"What are the structural barriers and drivers to the development of the emerging sector of seaweed cultivation in Iceland on a local, regional and national level?

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Abstract

Climate change necessitates a transformation of our resource use. Seaweed can play an important role in this transformation, as it grows with minimal land and water inputs, with many industry applications. Iceland, with optimal growth conditions, and a favorable market position seeks to scale up their algae production from wild harvesting to cultivation. However, there are several environmental, social, operational, commercial and regulatory obstacles that must be overcome. A literature review, combined with interviews was utilized to analyze the emerging industry on a local, regional and national level, identifying the key obstacles and drivers. The lack of legislation emerges as the biggest inhibitor of the industry, halting investment, and general activity for cultivators. Other challenges include uncertainties about environmental conditions, including ideal siting, managerial practices to maximize ecosystem services and bioremediation capabilities, a lack of market demand and shared visions.

Introduction

The 2023 IPCC Climate Change Report urgently calls for immediate climate action, highlighting the rapid and large-scale impacts of climate change across the atmosphere, ocean, cryosphere, and biosphere (Calvin et al., 2023). Our activities in the Anthropocene (Dalby, 2020), mainly "energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals" (Calvin et al., 2023, p. 4), are responsible for changes in weather patterns and climate extremes across the globe. This results in devastating consequences on human and planetary well-being (Calvin et al., 2023). It is now more critical than ever to achieve a global transition across all commercial sectors to reduce emissions and resources and ensure a livable planet for current and future generations.

The Paris Agreement 2015, the most recent famous landmark for climate change action, acknowledges the need to establish solutions and responses to climate change based on the best available scientific knowledge (United Nations, 2015). As part of the Paris Agreement, Iceland is committed to reducing greenhouse gas emissions and achieving climate neutrality in 2040 (Ministry for the Environment and Natural Resources, 2021). Under the Paris Agreement, Iceland submitted a Nationally Determined Contribution (NDC). Together with Norway and the European Union Member States, Iceland aims to reduce 40% of its emissions compared to 1990 (Ministry for the Environment and Natural Resources, 2018). Other commitments of the Icelandic government include meeting the United Nations Sustainable Development Goals ("Iceland's Implementation of the 2030 Agenda for Sustainable Development - Voluntary National Review," 2019).

Duarte et al. (2021) states that meeting the United Nations sustainable development goals requires finding new bioresources that meet the following conditions:

> Be grown sustainably, with minimal requirements of arable land, water, and energy; support a net production of healthy food for humans and animals grown on land and at sea, and sustainable and cost-effective energy; and provide sustainable materials harmless to the environment, all while delivering positive, rather than negative, impacts on biodiversity and the environment (Duarte et al., 2021).

The search for bioresources with such a broad slate of positive contributions leads to algae aquaculture as a scalable and sustainable solution (Duarte et al., 2021). This idea is supported by other academics who see aquaculture as a crucial pillar of our future seafood supply but are also warn about the negative impact of the increased production on the environment's safety (Alleway et al., 2023). Seaweed resources are an essential factor in the European Blue Growth and Bioeconomy, which are EU-wide long-term strategies that aim to achieve sustainable, circular development and growth while simultaneously creating jobs, innovation and services (Araújo et al., 2021). Iceland, in particular, has witnessed the emergence of its algae aquaculture sector, which could cover many of the requirements mentioned above. The Icelandic government is confident about the economic potential hidden in the plants, concluding their 2023 report on the State and Future of Aquaculture in Iceland with the explicit goal of accelerating algae farming growth (Boston Consulting Group, 2023). Their confidence is rooted in the multitude of industry uses for algae, favorable geographical conditions for cultivation, and the ability of macroalgae to contribute to ecosystem services (Boston Consulting Group, 2023). However, this hope and confidence currently lacks legislative backing. There is little to no legislation, regulation and

government guidance for aspiring algae producers who want to farm commercially instead of only wild harvesting (Boston Consulting Group, 2023). This shows, for example, in the form of a complete lack of licensing for commercial cultivation. As of now, licensing exists only for wild harvesting, in which the focus is to use it sustainably, meaning "It is not permitted to mow an area when less than four years have passed since the area was last mowed" (island.is, 2021). Given the predicted demand for algae in the following years, Iceland must expand into the cultivation field (Boston Consulting Group, 2023). No previous assessments combining literature with interviews have been made of the nascent industry, highlighting the relevance of this thesis which comprehensively analyzes the barriers and opportunities of the algae cultivation industry on the local, regional, and national level.

Seaweed aquaculture overview

Ecology of seaweed

Seaweed is the collective term for benthic marine macroalgae visible to the naked eye (El-Manaway & Rashedy, 2022). To this day, several thousand species have been identified. They are broadly classified into red (*Rhodophyta*), brown (*Ochrophyta*) and green algae (*Chlorophyta*) (Zhang et al., 2022). A complete list of the native species of Iceland can be found in Appendix 1. It grows in various regions across the planet, widely dispersed in ecological niches from coastal shallows to deep coral reefs to sandy bottoms to intertidal zones, from freshwater to brackish to marine water (El-Manaway & Rashedy, 2022). Suitable conditions for seaweed aquaculture vary, depending on region and species. Typical conditions include sunlight for photosynthesis, nutrient availability, salinity, temperature range, hydrodynamics, pH, oxygen, and carbon dioxide and wave exposure (Tullberg et al., 2022; El-Manaway & Rashedy, 2022).

An environmental impact assessment is conducted to check the economic and ecological suitability for cultivation. Deploying algae aquaculture systems may have irreversible impacts on the oceans. The risk of introducing alien species, parasites, and pathogens must be assessed, as must preservation strategies for local biodiversity (Barbier et al., 2020). Algae play an essential role in the ecosystem as carbon sinks, producers of oxygen, habitats for flora and fauna, food sources, and buffers for coastal zones (El-Manaway & Rashedy, 2022).

