Addressing Challenges to Nearshore Macro-Algae Cultivation in Germany and the Netherlands

Barbara Katherina Thurnay (S4904583)

Campus Fryslân, University of Groningen

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M.C. (Tim) Huiskes

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Abstract

Macro-algae can have numerous ecological and social benefits (e.g., carbon sequestration, de-acidification, oxygenation, employment). As macro-algae cultivation is slowly gaining traction in Europe, it is crucial to understand the obstacles the sector is facing to ensure sustainable and commercially viable seaweed production in Europe. After a literature review on challenges to seaweed cultivation, I conducted eight interviews with key informants of the Dutch and German macro-algae sector to understand the biggest perceived challenges, existing support and useful practices, and proposed measures. The main challenges to sustainable, commercially successful seaweed cultivation in Germany and the Netherlands are the lack of demand and visibility, knowledge deficits, and licensing difficulties. The sector is receiving support in terms of finances and information. Useful practices are collaboration, the trial-and-error mindset and long-term thinking. The main proposed measures are optimization and standardization, and increasing visibility as well as funding. A subsidy offsetting the currently high cultivation costs could help bridge the demand gap alongside strategies for increasing the visibility of seaweed for policy-makers, industrial customers, and consumers. Licensing should eventually be streamlined.

Keywords: seaweed, macro-algae, cultivation, Germany, the Netherlands, Europe, regenerative aquaculture.

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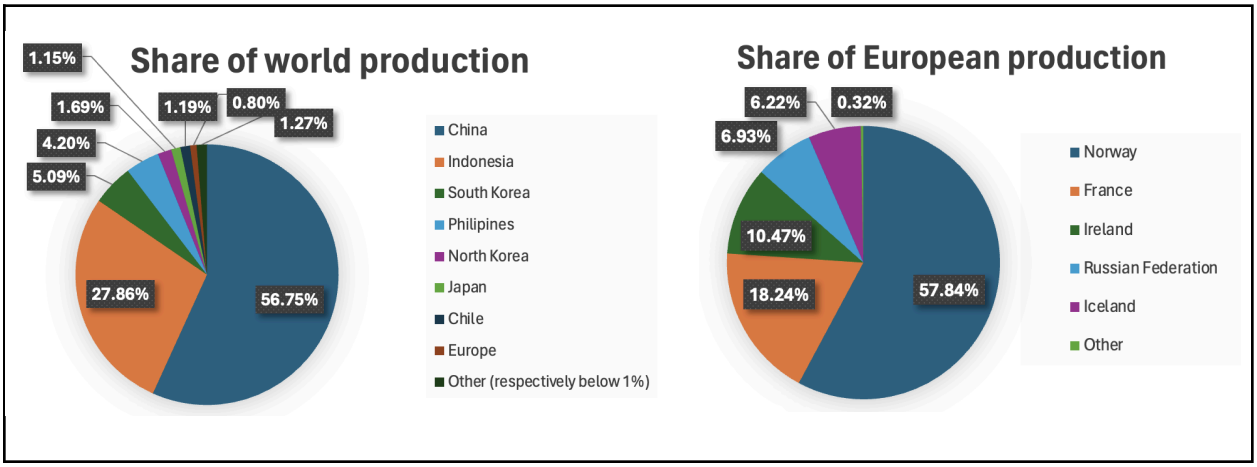
Table of Contents

In the past few years, interest in macro-algae cultivation has been growing in Europe (Kraan, 2020). As recently as February 2024, over twenty algae species were added to the EU Novel Food Status Catalog, meaning they can be sold as food or food supplements in the European Union (DG MARE, 2024). However, currently, almost all macro-algae aquaculture comes from Asia (Duarte et al., 2021). Europe is only responsible for 0.8% of macro-algae production (see Figure 1) with a total algae turnover of €350 million in 2018 (Kuech et al., 2023), which amounted to 300,000 tons of fresh-weight seaweed (North Sea Farmers & Bronswijk, 2021). In the same year, the Netherlands alone harvested 910,000 tons of tomatoes (Statista, 2021). Yet, locally grown seaweed is crucial to satisfying European demand, as macro-algae worth €554 million were imported in 2016.

Figure 1

Pie charts on seaweed productions shares, world-wide and within Europe (2019)



Note. Own work using Excel. Data from “Seaweeds and Microalgae: An Overview for Unlocking their Potential in global aquaculture development,” by Cai, J., Lovatelli, A., Aguilar-Manjarrez, J., Cornish, L., Dabbadie, L., Desrochers, A., Diffey, S., Garrido Gamarro, E., Geehan, J., Hurtado, A., Lucente, D., Mair, G., Miao, W., Potin, P., Przybyla, C., Reantaso, M., Roubach, R., Tauati, M., & Yuan, X.. 2021, *FAO* (No. 1229), 2 (https://doi.org/10.4060/cb5670en).

European seaweed is vital for Europe due to biosecurity concerns with Asian cultivation (Ward, 2019; Sugumaran et al., 2022), and the need to reduce transport emissions in an age of anthropogenic climate change (IPCC, 2022). Considering demands for mitigating and adapting to climate change, local production is rising to new prominence.

Algae are photosynthesizing organisms, they absorb carbon dioxide and release oxygen (Pereira, 2021, p. 177). There are micro-algae (only visible through a microscope) and macro-algae (which, depending on the type – red, green, or brown – can be over 50m long). As of 2020, 11,017 species of macro-algae had been discovered (Stiger-Pouvreau & Zubia, 2020). I will use the terms macro-algae and seaweed interchangeably, as they mean the same thing. Seaweed cultivation can be done in three different settings: (a) offshore, (b) nearshore, and (c) on land (Zhang et al., 2022). This paper focuses on nearshore seaweed cultivation as plans for offshore farming are not commercial yet (North Sea Farmers, n.d.) and on-land cultivation has been critiqued for utilizing scarce land and water resources (Zhang et al., 2022). Hence, this paper is centered around nearshore seaweed cultivation.

Seaweed farming has massive potential. For one, in terms of the products sourced from it, e.g., food, feed additives reducing methane emissions of cattle (Abbott et al., 2020), cosmetics (López-Hortas et al., 2021), and pharmaceuticals (Baskaran et al., 2020). Further, as a nature-based solution, seaweed contributes to climate adaptation and mitigation via local carbon sequestration (European Commission & Directorate-General for Maritime Affairs and Fisheries [DG MARE], 2023), buffering ocean acidification (Xiao et al., 2021), and bioremediation, i.e., excess nutrient uptake (Tanaka et al., 2020). It can also offer seabed protection, coastal protection, habitat provision, and employment (Clark et al., 2021). Unlike crops grown in traditional agriculture, it does not require fertilizer or insecticides (Meena & Jagtap, 2022). Thus, seaweed cultivation can be a step towards several Sustainable Development Goals (SDGs), in particular SDG 14 (Life below water). It also addresses the planetary boundaries of ocean acidification and biogeochemical flows in particular (Richardson

et al., 2023). Yet, potential drawbacks such as seabed shading, nutrient depletion, marine pests, and changes to currents (Clark et al., 2021) need to be carefully considered.

However, in Europe, cultivation practices have not fully evolved according to Kuech et al.. 68% of European seaweed is harvested from wild stocks, while only the remaining 32% is cultivated (76% sea-based, 24% land-based) (Kuech et al., 2023). Harvesting seaweed from wild stocks is associated with sustainability concerns because data has shown seaweed abundance reduction in some contexts (Kuech et al., 2023).

The regulatory environment is not prepared for the emerging seaweed sector yet (Duarte et al., 2021). To create good policy for seaweed cultivation, it is crucial to understand what challenges macro-algae farmers in Germany and the Netherlands are currently facing.

This research is novel in that it aims to better understand what challenges seaweed farms are facing, and how to tackle these in the Dutch and German context in particular. More general, global perspectives have been published (e.g., Sugumaran et al. (2022), Kim et al. (2017)) and I draw on these in my research. I am studying both countries because the respective national sector is too small to assess. Assessing two countries might also be a limitation because they have different infrastructures and policy frameworks. However, Germany and the Netherlands share many characteristics (e.g., North Sea coastline, temperate climate and geographical location, an established marine industry (Smaal & Lucas, 2000; Aschenbrenner & Winder, 2019), and progressive policy for climate change mitigation (Wang et al., 2023)), hence they are easier to assess together than other countries.

The research situates the seaweed industry in the Netherlands and Germany within the Multi-Level Perspective framework by Geels et al. (2017) which can inform the transition towards a strong seaweed sector in the region. The research question for this thesis is: *How can the core challenges of seaweed farms in Germany and the Netherlands be overcome to achieve sustainable and commercially viable seaweed cultivation?*

This thesis has begun by giving background information and introducing the topic of sea-based macro-algae cultivation in the Netherlands and Germany. In the second section, the research questions and methods will be described. In the third section, the results following from literature review and key stakeholder interviews will be presented in the three categories of Legislative and Political Challenges, Existing Support and Useful Practices, and Proposed Measures, following the sub-questions of the main research question. In the fourth section, contestations will be addressed and the research questions will be answered. In section five, I will conclude the thesis.

Methodology

This research aims to better understand and outline the challenges that Dutch and German seaweed cultivators are faced with, as well as existing support for them and the useful practices they already employ. Finally, I seek to propose solutions to foster seaweed cultivation in the Netherlands and Germany, also based on solutions proposed by interviewees. The methods employed are exploratory literature and key informant interviews.

Research Question and Sub-Questions

In the research question, *How can the core challenges of seaweed farms in Germany and the Netherlands be overcome to achieve sustainable and commercially viable seaweed cultivation?,* 'sustainable' refers to a sector that "meets the needs of the present without compromising the ability of the future generations to meet their own needs" (Hajian & Kashani, 2021), following the United Nations Brundtland Commission's definition of sustainability. Moreover, 'commercially viable' means that the sector can financially sustain itself. A mixed method approach aims to answer the research question through the following sub-questions:

- *1.1 Which core legislative and political challenges have seaweed farms in the study area faced?*
- *1.2 How have they received support and from whom?*
- *1.3 Which useful practices have they found and established?*
- *1.4 What is needed for German and Dutch seaweed farms to achieve prolonged, sustainable, commercial success?*

In Figure 2, the research questions are aligned with the respective methods of research.

