, which goes in line with their aim to continue to work in the food sector. This possibility will be further described in section 7.1.4. The scenario is likely to be a long way off, partly because of the significant investment required to set up a biorefinery, and partly because the only biorefinery supplier identified was at an early stage of development and was not targeting the European market. Figure 8 has many similarities to the previously analysed models (Figure 6-7), thus only the differing aspects will be discussed.

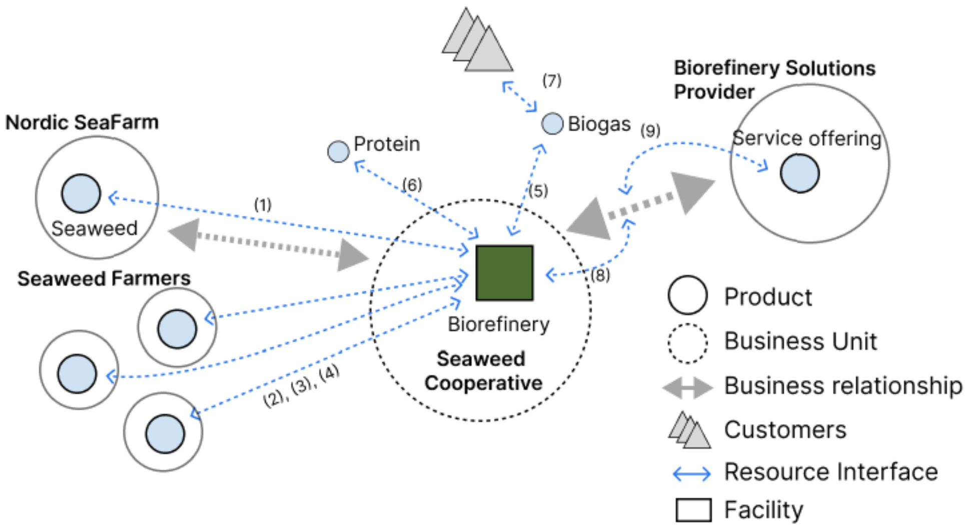

Figure 8. *A model representing the resource network with Nordic SeaFarm as a member of a seaweed cooperative.*

(1 - 4) The large volumes required, a minimum of 0.5 million tonnes, indicate that several actors need to combine their seaweed resources creating the seaweed cooperative. The time constraints posed by the need to process the seaweed within a few days also puts pressure on the organisational coordination and logistics.

(5 & 7) The production of biogas could presumably be used for running the biorefinery, and potential excess sold to an end consumer. The production of biogas, however, would not be the main business of the biorefinery cooperative and rather a side stream from the production.

(8) The service offering in this case is specified for the purpose of the biorefinery owner. **(9)** In turn the features of the biorefinery, both technical and organisational depend on the relationship between the seaweed cooperative and the provider of biorefinery solutions. The dependent technical features are the biorefinery process, but also its capacity and location. The dependent organisational features are the operational knowledge required, which the provider of biorefinery solutions could accommodate, and in addition the close collaboration in the development process.

7.1.4 Downstream Coordinator

To expand its scope in the future, Nordic SeaFarm has the potential to function as a downstream coordinator of side stream or protein valorisation, for the production of food. The foundation for this role lies in Nordic SeaFarm's primary interest in establishing their position in the food industry, rather than in pharmaceuticals or cosmetics. This is further motivated by the fact that going into cosmetics and pharmaceuticals would require heavy research and additional resources since it differs significantly from Nordic SeaFarm’s current scope. As the complexity increases when more products are added to the portfolio as the management of tight collaborations in several industries is presumably time- and resource-consuming. In addition, since Nordic SeaFarm is currently focusing on the food industry, relationships have already been established and further expansion within the industry suits their current scope. This scenario could be advantageous for the biorefinery since they could then exclusively focus on optimising their process for few high-value products for the pharmaceutical and cosmetics industry. Adding to this, it would assumingly be less challenging for the biorefinery to limit the customer base to a few industries. It could thus be beneficial to exclude the food industry and eliminate the need to develop relationships there.