Figure 2

Research questions and respective methods

Sub-question	Exploratory literature review	Interviews with key informants
Which core challenges have seaweed farms in the study area faced?	x seaweed farming globally	x seaweed farming in the Netherlands and Germany
How have they received support and from whom?		x
Which useful practices have they found and established?		x
What is needed for German and Dutch seaweed farms to achieve prolonged sustainable commercial success?		x

Note. Own work

Literature Review

I have conducted an exploratory literature review to partly answer (in conjunction with key informant interviews) sub-question 1.1. My literature review considered peer-reviewed journal articles to identify the challenges seaweed farmers in the Netherlands and Germany are facing. Governments and NGO reports were included to enhance the understanding of the practical side of seaweed cultivation. English and German papers were assessed, although there was little relevant literature found in German. Publications from 2010 up until now were considered to gain a comprehensive understanding of the recent emergence of the seaweed sector in the Netherlands and Germany and its challenges along the way, with a few exceptions for natural science papers. SmartCat and Google Scholar were used for finding peer-reviewed articles, and Google for government and NGO reports. I also employed backward citation tracking to further identify relevant interviewees and articles, respectively.

Search terms for sub-question 1.1 were “seaweed” and “macroalgae”/”macro algae”/”macro-algae” (“Macroalgen”/”Macro Algen”) in combination with “challenges”/“barriers”/“difficulties” (“Herausforderungen”/”Schwierigkeiten”/”Probleme”), especially with “Netherlands”/”Germany” (“Niederlande”/”Deutschland”).

Key informant interviews

Key informant interviews are critical in providing in-depth information on a niche topic, as outlined by Elmendorf & Luloff (2006). Therefore, in a second step, I conducted eight key informant interviews with stakeholders of the seaweed industry, namely three seaweed farmers (Interview 1Fg (in Germany), 3Fn, 5Fn (in the Netherlands)) as well as a representative from a seed provider (Interview 6S), two networkers for seaweed (Interview 2N, 4N), and a stakeholder from a policymaking institution (Interview 8P). Further, I interviewed someone from an offshore energy institute, with insights into co-use (e.g., Wind + Weed) (Interview 7O). The interviews took on average 45 minutes and were conducted online, via Google Meet and Microsoft Teams.

I identified the interviewees through online research. Further, I used snowballing to learn about and be connected with other relevant stakeholders via my interviewees. However, I quickly reached data saturation here, especially in the Netherlands, as interviewees mostly referred to actors already identified.

The key informant interviews were informed by challenges identified in the literature review and conducted in a semi-structured manner, following the common structure of Introduction, Warm-up, Main body of the interview, and Cool-off & Closure (Chu, 2024). The interview guides are in Appendix A.

The interviews were recorded using the *Voice Memos* app and transcribed using Otter.ai. This was edited by the researcher to remove transcription errors. The transcripts were sent to the interviewees to check for misunderstandings. Two of the interviewees asked for revisions to their transcripts.

I coded the interviews using Atlas.ti which was supplied by the University of Groningen, to increase data validity, and decrease bias. This was done inductively, although the interview questions were based on the literature.

Ethical Considerations

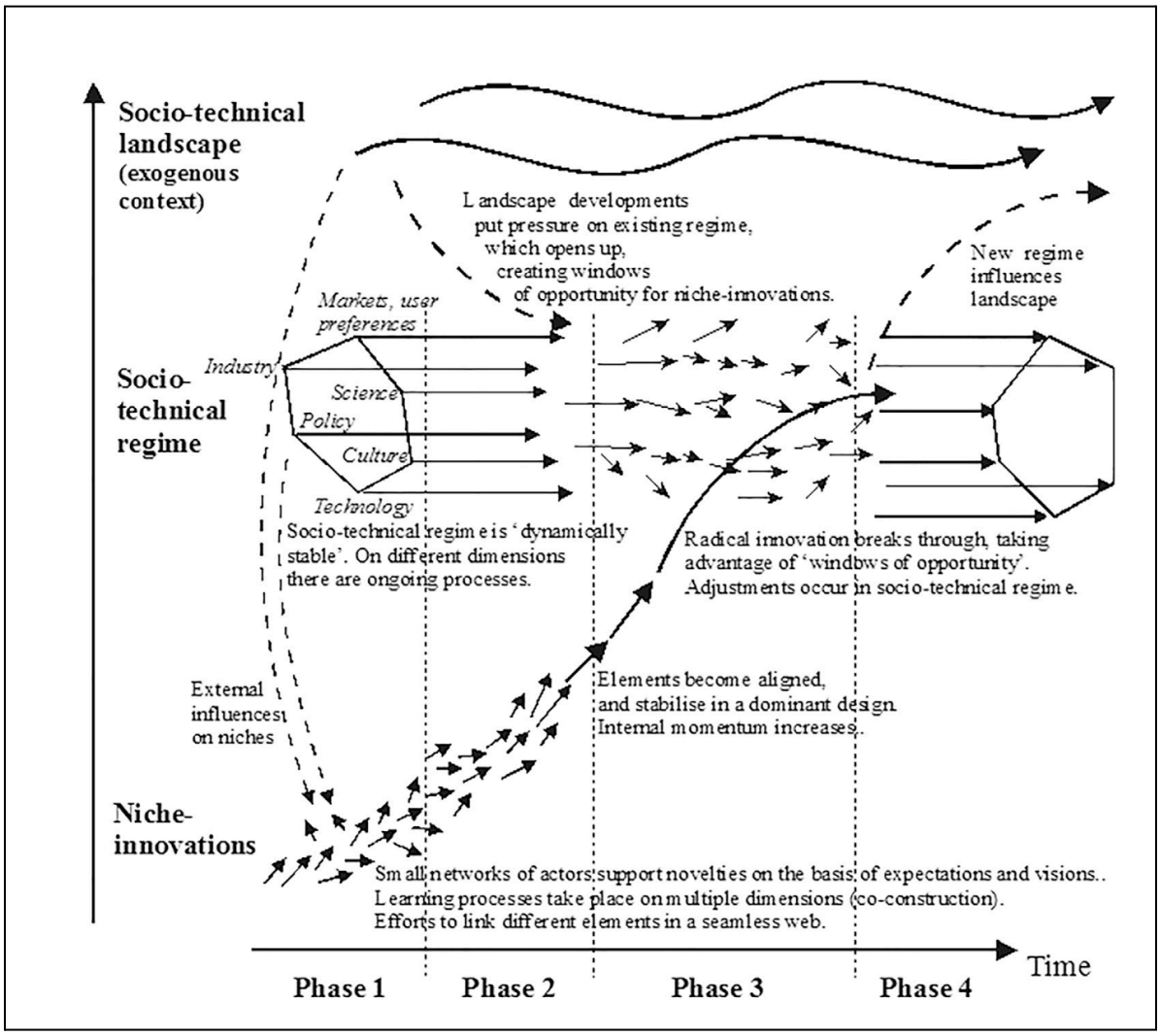
All participants were informed about potential risks of participating and gave verbal and written consent (see consent form in Appendix B). Statements were anonymized, both in terms of the individual and their organization. The research project received ethical clearance by the Ethics Committee of Campus Fryslân, University of Groningen.

Theoretical Framework: Multi-Level Perspective

To understand what innovation stage seaweed cultivation is in and what challenges the sector is facing, it is helpful to contextualize it within the Multi-Level Perspective Framework by Geels et al. (2017), see Figure 3.

Figure 3

Multi-level-perspective



Note. From "The Socio-Technical dynamics of Low-Carbon transitions," by F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S.. 2017, *Joule, 1*(3), 466 (https://doi.org/10.1016/j.joule.2017.09.018).

This is a suitable framework for this research because it comprehensively addresses the intricate interactions between emerging innovations, existing socio-technical structures, and broader socio-environmental trends. The multi-level perspective understands transitions as disruptive, contested, non-linear processes. It situates transitions in a micro (niche-innovation), meso (socio-technical regime), and macro (socio-technical landscape) context, which influence

one another, as shown in Figure 3. As the innovation gets adopted into the regime and changes it in the process. The innovation moves through four phases: I) Radical innovation, II) Niche market, III) Breakthrough, and IV) Regime substitution.

I use the model to structure the factors needed for the transition of seaweed cultivation into the popular sphere. Therefore, I mainly focus on the micro and meso level, as the macro (landscape) level is more difficult to change. Further, I emphasize the second and third phase of the MLP as these are most relevant to the current status of the seaweed cultivation sector in my study area.

Results

This section will start by applying the Multi-Level Perspective Framework to seaweed cultivation in Germany and the Netherlands. Then, *legislative and political challenges*, *existing support and useful practices,* and *possible measures* (see sub-questions) to address the challenges faced by Dutch and German seaweed farmers will be outlined, as reported in literature and discussed by interviewees.

Situating seaweed cultivation in Germany and the Netherlands in the Multi Level Perspective Framework

While seaweed cultivation is already established in many East Asian countries, and thereby already part of the "regime", its cultivation (vs. wild harvesting) is relatively new in Europe (Barbier et al., 2019). Seaweed cultivation in Germany and the Netherlands is in Phase 2 (Niche market) as there is certainly already landscape pressure (i.e., the climate crisis and environmental pressure) on the existing socio-technical regime (Rietig, 2011), i.e., the aquaculture sector and more generally non-regenerative modes of production. Yet, the regime is not adjusted to the emerging niche industry so far, which is reflected in the challenges listed hereafter. In my research, I identified three macro-algae cultivation sites in Germany and the Netherlands, one of which has been turned into a model farm, where seaweed is cultivated for educational, not commercial, purposes (Interviewee 5Fn). Shifts in components of the socio-technical regime such as technology, culture, policy, science, industry, the market, and user preferences (see Figure 3), are necessary for seaweed cultivation to break through (Phase 3) and eventually become part of an adapted socio-technical regime of Germany and the Netherlands (Phase 4).