The downstream role is derived from the discovery that there might be untapped potential in the biorefinery side streams. Developing food products is further motivated since it could be an opportunity to reach a relatively unexplored market since that market is not currently prioritised by most biorefineries. However, this would require a strategic fit between the biorefinery and Nordic SeaFarm since the biorefinery would opt out of the side stream product development. In the scenario of buying protein, the ambitions have to align with the other companies in the seaweed cooperative. The scenario of Nordic SeaFarm buying and developing food from the side stream, or protein, from a biorefinery is presented in Figure 9, with connected resource interfaces described below.

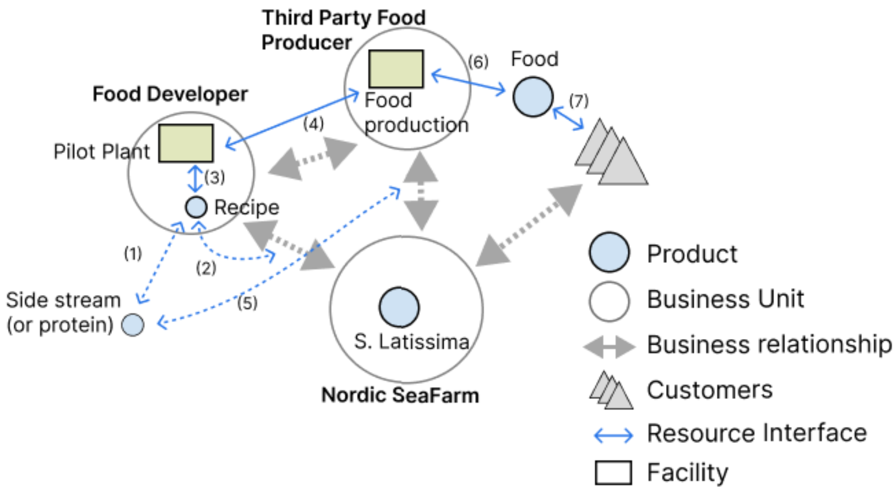

Figure 9. *A model representing the resource network for the development of side streams.*

The biorefinery process determines the volume of side streams, and properties such as flavour, texture, purity, if it is edible, and if some unwanted compounds need to be removed through further processing. The economic value of the side stream is also determined here since this would be the product sold to Nordic SeaFarm. **(1)** The properties of the side stream in turn decide the taste of the product, what could be produced from the side stream, the recipe, and how much seaweed a food product would contain.

(2) Input from Nordic SeaFarm regarding the type of end product they would want to produce combined with expertise from the food developer determines the recipes developed. **(3)** In line with what was said in section 6.2 the technical aspects of the pilot plant affect the recipe development since production has to fit with existing equipment, thus limiting the development process to certain food categories.

(4) A mixed interface involving the education of third-party producers on how to produce the new product in their facility. Technical aspects regarding the processing equipment available at the third-party producer are considered when testing in the pilot plant, for easier upscaling.

(5) The volume of the side stream decides which third-party food producers Nordic SeaFarm would be able to work with. Large food producers require large production volumes.

(6 & 7) The properties of the food (end product) depend on the technical aspects of the production facility as a producing resource such as capacity and what other input products are used. The type of food that is produced additionally dictates the customer type to prioritise, and conversely, the customer type also influences the choice of food to offer.

7.2 Key Considerations: Timing and Uncertainty

Since the seaweed biorefinery value chain is in its infancy and future large-scale success has yet to be proven, one challenge is to anticipate in which capacity Nordic SeaFarm will most successfully operate. Due to the early stage of the value chain and the uncertainties that come with it, the timeline as well as timing connected to the different scenarios presented in the previous section becomes an important topic of discussion.

The scenario that seems most immediate from Nordic SeaFarm's perspective is the role of a contract-based supplier. This would require the least investments and could be done without scaling up production. Solely supplying on a contract basis would be suitable if Nordic SeaFarm limits its scope and ambitions regarding its position in the value chain. However, tests have to be done on S. Latissima to ensure that it is a suitable species for a specific biorefinery. For Nordic Seafarm to adhere to its aim of operating in the food sector, significant research would have to be done on the side streams to ensure they are suitable for food production. For example, ensuring that unwanted components such as high iodine contents, and other non-essential harmful elements are limited or removed. The stability of the components in the seaweed side streams must also be investigated to find what restrictions in terms of storage and transportation are present. Due to the instability of proteins in seaweed, this aspect holds considerable significance as it directly impacts the subsequent development of the side streams. Further on, energy intensity of the purification of the side streams needs to be researched, as that is found to be an important aspect of the economic viability. Research should be done through partnerships with research institutes or universities but would require substantial organisational efforts to align the collaborating partners. On this note, it would also require significant collaborations with food developers, like Culinar or Solina, to ensure an economically viable, well-tasting, and attractive product. Nevertheless, if these collaborations and developments prove to be fruitful, Nordic Seafarm is in a good position to also work as a consolidator of seaweed to be able to start scaling up production and begin expanding its network of suppliers.