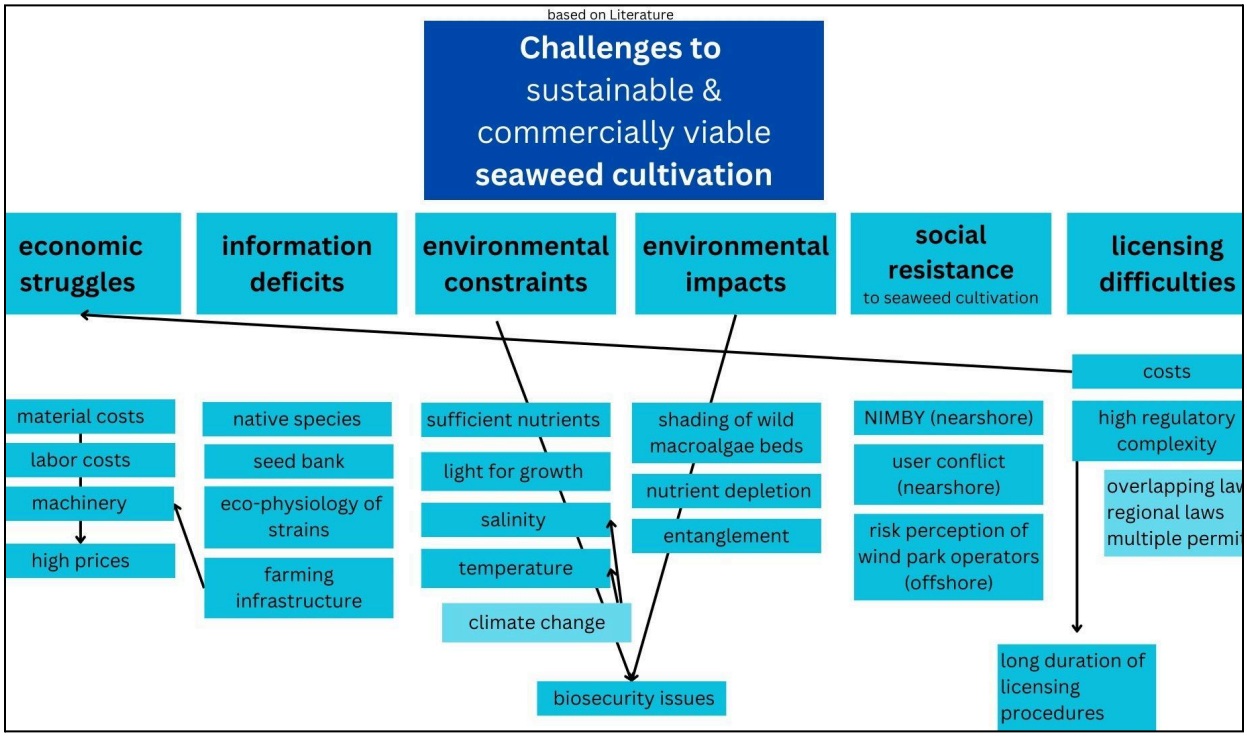
Legislative and Political Challenges

In this section, Legislative and Political Challenges will be outlined (see Research question 1.1), sourced from the literature review and key informant interviews. The aspects of each section are ordered by the relevant components of the socio-technical regime (Markets & user preferences, industry, science, policy, culture, and technology) when applicable, although most of the points relate to multiple components of these. I have grouped them under the one with the highest alignment, respectively. I discuss markets and user preferences (lack of demand), technology and science (knowledge deficits), policy (environmental constraints and effects, licensing difficulties, and the lack of visibility) and culture (social resistance to cultivation).

In Figure 4, challenges to sustainable and commercially viable seaweed cultivation, as identified in the literature review, are displayed.

Figure 4

Challenges for sustainable and commercially viable seaweed cultivation (based on Literature Review)



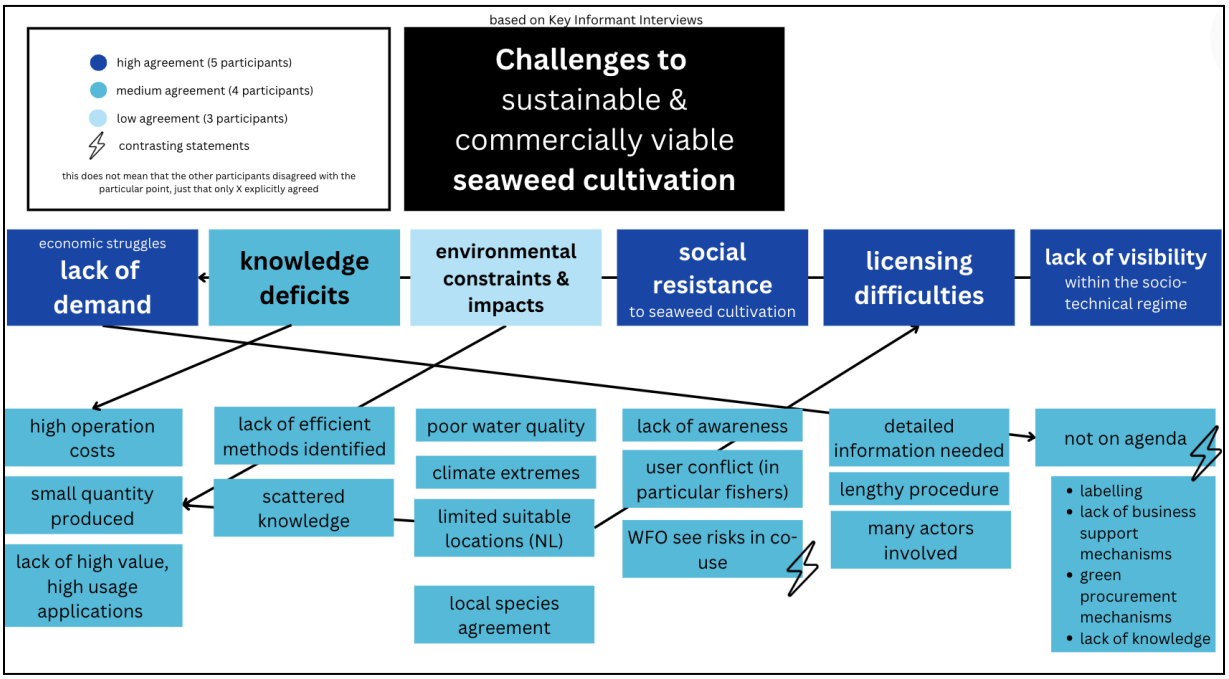
Note. Own work.

The different challenges are grouped in economic struggles, information deficits, environmental constraints, environmental effects, social resistance to cultivation, and licensing difficulties. Further details are outlined in the respective sections, information deficits under knowledge deficits as interviews showed that rather than information, knowledge is a central issue. The different factors cannot be assessed individually but are intricately interconnected.

In Figure 5, challenges to sustainable and commercially viable seaweed cultivation (based on interviews with key informants on Germany and the Netherlands) are depicted.

Figure 5

Challenges for sustainable and commercially viable seaweed cultivation (based on Interviews)



Note. Own work. Color coded by agreement: The darker the color, the higher the agreement among the eight interviewees. The lightning sign indicated contrasting statements.

The different challenges are grouped in lack of demand, knowledge deficits, environmental constraints and effects, social resistance to cultivation, and policy & decision-making. The highest agreement is found for the issue of demand, quantitatively (in terms of how many interviewees agreed to it) but also qualitively, as interviewees voiced that it was currently the most relevant and pressing issue (Interview 3F). High agreement was found for social resistance to cultivation, licensing difficulties, and a lack of visibility, a factor which was central in the interviews. Medium agreement was found for knowledge deficits. Only few participants agreed on the issue of environmental constrainsts and impacts. The factors will be outlined further in the respective section.

Markets and User preference: Lack of demand

Currently, macro-algae cultivation in Europe is very costly. At the present prices, European seaweed is not competitive with Asian supply (e.g., Nori from South Korea: €15,95/100g (Pit&Pit, n.d.) versus Nori from Norway: €56,85/100g (Lofoten Seaweed, 2024)). Therefore, costs need to be decreased. Labor costs are higher in Europe than in most of the countries with the biggest seaweed production (see Figure 1). Thus, reductions in labor needs by mechanizing seeding and harvesting are required (Campbell et al., 2019). Buck & Buchholz (2004) report that in simple, flexible, off-shore systems, anchors and ropes are the main cost drivers. The seaweed cultivation machinery industry is still in the take-off phase now, which makes its products particularly expensive.

Economic problems were reported to be the biggest obstacle to seaweed cultivation in the interviews with stakeholders for the Dutch and German seaweed sector. According to the interviewees, seaweed cultivation is not yet commercially viable in the great majority of farms in this context due to currently low demand. German and Dutch seaweed farmers face difficulties even selling their harvest (Interview 1Fg, 3Fn, 6S). Similar issues are faced in other European countries and the US (Interview 6S). Two explanations are given for this: (a) European seaweed cultivation is too expensive to compete with Asian seaweed. (b) There are too few high-value applications for European seaweed.

Firstly, it is argued that European seaweed is simply *too expensive* to compete with Asian seaweed (Interview 5Fn), due to high operation costs in small-scale production. European labor is more expensive, but efficient methods and infrastructure to outweigh this are lacking. Small farms like those currently emerging in the Netherlands and Germany struggle with attracting professional investors and industry clients (Interview 1Fg, 5Fn). Many actors believe that when European seaweed production is scaled up, costs will decrease (Interview 4N). However, funds are needed for this (Interview 4N). Currently, the EU is importing a large amount

of seaweed (Interview 8P), spending more money on this than the turnover of the entire algae production in Europe (including micro-algae and wild harvested macro-algae) (Kuech et al., 2023). Yet, seaweed farmers face difficulties selling their harvest. Consequently, higher European prices might currently dampen demand.

On the other hand, some interviewees link the lack of demand for seaweed biomass to a *lack of high-value, high-quantity applications* established with industrial customers. Seaweed is not part of European culture yet (Interview 3Fn, 1Fg) – while Japanese people consume on average 10.4g of seaweed per day (Murai et al., 2020), people in France, for instance, the second-biggest European seaweed producer, only consume 293mg daily (Ficheux et al., 2022). Consequently, applications did not have time to develop historically. The currently established seaweed applications do not use a lot of seaweed, e.g., plastics which only use a few tons of seaweed a year since seaweed is used in very thin coatings (Interview 4N). Instead of competing with cheaper Asian seaweed, Interviewee 3Fn plans to establish new high-value products that are specifically sourced with European-produced seaweed. This opens up new visions for the future of the sector. Instead of covering large areas with seaweed farms, small-scale farming could succeed, if high-value products exist (Interview 8P). Responding to the current lack of high-value applications for their seaweed, the company of Interviewee 3Fn has decided to slow down on cultivation since their storage is filled and instead focus on networking to establish markets and develop products in conjunction with the processing stakeholders. This results in running operational costs without an income from sales, as product development is expected to take several years.

Most interviewees see both explanations as relevant to the low demand currently, even though these offer very different views of the future of the sector: (1) intense scale-up versus (2) localized, small-scale production.

Science and Technology: Knowledge Deficits

As the European seaweed cultivation industry is only emerging now, there is a lack of knowledge reported in literature across many areas, specifically for European species. The conditions suitable for different species need to be better understood (Sugumaran et al., 2022). More knowledge on Euryhaline species, which can tolerate wide ranges of salinity, is particularly relevant (Kim et al., 2017). Seed banks are proposed to ensure genetic diversity (Kraan, 2020) which is crucial for environmental protection and disease resistance (Campbell et al., 2019). There are knowledge gaps in terms of environmental impacts and benefits (Kuech et al., 2023) identified. This information is crucial for the sustainable cultivation of seaweed as well as the quantification of ecosystem services and the potential introduction of ecosystem service monetization.

Secondly, efficient seaweed cultivation infrastructure is needed to reduce costs. There is a lack of efficient cultivation, harvesting, and processing techniques (Kuech et al., 2023) and suitable infrastructure, as farming systems should be robust and cost-efficient (Kim et al., 2017). As Bak et al. (2020) state that while many efforts have been undertaken in this, structures often suffered from overengineering, which caused high installation costs. Hence, simple and flexible structures are needed (Bak et al., 2020).

In the interviews, none of the interviewees reported problems choosing which species to farm. Interviewees 1Fg and 3Fn (the only interviewees commercially farming seaweed in the Netherlands and Germany) both simply farmed what was already there. In the German context, this was also explicitly the only thing allowed.

Based on the interviews, there does seem to be a need to identify and develop more efficient methods for the different processes in seaweed cultivation, as well as standardizing and communicating across the entire production chain to prevent small changes from affecting the harvest, e.g., different spinning oil for ropes (Interview 6S). But a disconnect with university

researchers was reported by Interviewee 1Fg. These would sometimes be missing practical experience which would lead to the proposal of interventions that had already unsuccessfully been trialed.

Knowledge is quite scattered (Interview 4N). Different stakeholders often prefer different cultivation methods, and it is uncertain which works best (Interview 6S). There are some efforts to centralize this knowledge by the European Commission Directorate General for Maritime Affairs and Fisheries, such as extending the existing toolkit on licensing to other relevant areas (Interview 8P).

Policy

The following challenges are (not only but also) related to policy. Environmental effects are partly addressed by regulatory frameworks, environmental constraints reported are partly due to agricultural policy, licensing procedures are defined by different governance structures, and the lack of visibility of European seaweed is particularly relevant in policymaking institutions as impactful decisions for the sector are made there.

Environmental Effects. As the literature states, while seaweed certainly has numerous benefits for local ecosystems, e.g., nutrient scrubbing (Tanaka et al., 2020), CO2 removal (Duarte et al., 2021), mitigating deoxygenation (Duarte et al., 2021), and new kelp bed habitat provision (Bak et al., 2020), its (especially large-scale) cultivation can also have drawbacks. To ensure sustainable seaweed cultivation, these need to be carefully considered.

Firstly, there is the concern that seaweed can shade wild macroalgal beds (Bak et al., 2020). Secondly, as seaweed takes up nutrients when growing (Tanaka et al., 2020), which can be helpful for eutrophicated waters, there is also the danger of nutrient depletion (Yellow Sea Fisheries Research Institute, 1989). Additionally, both small and large megafauna species can

get entangled in cultivation systems. Particularly deeper offshore areas are affected since the population of larger marine mammals is often the biggest there (Campbell et al., 2019).

Environmental effects were not central to the interviews, as those focussed on the obstacles to business development. I did find that environmental checks are not very prevalent so far, especially not in the Netherlands. While Interviewee 1Fg reported that they had to conduct an annual environmental monitoring, this is only required because of the farm's IMTA (Integrated Multi-Trophic Aquaculture) system, hence their aim to grow fish eventually. Environmental monitoring is not prevalant in the Netherlands (Interview 4N). Further, this was carried out by the farmers themselves, not by an independent actor. Industry-wide, there seems to be an agreement to only cultivate local species and only use local starting material, although the definition of local ranged from 50-100 km (Interview 8P) to 200 km (Interview 6S). However, one farm does cultivate a non-native (although previously local) species in the Oosterschelde, namely Wakame *(Undaria pinnatifida)*.

Environmental Constraints. According to the literature, seaweed farming is constrained by certain environmental factors necessary for sufficient growth: Seaweed needs sufficient nutrients, light, and a certain level of salinity and temperature (Campbell et al., 2019). However, these specific characteristics are often not fully researched for all species (Tanaka et al., 2020), which impedes effective site selection. Further, climate change is changing local conditions and thereby seaweed production. Warmer water makes the cultivation of cool-temperature seaweed challenging by affecting their reproduction and other biological functions (Park et al., 2017).

Finally, biosecurity must be carefully considered, to avoid spreading diseases. Especially, a lack of genetic diversity can make seaweed farms susceptible to diseases. This has major impacts on production. In China, disease outbreaks cause an estimated loss of 25-30% of harvested brown algae. Outbreaks can have long-term impacts when they trigger

seaweeds to produce hydrogen peroxide, which causes a change in the physiology of the seaweeds, increasing their vulnerability to future infections (Sugumaran et al., 2022). Biosecurity concerns are also relevant for the surrounding environment, as seaweeds may act as reservoirs for diseases and in this way spread them (Campbell et al., 2019).

In the interviews, environmental constraints were mentioned as a barrier by different stakeholders. Interviewee 1Fg considered environmental conditions as an obstacle in terms of poor water quality due to wastewater from agriculture. They explained that the nutrients of (intensive) agriculture get in the canal, the gates of which are opened when the level gets too high so that the nutrient-high water flows into the fjords, where they cultivate seaweed. This has been hypothesized to cause the eutrophication of their waters (Interview 1Fg).

Interviewee 5Fn and 2N were somewhat critical of the complicated Dutch conditions for seaweed cultivation, due to sandy beds and a shallow and rough sea. The only suitable location, according to Interviewee 5Fn, is the Oosterschelde, where the two Dutch seaweed farms are located. However, Interviewee 5Fn believes that the volume needs to be significantly increased to have an impact, which would not be possible in the Oosterschelde. Cultivation in wind parks on the North Sea could increase the volume but, according to Interviewee 5Fn, is not (yet) economically or environmentally feasible. While Interviewee 5Fn's company has a model seaweed farm in the Oosterschelde, they only cultivate seaweed commercially abroad, due to a lack of locations with suitable conditions in the Netherlands. Interviewee 4N shared concerns about the non-ideal cultivation conditions in the Dutch North Sea but also stressed that suitable locations for seaweed cultivation do exist in the Netherlands beyond the Oosterschelde, such as the Westerschelde, and the Waddeneilanden. They also mentioned that seaweed cultivation was somewhat easier in Germany due to the coastal characteristics.

Licensing Difficulties. According to the literature, receiving a permit for seaweed cultivation brings a high regulatory complexity. Firstly, this is due to overlapping laws on the topic, e.g., in the EU: Habitats Directive 92/43/EEC, the Maritime Spatial Planning Directive 2014/89/EU, the Marine Strategy Framework Directive 2008/56/EC, the Maritime Spatial Planning Directive 2014/89/EU, the Marine Strategy Framework Directive 2008/56/EC, the Water Framework Directive 2000/60/EC, the Alien Species Regulations 1143/2014/EU and 708/2007/EC, the Environmental Impact Assessment Directive 2011/92/EU, Novel Food Regulation 2015/2283/EU (Leinemann & Mabilia, 2019). Kim et al. (2017) state that there are often multiple permits needed to establish one seaweed farm. Moreover, there are regional differences (Kim et al., 2017). Thus, licensing can take a long time and is often also very expensive.

Statements by the interviewees differ by country here. For Germany, Interviewee 1Fg, agreed with most of the findings from the literature. The licensing required very detailed information: “How much mussels we need to do to be able to do how much fish, then also the length, the consistency, the material, for all the lines, how we put the anchors.” This required them to submit a proposal of about 80 pages, which included exact calculations on nutrient dynamics. The entire process of licensing ended up taking about three and a half years. Many actors were involved, Interviewee 1Fg estimated that at one point there were 23 people at one table, discussing the permit. In the end, they had to get a permit from the German Ministry of Fisheries, the “Wasser- und Schifffahrtsverwaltung” (Water and Seafare Administration), and the “Landesamt für Küsten- und Naturschutz” (Federal Administration for Coast and Nature Preservation). Further, they needed a “wasserrechtliche Lizenz” (Water Law Licence). Interviewee 1Fg did attribute part of the complexity of acquiring the license to the fact that their farm was setting up an IMTA system. Generally, they reported licensing difficulties to be much lesser in research projects than in commercial cultivation. Besides, according to Interviewee

1Fg's knowledge, they were the first to do this kind of aquaculture in their area, perhaps making the regulatory bodies hesitant of hasty decisions that would also impact future aquaculture endeavors. Therefore, seaweed cultivation licensing in Germany is lengthy, although they did not report it to be costly as some literature states.