If a network of suppliers has been effectively established, then assuming the role of a consolidator to further facilitate the scaling up of the cultivation of seaweed may prove to be a feasible option. Subsequently, Nordic Seafarm could undertake a more central and organisational role within the network, thereby enabling the formation of a seaweed cluster generating sufficient supply. In the long run, this could also attract biorefineries to set up a biorefinery on the west coast of Sweden through the development of strategic partnerships with biorefining companies aiming to establish themselves in new locations.

Another option rather than being a consolidator is the scenario presented in 7.1.3 where a seaweed cooperative would be established to accumulate biomass and the possibility to share investments. The scenario described is potentially the furthest away in terms of time, primarily because of the reliance on biorefinery solutions providers to advance further, the large investments required and the significant volume requirements. The biorefinery solutions provider approached in this study is currently not considering the establishment of a biorefinery in Europe, which would require other actors to enter the market or a shift in focus from the current provider. In the event that another actor was to enter the market the scope of that biorefinery solutions provider, specifically what type of biorefinery they can offer, is of significance. It must align with the scope of Nordic Seafarm, which aims to extract food ingredients rather than the most high-value compounds, limiting the pool of potential providers. In the event of a seaweed cooperative being established, Nordic SeaFarm could potentially still take on a role as a consolidator of seaweed since coordination would be required in this scenario as well.

7.3 Navigating Strategic Relationships

From Nordic SeaFarm's point of view, an important relationship to establish in the contractor-based scenario would be with a biorefinery. A relationship with a biorefinery would be needed to explore new opportunities and take part in the resource network, which would be the objective of Nordic SeaFarm initiating the relationship. The relationship would presumably require interaction on a regular basis since adaptations might have to be made to the biorefining process as well as cultivation and harvesting practices. An important aspect to consider is that the ambitions of the biorefinery must be in line with Nordic SeaFarm's ambition regarding food development, to enable procurement of the side streams. If S. latissima would be proven to have advantageous properties over the available biomass, the reciprocal commitment and interdependence would possibly increase, since it could motivate the biorefinery to modify its biorefinery process to process the species more efficiently.

An important relationship in the scenario of consolidation is, like in the previous scenario, with a biorefinery since the consolidation of seaweed must align with the demand from the biorefinery. In addition, the role of becoming a consolidator would have to evolve together with a biorefinery in close collaboration, ensuring that the quality criteria of the seaweed are met. Potentially, this could strengthen the relationship between Nordic SeaFarm and the biorefinery through mutual adjustments, which could possibly tie the two parties to each other long term. This could possibly augment the influence of Nordic SeaFarm in the value chain.

If a consolidator role is established, the relationship between Nordic SeaFarm and other seaweed suppliers would become of great significance, as possible synergies between farmers are explored. Taking a consolidator role would require the management of efficient collaboration, which could include logistics, transportation, and consolidation, as well as quality assurance and the setting of standards. For the successful implementation of a consolidator role, networking with other farmers becomes important since this could help explore the feasibility of such a goal and new opportunities. These relationships would presumably entail reciprocal commitments and frequent contact as conformance is of importance. As previously mentioned, the consolidator role and the ties with other seaweed farmers could possibly unite and align farmers on the west coast of Sweden and create a local seaweed cluster, similar to the cluster surrounding GroPro. This could then further attract biorefineries in the long term, through strategic partnerships where the consolidator could initiate collaboration with a biorefinery by offering a sufficient supply of seaweed. The opportunity of a biorefinery being established nearby could in turn motivate seaweed farmers to take part in the cluster and scale up production. This goes in line with the view of several biorefineries stating that they will drive seaweed demand.