The two Dutch farms, represented by Interviewee 5Fn and 3Fn, were both already licensed when acquired by the current owners. Interviewee 3Fn stated that their license has been renewed every five to six years without any difficulties. It seems that, at least once a license is obtained, it is relatively easy to maintain. Interviewee 5Fn warns that while they currently do not have any licensing problems either, they assume it would be more difficult to acquire an entirely new permit nowadays as any of the about seventy local stakeholders in the Oosterschelde could officially object if someone new were to enter. In an instance, they reported a legal conflict between a mussel farmer and a seaweed farmer. This information could not be verified. However, it is interesting that this was brought up, as it indicated the sector culture may not be as collaborative as often claimed.

Interviewee 4N states that licensing is not presently a significant obstacle for seaweed farmers, but might grow to be one as the seaweed industry expands – due to limited space. More space would be available offshore. Interviewee 6S sees challenges in licensing as the current procedures would take around five years. Farmers have to consult with the province, municipality, state, and even the EU, in the case of the Oosterschelde, which is part of the "Natura 2000" area, alongside with engaging the local community (Interview 6S). Interviewee 6S calls for licensing to be standardized and sped up. Interviewee 8P states that licensing is one of the key barriers due to its duration, complexity and sometimes lack of integration in national governance structures.

Lack of Visibility within Socio-Technical Regime. A lack of visibility of seaweed within the socio-technical regime was not identified in the literature review, but did play a role in the interviews (Interview 1Fg, 6S, 8P). Perhaps at the core of this lies the understanding that “most of the [EU] member states do not consider seaweed farming as an integral part of their aquaculture” (Interview 8P), hence it is simply not on the agenda of the relevant institutions which are (inadvertently) setting the stage for seaweed cultivation. This can have multiple implications, such as labeling issues, a lack of business support mechanisms and an insufficient presence in big green procurement procedures (Interview 8P).

Further, a lack of expertise about macro-algae was reported in grant panels. Interviewee 6S states that because of this, companies that are great at selling themselves, rather than those with the practical knowledge, receive funds. “Then the money just evaporates.” (Interview 6S). Interviewee 1Fg highlighted the issue of ammunition. Although the relevant German Federal State would be legally required to free its waters from ammunition, Interviewee 1Fg’s company had to pay for ammunition detection measures themselves because the government did not prioritize seaweed cultivation areas.

Culture: Social Resistance to Cultivation

Literature reports that since seaweed cultivation (as opposed to harvesting wild seaweed) is relatively new in Europe (European Commission & DG MARE, 2023), people are sometimes resistant to new (nearshore) cultivation plots. They fear that the recreational and aesthetic value of the water will be impacted (Kim et al., 2017). Further, the nearshore area is limited, which causes user conflicts (Kim et al., 2019). There is also resistance to offshore seaweed farming. Bak et al. (2020) state that many wind turbine owners are not willing to cooperate with seaweed cultivation initiatives or farmers.

In the key informant interviews, little resistance from residents is reported, although Interviewee 1Fg states it is not unlikely to become a problem in the future due to new high-end

apartments being built in proximity to their farm. Currently, resistance does not seem to be the problem impacting demand but a lack of awareness (Interview 4N), as seaweed is not part of Dutch and German culture historically (Interview 3Fn, 1Fg).

Rather, user conflicts seem to be of major concern. Especially in the Netherlands, space is very limited. “Every centimeter already has some sort of destination, whether it is windmills or recreation or something else.” (Interview 2N). The particular area, in which the farm of Interviewee 1Fg is located, is also already quite full. Interviewee 2N and 6S explicitly mention fishers as the biggest user conflict, since fishing is not possible where there is a seaweed farm.

Regarding offshore multi-use, the interviewees explained the resistance of many wind farm operators with potential risks, e.g., damage to the wind parks (Interview 2N, 4N, 7O), especially given the cost of offshore construction; hindered maintenance activities (Interview 2N, 7O); and altered sea currents (Interview 2N). Interviewee 8P, on the other hand, reports wind farm operators to be keen to multi-use wind park space for multi-trophic aquaculture.

Existing Support Mechanisms and Useful Practices

In this section, existing support mechanisms as well as useful practices employed by seaweed farmers to bridge the current demand gap will be outlined, as covered in the interviews: investments, collaboration and passion, trial-and-error mindset, and long-term thinking. This is aimed to help answer research question 1.2 and 1.3. All of these, except for investments, which come from certain actors within the socio-technical regime, can be located at the niche level, where seaweed currently is placed at within the Multi-Level Perspective Framework.

Investments and Support from Actors within the Socio-Technical Regime from the Meso Level (Existing Support Mechanism)

The interviewees reported quite some opportunities for funding, although, in terms of investors, this also depends on the scale of production (Interview 5F). There are subsidy programs through the Dutch provinces (Interview 3Fn). The European Maritime Fisheries and Aquaculture fund, through which money is allocated to each of the member states, distributes funds within the national fisheries and aquaculture sectors (Interview 8P). In the Netherlands in particular, the Rijksoverheid voor Ondernemend Nederland (RVO) can also aid in licensing (Interview 6S). Importantly, a high magnitude of investments are also reported via research institutes (Interview 1Fg) which offers a reliable income to farmers in times of challenging demand conditions.

Interviewees also state that there is knowledge available via different government and non-governmental actors (Interview 1Fg, 4N). An example of this is the EU4Algae platform (*EU4Algae*, 2024).

Niche Networks and Co-construction at the Micro Level (Useful Practices)

Collaboration and Passion. There is a lot of willingness to collaborate within the European seaweed sector. At first, there was a harsher climate (Interview 2N). However, now, the stakeholders share the understanding that collaboration is necessary for the industry to succeed (Interviewee 4N). Interdisciplinary networks provide innovative impulses (Interview 1Fg). When new products are successfully introduced to the market, it benefits everyone because it offers a new application for seaweed (Interview 3Fn).

Most people in the seaweed industry seem to be highly intrinsically motivated and passionate about the topic. Interviewee 4N calls being a seaweed farmer a “fairy tale like profession”. Interviewee 6S reports a lot of “buzz” around seaweed.

Trial-and-Error Mindset. Instead of focusing on difficulties and obstacles, many interviewees, in particular the farmers, voiced a trial-and-error mindset. According to them, at the core, seaweed farming itself is “not rocket science” (Interview 1Fg). “It is learning by doing” (Interview 1Fg). Similarly, Interviewee 3Fn stated the steps to growing their farm were clear to them. While they faced difficulties and made mistakes, they were able to respond to them well (Interview 3Fn).

Long-term Thinking. Another way in which members of the sector seem to be coping with the currently tight market for seaweed is by practicing long-term thinking. In the company of Interviewee 1Fg, one owner has adapted by taking another part-time job, they have created a live-in situation for another owner, and participate in research. Similarly, Interviewee 3Fn reported choosing to slow down cultivation to focus on building markets through product development, with the ultimate goal of going back to full-time seaweed farming once those markets exist and demand is secured.

Possible Measures

In this section, I will discuss measures for seaweed farms to achieve prolonged sustainable commercial success (see *Research question 1.4*) as proposed by key informants during the interviews conducted. They are structured by the relevant aspect of the Multi-Level Perspective Framework to be adapted: Key points for the seaweed industry (i.e., Niche innovation) are optimization and standardization, increasing visibility, mindful species selection, and increasing consumer acceptance and awareness of European seaweed. Policy changes would be needed for ecosystem service monetization, funding increases, water and ecosystem protection, and streamlining licensing.

Niche Innovation (Micro Level)

Optimization and Standardization. To decrease operational costs and thus increase demand, many of the interviewees called for optimization of the cultivation process. Propagation (e.g., bioreactor system for maintaining kelp seeds, also with little knowledge) (Interview 2N), cultivation (Interview 4N), seeding (Interview 4N), monitoring (Interview 4N), harvesting (Interview 2N, 4N), storing (Interview 2N, 6S), pre-processing (Interview 6S), biorefinery (Interview 2N), licensing (Interview 6S) and application development (Interview 2N) should be optimized and standardized. This would decrease the use of manual labor and the costs of operation, by increasing efficiency, (perhaps using mechanization). Specifically, standardizing the storage and preprocessing of seaweeds could enable access to high-value, medium-sized markets (Interview 6S). Further, funds should be spent on optimizing existing solutions like long-line farming rather than working on new, continuously failing solutions like net farming (Interview 6S).

Interviewee 6S expressed the need for standardizing farming practices to be able to establish proven good practices that work in different locations. Using the same type of starting material, seeding density, rope type, and way of application in a few lines at different farms would be helpful for setting a standard (Interview 6S). This could also help achieve consistency in terms of quantity and quality.

The interviewees reported a lack of processing infrastructure. Interviewee 3Fn eventually established their own machinery. The company of Interviewee 1Fg air dries their seaweed which doesn’t require any machines. They sell their seaweed directly to consumers, either dried or fresh. Interviewee 8P points out the infrastructure needs to be developed by the operators alongside the relevant governmental bodies.

Increasing Visibility. Many interviewees proposed strategies for improving visibility (see also *Lack of visibility within the socio-technical regime*). This could be worked towards with projects for community based sea gardens to increase awareness for and interest in seaweed amongst the general population (Interview 1F). In particular, visibility should be increased within governing bodies (Interview 4N), to receive systematic support (Interview 3Fn). Once governing bodies are aware of the benefits of and application opportunities for European seaweed, it will be higher on the agenda (Interview 3Fn), enabling further support. Interview 8P states that increasing visibility of seaweed in national governance bodies is something their institution is working on, but progress is reportedly slow. Networking is crucial, also with industry customers, to jointly establish new seaweed applications (Interview 3Fn). Visibility is needed in policy as well as in the processing industry, for developing new, high quantity uses.

Mindful Species Selection. Yet another proposed measure for tackling the demand issue is being more specific about the species cultivated and the problems they solve, as most farmers currently do not consider this question very actively but rather choose the location first and then simply farm what is already there (Interview 1Fg, 3Fn). It may be instead be beneficial to cultivate particular species that are high in demand, e.g., *Palmaria palmata*, which is currently only wild-harvested (Interview 6S), or European-grown alternatives for currently imported seaweeds like Laminaria species (Interview 8P). Interviewee 3Fn states that actors should more clearly determine what problems they are aiming to solve. This can also include choosing species based on the specific problem aimed to solve, e.g., *Asparagopsis taxiformis* for methane reduction in livestock (Interviewee 6S, Roque et al., 2019), *Fucus vesiculosu* for better color preservation in pork patties (Agregán et al., 2019), or *Ulva armoricana* for pharmaceuticals with antioxidant, antiviral, and immunostimulatory activity (Berri et al., 2017). However, species cultivated should be local (see *Environmental effects*).

Increasing Consumer Acceptance and Awareness. Another way to build up demand for seaweed is to increase consumer acceptance and awareness and educate on the benefits of European seaweed cultivation (Interview 8P), possibly also decreasing social resistance to seaweed cultivation. Proposed strategies are the introduction of seaweed to high-end restaurants to eventually interest people in eating it at home (Interview 3Fn, Mouritsen et al. (2018)) and educating people on healthy and sustainable eating practices (Interview 1Fg).

Interview 1Fg calls for the re-education of fishers to cultivate seaweed, following the example of the Green Wave movement. Fishers and others could facilitate sea gardens to serve as spaces to educate on and connect with the sea, thus raising awareness about ocean conditions and seaweed as a nature-based solution to many challenges. A project of shipowners cultivating seaweed is already supported by Interviewee 1Fg's company. Interviewee 5Fn reported that they are looking into turning their model farm into an academy farm for students, also raising awareness and improving understanding.

Indeed, there is already a market for seaweed in Europe, proven by the almost €350 million worth of seaweed imported in 2018 alone (Kuech et al., 2023; Interview 8P). What is perhaps needed is a label making the European origin of local seaweed salient, as many people might not even know that seaweed is also cultivated in Europe.

Policy (Meso Level)

Ecosystem Service Monetization. To bridge the current price gap and incentivize seaweed cultivation, ecosystem service monetization can be a helpful tool. Interviewee 6S called for monetization of ecosystem services, in particular, de-eutrophication and de-acidification, perhaps biodiversity as well, although this is harder to quantify. They explicitly did not include carbon capture, as this would depend on the end use of the seaweed. Monitoring

would be crucial for any ecosystem service monetization, e.g., by sensors or satellite images (Interview 6S).

Interviewee 8P also sees potential benefits in ecosystem valuation but stresses that the biomass sold should remain the main income. Seaweed cultivation companies should be financially self-sufficient. Further, they stressed that different ecosystem services first need to be quantifiable with reliable measurement tools.

Funding increases. Funding, especially at this stage, is crucial for bridging the niche innovation stage (see Multi-Level Perspective Framework) with low demand and high costs. Local governments should offer first seed investments (Interview 4N). There already are some subsidy programs through the Dutch provinces (Interview 3Fn). Subsidies should be shifted from the oil and gas industry towards climate-positive sectors, e.g, macro-algae cultivation (Interview 8P). Interviewee 4N calls for a national offset subsidy to compensate for the currently high cultivation costs and thereby accelerate optimization, perhaps similar to the decoupled direct payments based on agricultural land size (Scown et al., 2020). This subsidy can fill the financial gap between the costs and the market price (Interview 4N).

Water and Ecosystem Protection. Impacts of seaweed cultivation on the ecosystem and vice versa should be minimized to ensure successful and sustainable seaweed cultivation. It is important to regulate wastewater from the agricultural sector to facilitate healthy conditions in the water bodies potentially suitable for cultivating seaweed (Interview 1Fg): “There needs to be a master plan to protect the […] sea, and then we can talk about how to produce seaweed.” (Interview 1Fg). Interviewee 8P agrees with the need to ensure the safety of cultivated seaweed but from a food-safety perspective. They state that the relevant legislation is health-related.

Streamlining Licensing. As licensing is a commonly mentioned barrier, many proposed measures tackle this issue. Procedures should be sped up (6S), as it currently takes around five years in the Netherlands (Interviewee 6S) and three and a half years in Germany (Interviewee 1Fg). The procedure should be standardized (Interview 6S), also to make location regulations more clear, on a provincial and municipal level (Interview 4N).

Interviewee 6S also points to a helpful procedure in the Netherlands: pilot licenses. Acquiring these takes around nine months and helps the farmers test if a place is a good location for cultivating seaweed. Further, this slowly introduces local residents to the idea of a seaweed farm in their neighborhood, making their cooperation in the full licensing procedure more likely (Interview 6S). Thus, this may also be a helpful practice to implement in Germany.

Discussion

In the result section, *Legislative and Political Challenges*, as well as *Existing Support Mechanisms and Useful Practices*, and *Possible Measures* were identified. In this section, I will weigh the different aspects mentioned and consider some points of contestation to understand how the seaweed cultivation sector in Germany and the Netherlands can move to the next stage of the Multi-Level Perspective Innovation framework (Geels et al., 2017), from Phase 2 (Niche market) to Phase 3 (Breakthrough) and eventually, Phase 4 (Regime substitution, i.e., widespread adoption).

Legislative and Political Challenges

As laid out in the results section, the challenges identified are the lack of demand, knowledge deficits, environmental constraints and effects, social resistance to cultivation, lack of visibility within the socio-technical regime, and licensing difficulties (see also Figure 5). The most crucial issue is the lack of demand which is driving economic struggles, This issue was mentioned in most interviews with stakeholders of the seaweed sector (Interview 1Fg, 3F, 4N,

6S, 8F), although to different extents in line with the stage of development of the respective cultivation site. If farmers cannot sell their seaweed, all other issues fall into the background. Accordingly, this issue and the problems that co-determine it, i.e., lack of visibility and knowledge deficits (see Figure 6), are the most important ones at this stage. Changes in the socio-technical regime, particularly in terms of policy, and within the niche sector are required to increase demand for European seaweed by decreasing costs and establishing new high-value applications. Yet, licensing certainly is a problem currently and should also be addressed, although not with the same prioritization. In the following section, I will discuss contestations regarding the demand question as well as the lack environmental protection efforts.

Demand Question

Regarding the lack of demand, two perspectives became apparent. One view is that European seaweed is too expensive, so the price should be decreased through systematization and mechanization efforts and scaling up. This should increase demand. This perspective is in line with the theory of Economies of Scale, introduced by Marshall (1920). He sees many advantages in large-scale production, namely more efficient resource use, labor specialization, and improved production efficiency. Further, he claims larger scale production is associated with lower investment risks, buying supply in big quantities, hence often cheaper, selling large quantities for a relatively high price (because it is convenient to the consumer), being known by many, advertising funds, being more engaged in the industry due to having more representatives (i.e., employees).

However, there are also more critical perspectives to scaling up, e.g., the case for small-scale and locally appropriate, perhaps post-growth, economies to sustain the environment as well as the local population (Schumacher, 1975). This point of view is also often drawn when discussing measures for the ongoing anthropogenic climate crisis and intense natural resource use. While seaweed cultivation can have net positive climate impacts due to carbon

sequestration, intensive large-scale seaweed cultivation has also been found to cause nutrient depletion, e.g., in the Republic of Korea (Shim et al., 2014). Further, precisely the local mode of production in German and Dutch seaweed farms can be a significant advantage over imported Asian seaweed. If Europe were to introduce huge farms in selected countries, this benefit could be lost. Indeed, the great thing about seaweed is that it needs so little to grow, therefore it could be even more localized with projects such as Cool Blue (Cool Blue, n.d.).

On the other hand, Interviewee 3Fn links the lack of demand to a *lack of high-value, high-quantity applications* established with industry customers, also due to seaweeds not being part of (non-coastal) European culture so far (Van Den Burg et al., 2019). According to the 2023 EU blue economy report (European Commission et al., 2023) current seaweed uses are food (36%), food-related (i.e., food supplements, nutraceuticals, hydrocolloid production; 15%), animal feed (10%), cosmetics and well-being products (17%) as well as fertilizers and biostimulants (<11%). Even if most of these uses seem to be high-value applications (in contrast to the emerging use of seaweed as biofuel (Netalgae, n.d.)), there are simply not enough products yet. Thus, these need to be established by the producers in cooperation with industrial customers. The interest from consumers seems to be there as, according to Govaerts and Olsen (2023), they perceive seaweed (food) products as unique and natural. Further, European consumers are willing to pay more for climate-friendly foods (Feucht & Zander, 2017), e.g., beef with lower methane emissions due to macro-algae feed. A wealth of possible applications in the pharmaceutical, nutraceutical, and even construction sector have been identified (Milledge et al. (2015), Susilorini et al. (2014), Pati et al. (2016))

Lack of Environmental Protection Efforts

To achieve sustainable seaweed cultivation, it is crucial to consider environmental effects. While seaweed can have numerous environmental benefits there is also the risk of harming the local ecosystem, e.g., by introducing non-native (potentially invasive) species, the

facilitation of disease, and changes to the local physiochemical environment (Campbell et al., 2019).

Many seaweed farmers share a sincere care for the environment, particularly the ocean. Nonetheless, environmental effects of seaweed cultivation should be carefully monitored. However, currently this does not seem to be the case. None of the interviewees on the Dutch context reported experience with environmental monitoring. Interviewee 1Fg, from Germany, points out that environmental monitoring assessments have to be conducted annually, however, only because they are an IMTA farm. Further, assessments are not conducted by independent actors but by the owners of the company. This may not be a problem now, but if seaweed cultivation were to be scaled up and environmental effects were not carefully monitored by independent actors, dire consequences for the environment could follow.

Further, while there is a agreement within the sector to only use local starting material (Interviewee 6S, 8P), i.e., no further than 200 km from the farming site, as well as relevant EU legislation (e.g., the Invasive Alien Species Regulation (European Commission, 2022a)), the localness is not clearly defined (see *Environmental Effects*). While novel foods do have to be approved by the EU Commission on the basis of a positive safety assessment by the European Food Safety before they can enter the EU market (DG MARE, 2024; European Commission, 2022a), this has no relevance for non-food seaweed products. Consequently, measures for ecosystem protection should be implemented in a legally binding way to ensure sustainable seaweed cultivation.

Existing Support and Useful Practices

As discussed in the results section, Existing Support and Useful Practices reported in the interviews are collaboration and enthusiasm, investments, employing a trial-and-error mindset, and long term thinking. As these points are quite straightforward, and no contestation arose during the interviews, I will not discuss these aspects further in this discussion. While these

coping strategies are certainly helpful for the short-term survival of the industry, more systematic efforts are needed for seaweed cultivation in Germany and the Netherlands to flourish. I will outline these hereafter.