In the scenario that a seaweed cooperative is established, the cooperative would be the enabling factor for procuring a biorefinery. The relationships within the cooperative would thus be of high significance. For the cooperative to work, trust, frequent contact, and a high level of commitment from all parties would be required. A well-functioning relationship between the cooperative and the provider of biorefinery solutions would also be essential since they would be offering their expertise as well as developing the biorefinery according to the cooperative's needs.

To take on the downstream role as a coordinator of side stream valorisation, establishing or extending current relationships with one or several food developers and food producers is critical. Resource features among such actors and their products would need to be combined and adapted from seaweed to end products, extending the models presented in 7.1.1, 7.1.2 and 7.1.3 with additional resource interfaces presented in 7.1.4. These would be the actors adding value to the side stream through recipe development and further processing. This triadic relationship entails frequent contact and reciprocal commitment in the product development phase. Perhaps even more importantly, partnerships with universities and research institutes for the development of the side stream into a suitable food ingredient need to be established. Without such collaborations, it would not be feasible to create a product with the food developer.

7.4 Industry Challenges

An overarching theme throughout the interviews as well as in the initial literature review on seaweed biorefining is the sustainability aspect of the industry. All interviewed companies have sustainability as a core driver of the business but differ in their definition of sustainable operations. One aspect of this is the decision on using wild harvested or cultivated seaweed. A majority of the respondents claimed that the amount of seaweed required for a biorefinery cannot be sourced through wild harvest in a sustainable manner. However, others are concerned that the impact of large-scale cultivation on the marine ecosystem is still unknown, and that other potential sustainability issues connected with large-scale cultivation such as plastic pollution and the risk of diseases need to be considered. Ramping up cultivation also means that it has to be done offshore, meaning more pollution from non-renewable fuels. Thus, only working with seaweed and the biorefining of it does not guarantee sustainability, as many aspects have to be considered and the environmental impact of seaweed cultivation as well as wild harvest seem unclear.

A major challenge for the European seaweed industry is the scarcity of biomass. This scarcity also has an impact on the sustainability of the industry, as biomass currently has to be transported long distances within or into Europe, increasing transport pollution and energy consumption for drying processes. Most biorefineries raised the issue of biomass scarcity, although they expect that the cultivation of seaweed in Europe will expand in proportion to the rising demand. However, if it does not scale sufficiently, if large-scale offshore cultivation proves to be difficult, or if wild harvested seaweed experiences regulations, the course of action for European biorefineries remains uncertain.

Other challenges include the premium price of European biomass and the vast investments and costs associated with the development, procurement of machinery, and operation of a biorefinery. There is concern that the price of biomass will have to decrease considerably, which would be directly linked to the scaling up of cultivation. The development of biorefineries is currently carried out by individual companies in collaboration with academia, with funding from the EU and various private or public actors, and the processes often end up being protected by expensive patents. In addition, the processes have yet to be proven on a large scale. Adding to these challenges regarding the novelty of the industry are the concerns raised in 4.3, concerning the need for investments and general interest in biorefining of seaweed has to stay high for the industry to succeed long term. These are all aspects that a company seeking to enter the market has to take into consideration.

8 Concluding Discussion and Recommendations

From what is discussed in the previous chapter, the current chapter will put forth suggestions for Nordic SeaFarm and present a concluding discussion regarding the future of the seaweed biorefinery industry. Potential risks and opportunities for Nordic SeaFarm will also be presented along with recommended topics for future research.

8.1 Recommendations

As a starting point, it is recommended that Nordic Seafarm establishes a collaboration of a contractor-based nature with a biorefinery to secure a large customer which in turn enables expansion of the production. Moving forward, it is advisable for Nordic SeaFarm to pursue a collaborative partnership with a biorefinery that is prepared to opt out of the ownership of its side streams. Concurrently, Nordic Seafarm should find partners in research to test and develop the biorefinery side streams to produce food products. This would provide a preface for product development and testing as well as provide access to a larger network and possibilities through the weak ties established. Building on this foundation, it would be possible to further expand the network to include other farmers. As the anticipated demand from seaweed biorefineries increase, the potential for assuming a consolidating role would also increase. The consolidating role would as previously mentioned enable taking on a more central role in the value chain which could tie both biorefineries and farmers to a certain process and value chain network. In conclusion, the recommended strategy is a mix between the scenarios presented in 7.1.1, 7.1.2 and 7.1.4 but taken in subsequent steps to organically expand their scope and initiate relationships with relevant actors.