Possible Measures

As discussed in the results section, solutions proposed by the interviewees are optimization and standardization, increasing consumer acceptance, increasing visibility, ecosystem service monetization, funding, water and ecosystem protection, licensing, and mindful species selection. As the lack of demand is currently the most pressing issue of the industry, measures taken to address this are most urgent. Therefore, the visibility of European seaweed for policy-makers, industrial customers, and consumers needs to be increased, funding should be expanded, ecosystem service monetization considered, and the entire supply chain systematized and optimized. Efforts should be taken to streamline licensing, once demand is secured. In this section, I will discuss the proposal of an offset subsidy, and ecosystem service monetization.

Offset Subsidy

Interviewee 4N proposed an offset subsidy, offsetting currently high production costs to enable high volumes to be produced and thereby enable price reductions via optimization and standardization. This would replace the current system of accessing investments through pitches. Applying for short-term or one-off funds continuously takes time away from farming and may also advantage marketing-heavy companies over those with more practical knowledge (Interviewee 6S). An offset subsidy would be more predictable (i.e., long-term planning would be easier), offer more freedom to farmers, and could enable a focus on output rather than on innovation-for-innovation-sake, precisely what is needed to systematize and optimize production.

Offset subsidies have been proven successful when used for renewable energy sources, the feed-in tariff (FIT), as employed for example in Germany, and Spain. FITs offer renewable energy generators the “right to sell all their production in the electricity network and to obtain, in exchange, a retribution based on a fixed price or, alternatively, on the daily price of electricity market plus an incentive that compensates the environmental value” (García-Alvarez & Mariz-Pérez, 2012, p. 53). Germany and Spain are now the top two countries of total renewable energy capacity within the EU (Statista, 2023). Offset subsidies internalize the external costs associated with conventional products (García-Alvarez & Mariz-Pérez, 2012), in this case fossil fuels and agri- and aquaculture respectively. Therefore, offset subsidies can be a useful tool to bridge the niche innovation phase of seaweeds and reach its breakthrough (Phase 3). However, key specifics would need to be defined, e.g., what payments would be based on (i.e., weight or cultivated area), and on what level this would be introduced (i.e., EU or national). Besides, potential negative impacts should be considered, e.g., unsustainable cultivation practices and misuse. Thus, further research is needed.

However, while this subsidy may bridge the current demand gap, it would not ultimately solve the issue of demand as prices are unlikely to decrease to Asian levels and new application products still need to be developed to fuel demand. Yet, it would give the industry time to work on this while simultaneously lowering costs through systematization and optimization.

Ecosystem Service Monetization

The monetization of ecosystem services provided by macroalgae cultivation is one of the ways in which seaweed farmers could be supported. Yet, it is crucial to assess whether these services are certain enough to be financially quantified. Importantly, seaweeds can lose their ability to offer ecosystem services, or even have negative ecosystem impacts, when the ecosystem experiences anthropogenic disruption (Cotas et al., 2023). The evaluation of different

ecosystem benefits are in different phases and come to different conclusions. I will explore two examples, carbon removal (local and global), and nutrient removal.

As for carbon, it is clear that seaweed does take up carbon through photosynthesis, however, the rate of carbon fixation depends on light intensity, carbon dioxide concentration, temperature, and salinity (Wageningen Marine Research et al., 2020). Therefore, it differs per location. Further, even if local carbon uptake and thereby local de-acidification can be quantified (Xiao et al., 2021), the role of seaweed as a decarbonisation tool is much more complicated. Whether carbon can be sequestered through seaweed cultivation depends on the seaweed's further processing and use (Ould & Caldwell, 2022). These factors should be considered before offering carbon credits for seaweed cultivation. Evidence on ocean de-acidification is stronger, thus monetization for ocean-deacidification makes more sense.

"Eutrophication is an increase in the concentration of chemical nutrients in an ecosystem to an extent that increases the primary productivity of the ecosystem." (Webber, 2010, Preface) Tackling eutrophication through seaweeds, particularly in IMTA systems which are aimed at reducing nutrient pollution from aquaculture (Nederlof et al., 2021), has been reportedly successful, e.g., by Seghetta et al. (2016). Seaweeds take up nutrients while growing, e.g., phosphorus and nitrogen, therefore, the primary productivity of the ecosystem increases. This mechanism is well established. However, it is not equally helpful in all conditions, i.e., if there is a nutrient deficiency, it is harmful (Harrison & Hurd, 2001; Yellow Sea Fisheries Research Institute, 1989). Thus, the function of seaweed as a nutrient scrubber should not be generally rewarded but only with consideration of the local conditions.

Limitations

All interviews were conducted in English, although it was not the native language of neither any of the interviewees nor the researcher. This may have led to misunderstandings. I accounted for this by giving the interviewees the chance to check their transcripts. Further, the

interviews were conducted online via video meetings, therefore participants may have felt less comfortable sharing more vulnerable information (Oates et al., 2022). As the semi-structured interviews were based on literature review and guided by the Multi-Perspective Framework, this may have caused me to disregard or not discuss aspects not covered in literature. Finally, only one of the interviewees was an expert on the German context (1Fg) which could have lead to an uneven weight of the Dutch context as all other interviewees were familiar with that, although not exclusively as the European seaweed sector is well connected.

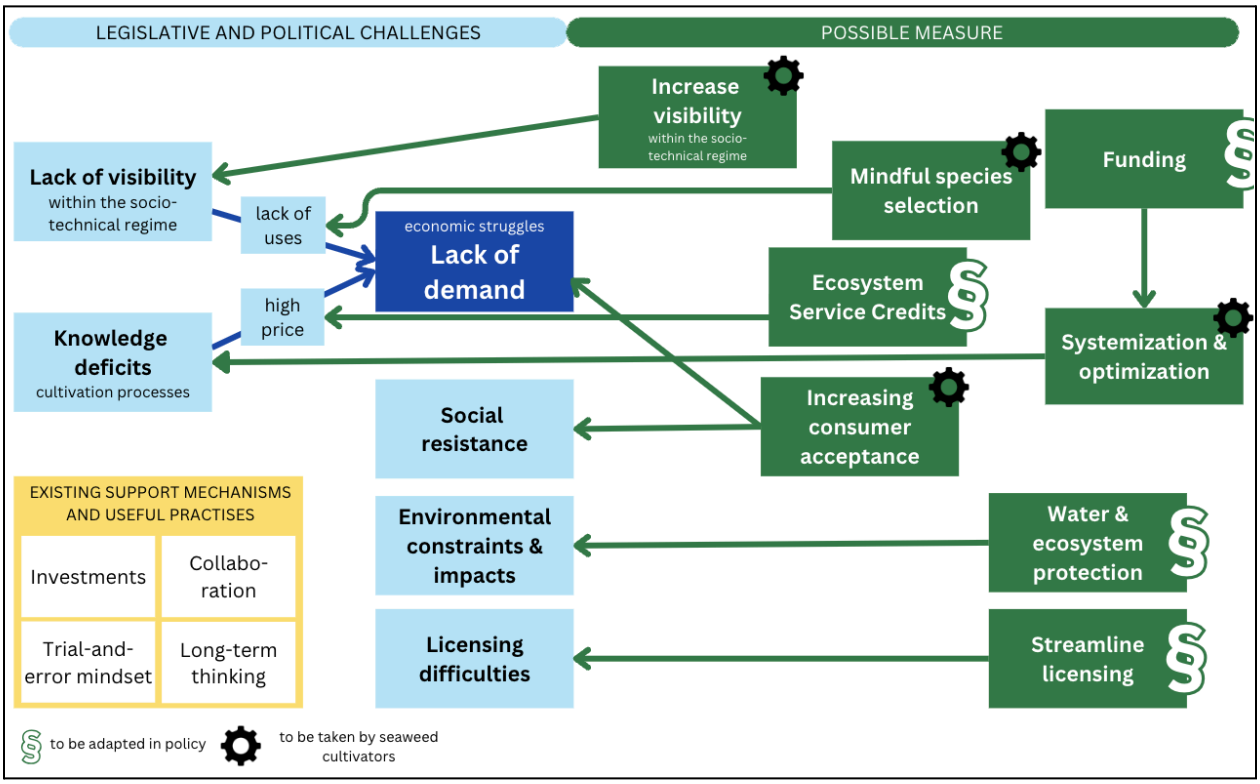
Conclusion

This thesis aimed to answer the research question, *How can the core challenges of seaweed farms in Germany and the Netherlands be overcome to achieve sustainable and commercially viable seaweed cultivation?* The challenges faced by seaweed farmers in the Netherlands and Germany are diverse and connected to a diverse range of disciplines, Hence, an interdisciplinary approach is necessary. Further, while the scope of this research project is very small due to its Dutch-German focus, it relates to the larger global issue of an agricultural crisis and macro algo cultivation in other contexts. Macro-algae cultivation can be considered part of regenerative agriculture and thus is contributing to the agricultural transition.

In Figure 6, my findings are outlined, in terms of legislative and political challenges (blue), existing support mechanisms and useful practices (yellow), and possible measures (green).

Figure 6

Legislative and political challenges, existing support mechanisms & useful practices, and possible measures for seaweed cultivation in Germany and the Netherlands



Note. Own work. The blue arrows represent causal links while the green arrows represent the problems tackled by the respective measure. The paragraph sign marks measures related to policy changes. The gear wheel indicated measures related to changes made within the seaweed industry, i.e., the emerging niche innovation.

The lack of demand for European seaweed is the most pressing issue within the Dutch and German seaweed sector. This issue is due to a lack of established uses, mainly because of the lack of visibility of European seaweed within the socio-technical regime, i.e., policy-makers, industrial customers, consumers, as well as high prices, exacerbated by knowledge deficits. Demand could be stimulated by new uses (by increasing the visibility of European seaweed for policy-makers, industrial customers, and consumers, and mindful species selection) and decreasing prices (by optimizing and standardizing production, made possible through funding). The current low demand situation could be bridged and move to the next phase of the

Multi-Level Perspective Framework, with an offset subsidy, as proven successful in the renewable energy transition. Ecosystem service monetization should be carefully considered for relieving some of the low demand pressure.

Challenges which are of secondary importance until the demand gap is closed are social resistance, environmental constraints and impacts, and licensing difficulties. They can be tackled by increasing consumer acceptance, water and environmental protection, and streamlining licensing (in particular first access via pilot licenses), respectively. The main aspects of the socio-technical regime are to be adapted by seaweed cultivators and policy-makers.

There are some differences between Germany and the Netherlands. For one, Germany produces more micro-algae than macro-algae (Araújo et al., 2021). Further, environmental monitoring exists in Germany, albeit only in an IMTA context. Moreover, licensing seems to be more complicated in Germany, although that once again is likely due to the IMTA model of the interviewee.

Before designing further measures to ensure the sustainable and commercially viable success of seaweed cultivation in Germany and the Netherlands, it is important to consider the different visions for the sector: (a) scale up and potentially competing with Asian seaweed for existing applications, (b) produce for the local context and create new applications for the European context. Different visions translate to different measures, and different ways in which the regime should be adjusted in Phase 4 of the Multi-Level-Perspective Framework.

Further Research Recommendations

Firstly, it would be very beneficial to learn more about the licensing procedure in the Netherlands from local farmers directly, as neither of the two Dutch farmers I interviewed had licensed their farm themselves. Unfortunately, my efforts to interview the people who originally licensed the farm were unsuccessful, thus, further research is required. Secondly, the question

of scale-up and the potential positive and negative impacts on local communities and ecosystems should be examined to more precisely understand what the Dutch and German seaweed sector should strive towards. Thirdly, research is needed to further validify and quantify claims on the environmental benefits of seaweed cultivation, as well as the potential pharmaceutical and nutraceutical applications. This would offer more certainty to investors and industrial customers. Fourthly, better understanding community (i.e., non-commercial) seaweed cultivation would offer new opportunities for localized seaweed production. Finally, an assessment of the entire European seaweed sector would be beneficial to offer a more comprehensive view of the situation in the entire continent, which is particularly relevant for the relevant EU legislation and policy.

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Appendices

Appendix A: Interview Guides

Farmers

1. I already know some things but for the interview could you shortly introduce yourself and your relation to seaweed?
2. What barriers has your organization experienced in seaweed cultivation in the Netherlands/Germany?
    a. What has your organization struggled with financially?/Where do you see economic barriers in the industry?
        i. ask specifically about labor costs, machinery, licensing, and taxes (check if they agree, ask to rank)
        ii. How has this changed over time?
        iii. How has your organization delt with this?
    b. Do you think that seaweed cultivation is socially accepted and celebrated? Have you experienced resistance? (onshore VS offshore)
        i. How has this changed over time?
        ii. How has your organization delt with this?
    c. How informed is your organization informed to make decisions on siting, species selection, cultivation and harvesting methods, and so on?
        i. How has this changed over time?
        ii. Where do you think this information could and should come from? Is there a role for the government, academia, the sector itself?
        iii. Are there specific platforms/ sources you use, and how could these be improved?
    d. How has the process of licensing been for your organization?/Do you see any barriers in the licensing procedure?
        i. How has this changed over time?
        ii. How has your organization delt with this?
3. What measures should the government take to promote/support and sustain sustainable seaweed cultivation? (municipalities, provinces, Rijksoverheid, EU)
4. Is there anything that you think is important to mention in the context of this interview on policy for sustainable seaweed cultivation that hasn't come up yet? What do you wish I had asked you?

Wind energy sector

1. I already know some things but for the interview could you shortly introduce yourself and your relation to seaweed?
2. What has been your experience in Wind + Weed?
3. What difficulties have you faced?

   a. What have you struggled with financially?/Where do you see economic barriers? (labor costs, machinery, licensing, taxes)
   b. Do you feel that Wind + Weed is socially accepted and celebrated (especially within wind energy sector)? Have you experienced resistance?
   c. Do you feel sufficiently informed to make decisions on siting, species selection, cultivation and harvesting methods, and so on?
   d. How has the process of licensing been for you?/Do you see any barriers in the licensing procedure, particularly for Wind + Weed?
4. What measures should the government take to promote/support and sustain Wind + Weed?
5. Is there anything that you think is important to mention in the context of this interview on policy for sustainable seaweed cultivation through Wind + Weed that hasn't come up yet? What do you wish I had asked you?

Seed supplier

1. I already know some things, but for the interview could you shortly introduce yourself and your relation to seaweed?
2. What barriers do you see for seaweed cultivation in the Netherlands?
   a. What have you struggled with financially?/Where do you see economic barriers? (labor costs, machinery, licensing, taxes) – What financial issues do you see in the *seed* industry?
   b. Do you feel that seaweed cultivation is socially accepted and celebrated? Have you experienced resistance? (onshore VS offshore) – probably not, might skip
   c. Are you under the impression that seaweed farmers are sufficiently informed to make decisions on siting, species selection, cultivation and harvesting methods, and so on? – Do you feel you sometimes lack information/knowledge for *seeding*? In which areas?
   d. How has the process of licensing been for you?/Do you see any barriers in the licensing procedure?
3. What measures should the government take to promote/support and sustain sustainable seaweed cultivation?
4. Is there anything that you think is important to mention in the context of this interview on policy for sustainable seaweed cultivation that hasn't come up yet? What do you wish I had asked you?

Policy-makers

1. I already know some things about you, but for the interview could you shortly introduce yourself, your department & your role in fostering seaweed cultivation?
2. What do you think the biggest barriers to seaweed (macro-algae) cultivation in Germany and the Netherlands are?
   a. From the farmers, I've mainly heard about the demand issue, what is your view on that, and what do you do to counter the problem?

    b. What is being done to protect the health of European waters? What role does this play for seaweed cultivation?
3. What policies are not working? What measures would you take, if you were completely in charge?
4. How is your department working on facilitating sustainable seaweed cultivation?
    a. How has the algae farmers toolkit gone beyond licensing?
    b. Do see a chance for shifting for targeted monetary support to a general offset subsidy?
    c. Do you see a value in ecosystem services financing (de-eutrophication, oxygenation)?
5. Does it make sense to upscale while monitoring is not in place yet for achieving a sustainable seaweed sectors?
6. Where do you see the future of seaweed cultivation in NL and Germany?
7. Is there anything that you think is important to mention in the context of this interview on policy for sustainable seaweed cultivation that hasn't come up yet? What do you wish I had asked you?

Appendix B: Consent form

Seaweed cultivation in the Netherlands and Germany

Dear _____,

Thank you for your interest in participating in this research. This letter explains what the research entails and how the research will be conducted. Please take time to read the following information carefully. If any information is not clear kindly ask questions using the contact details of the researchers provided at the end of this letter.

WHAT THIS STUDY IS ABOUT?

This study aims to understand what challenges seaweed farmers are faced with and what needs to be done at a policy level to ensure their sustainable commercial success. There will be around seven participants in total. You have been asked to participate because of your expertise in the seaweed industry.

WHAT DOES PARTICIPATION INVOLVE?

Participating in this study involves participating in an interview of 30 to 60 minutes, online or offline (at a location in the Netherlands or Northern Germany), depending on what is preferred by the participant.

DO YOU HAVE TO PARTICIPATE?

Participating is absolutely voluntary. You can choose to withdraw from the study at any moment and choose not to answer questions without consequences or providing reasons.

ARE THERE ANY RISKS IN PARTICIPATING?

This research might produce both positive and negative findings about the seaweed sector. Further, it might have consequences in terms of policy changes.

ARE THERE ANY BENEFITS IN PARTICIPATING?

There are no direct benefits in participating but the research may contribute to further knowledge on seaweed cultivation in the Netherlands and Germany and be informative for others in the sector.

HOW WILL INFORMATION YOU PROVIDE BE RECORDED, STORED, AND PROTECTED?

The interviews will be transcribed using Otter.ai, coded with Atlas.ti, and stored in the main researcher's university workspace. The raw transcripts will only be accessible to the researcher and the supervisor. The anonymized transcripts might be published in the appendix of the final research paper if the interviewee consents to this. The data will be deleted by the end of the required archiving period before September 1st, 2034.

WHAT WILL HAPPEN TO THE RESULTS OF THE STUDY?

The results of the study will be published in the University of Groningen platform for theses.

ETHICAL APPROVAL

This research study has obtained ethical approval from the Campus Fryslân Ethics Committee. The researchers will uphold themselves to relevant ethical standards.

INFORMED CONSENT FORM

Please sign the informed consent form to state that you intend to participate. You are still able to withdraw this consent at any time.

WHO SHOULD YOU CONTACT FOR FURTHER INFORMATION?

Barbara Thurnay, email (primary researcher)
Tim Huiskes, email (supervisor)

INFORMED CONSENT FORM
Title study: Seaweed Cultivation in Germany and the Netherlands
Name participant: _____

Assessment

- I have read the information sheet and was able to ask any additional questions to the researcher.

- I understand I may ask questions about the study at any time.
- I understand I have the right to withdraw from the study at any time without giving a reason.
- I understand that at any time I can refuse to answer any question without any consequences.
- I understand that I will not benefit directly from participating in this research.

Confidentiality and Data Use

- I understand that none of my individual information will be disclosed to anyone outside the study team and my name will not be published.
- I understand that the information provided will be used only for this research and publications directly related to this research project.
- I understand that data (consent forms, recordings, interview transcripts) will be retained on the Y-drive of the University of Groningen server for 5 years, in correspondence with the university GDPR legislation.

Further questions

- ☐ I wish to receive a copy of the scientific output of the project.
- ☐ I do not want my interview to be recorded.
- ☐ I do not want my recorded interview to be stored as part of the raw data.
- ☐ I do not want my anonymized transcript to be included in the final research paper (in the Appendix).

Having read and understood all the above, I agree to participate in the research study: yes / no

Date: _____

Signature: _____

To be filled in by the researcher:

- I declare that I have thoroughly informed the research participant about the research study and answered any remaining questions to the best of my knowledge.
- I agree that this person participates in the research study.

Date: _____

Signature: _____