An important aspect to consider is the potential risk of solely focusing on the side streams, given that the biorefinery's overarching objective is to minimise by- products to a negligible extent in the long-term leading to a potential conflict of interest between Nordic Seafarm and the biorefinery. However, supported by the presented theories regarding resource interfaces, the longer resources have been combined the greater the probability that they have been closely adapted leading to a strong interface which can be difficult to break. This would support the recommendation that Nordic Seafarm would establish a role as a consolidator who also buys the side streams early in the network development, to be able to tie actors to each other long term.

Cultivation of seaweed is as previously mentioned not done at a large scale in Europe today, which leads to uncertainties from a sustainability perspective. However, since there are uncertainties also regarding wild-harvested seaweed and the potential regulatory landscape it faces, expanding the role of seaweed beyond farming could prove advantageous and mitigate risks. There is also a risk of focusing on the food market due to the numerous regulations regarding the production of food in relation to its quality and composition. This is why the scaling should be done gradually to ensure feasibility prior to committing to substantial investments.

Further on, timing is an important aspect to consider for Nordic Seafarm since it poses another layer of uncertainties. Entering a new market poses many difficult decisions regarding selecting suitable partners and determining when to initiate such collaborations. The fact that it is an emerging value chain further entails uncertainties regarding what companies will succeed, making timing an important yet difficult aspect to consider. It is therefore recommended that weak ties are established with numerous actors in the industry to gain insight regarding network development and to mitigate the risk of investing in a relationship with an unsuitable actor. This would also entail Nordic SeaFarm's involvement in shaping the future of the industry and facilitating appropriate timing.

8.2 Future research

Drawing on the premise that side streams hold untapped potential and could offer solutions to the anticipated challenges in food supply, it is imperative to conduct additional research into the utilisation of side streams for food development. Due to a fast-evolving industry, it would be of interest to comprehensively investigate the management of collaborations and resource networks again in a few years' time, to investigate the development of the industry. Further on, it would be interesting to follow the interviewed companies and potential new actors in a longitudinal case study, to keep track of developments and setbacks within the industry. Since the study shows that biorefineries develop their own biorefining process, it would be interesting to investigate if there could be possible horizontal synergies for the biorefineries in the R&D phase, for faster and cheaper development of optimal processes. This could be researched through the lens of theories regarding open innovation and knowledge sharing. Additionally, to ensure that the industry is environmentally sustainable more research needs to be done on the impacts on the ecosystem due to large-scale cultivation and wild harvesting. Since the thesis shows that it is important to consider the resource networks and that relationships and resource interfaces are shaping the industry, triads between seaweed farmers, biorefineries and product developers could be an interesting topic for future research.

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Appendix 1

Interview guide – Biorefineries

- What is your role within the company?
- Can you tell us about the history of the company, why and how it started?
- Which actors would you say were or are the most important in starting up?
- Can you tell us how the progress of the company is to date?
- Is your plan to start a plant of your own, or sell production facilities?
- What industries are you currently aiming for?
- What products from seaweed do you see the most potential in?
- Do you have any plans to make products for the food industry?
- Will you use cultivated or wild-harvested seaweed?
- How much seaweed are you planning on processing?
- In what form will the seaweed be processed? (Wet/dry)
- What species of seaweed are you developing the biorefinery process for?
- How do you work with your customers/suppliers when developing your product and biorefinery processes?
- How do you envision the development of the company in the coming years?

Interview guide - Food Developers

- What is your role within the company?
- What does the process look like from when a company approaches you to create a new product until the finished product reaches the market?
- How long does it usually take?
- Who usually initiates collaborations when it comes to the food of the future?
- When in product development does the company come into the picture? How early in the value chain?
- What is your role in the value chain? How does Solina contribute to bringing new products to the market?
- What is the relationship with your customers? To food producers?
- Who are your customers? What does the value chain look like?
- How does your role change if it is an unprocessed raw material, or if it is, for example, protein produced in a biorefinery?
- Do you work with any seaweed products today?
- Which end products from seaweed do you see the most potential in? Which ingredients from seaweed?
- What volumes are required for a product developed by you, for it to be economically viable?

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