What is Aquaculture?

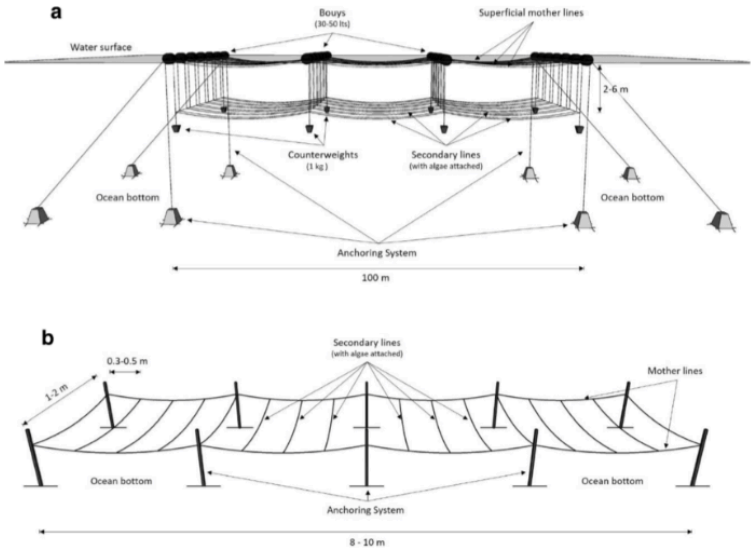
The FAO defined aquaculture as:

> The rearing or cultivation of aquatic organisms using techniques designed to increase the production of the organisms in question beyond the natural capacity of the environment; the organisms remain the property of a natural or legal person throughout the rearing or culture stage, up to and including harvesting." (European Union, 2017, p.5)

The farming method and infrastructure vary between algae species and their ideal growing environments. Longlines (see Figure 1) are commonly used, but rafts, nets, and tube nets are also employed (Tullberg et al., 2022). To produce seaweed, farmers often use a hatchery to cultivate the "propagules"—the pieces of algae that can grow into a new plant—and place them in an environment where they can grow out until they are a harvestable size (*Seaweed Aquaculture*, n.d.).

Figure 1

Examples of cultivation systems for macroalgae



Note: A: long-line culture system adapted for algae growing. B: bottom culture system for shallow location (Contador et al., 2019)

What does it mean to be sustainable in seaweed aquaculture?

According to Bunting (2024), there is widespread recognition that sustainability is founded on three interdependent components, namely economic development, social development and environmental protection. However, the practices and procedures to achieve this are not well-defined and differ in application and management (Bunting, 2024).

For this essay, sustainability is defined as follows:

1. Employing infrastructure and management to have a precautionary approach and practices that minimize negative environmental impacts and protect biodiversity (Alleway et al., 2023; Bunting, 2024)

2. Farming at an intensity or scale that can enhance ecosystem outcomes and stays within ecosystem carrying capacity (Alleway et al., 2023; Pernet & Browman, 2021)

Scaling up

Several factors must be considered, including what investments are to be made, the additional space needed and what technologies are necessary (Barbier et al., 2020; Vijayaram et al., 2024). Further, there must be a market demand to ensure the increased supply is sold. For this, it can help to identify a market niche to avoid competitors, such as in Iceland's case, Asia. (Boston Consulting Group, 2023). Scaling up also entails making the farm more efficient, making it possible to lower operational costs, and increasing productivity (Greene & Scott-Buechler, 2022).

Licenses

Ecosystem health is based on the interplay of different species and biotic and abiotic factors. Introducing a crop may result in negative consequences to the ecosystem. Adverse effects of poorly placed aquaculture farms include shading, physical obstruction, changed hydrodynamics, nutrient depletion, benthic enrichment, and altered biochemical interactions (Forbes et al., 2022). Further concerns include the ecosystem's carrying capacity, the introduction of new genotypes (exotic species or genetically modified species), diseases and threats to local wildlife through, e.g. entanglement (Percy & Hishamunda, 2001). Siting and environmental impact assessment can ensure the aquaculture farm is established in a suitable spot to minimize harm. Clarity with these conditions is essential and must be held against explicit policy principles (Percy & Hishamunda, 2001).

An essential part of tackling these challenges is establishing a licensing framework. Licenses or permits provide a framework of regulations and rules for algae farmers, including the definition of activity, methodology, timeframes, and monitoring (University of Stirling, 2020; Percy & Hishamunda, 2001). Ideally, the permits are established in collaboration with all relevant stakeholders on a local, regional and national level. This ensures that the industry receives a social license, which is "The ongoing acceptance or approval of an operation by those local communities stakeholders that are affected by it and who can affect its profitability" (Gallois et al., 2016, p. 46). Factors to achieve a social license are creation of local jobs, communication and engagement with local communities. This is especially important for international companies. This increases accountability and regulation, which ultimately leads to a more socially responsible and equitable development of the industry (Billing et al., 2021)

European Context

Current EU political priorities are focused on a transition to a sustainable economy, balancing the growth of economic activities, the protection of natural resources and the needs of a growing world population (Araújo et al., 2021).

The global seaweed sector has continuously grown, with harvests totalling 2.2 million tonnes in 1969 and rising to more than 35 million in 2019 (Tullberg et al., 2022). Wild harvests on this scale are unsustainable, as the shrinking algae stocks demonstrate. Thus, algae cultivation has emerged as a viable alternative. Most of the seaweed is farmed in East Asia, with China as the leading producer (Tullberg et al., 2022). Contrary to East Asia, where 97% of all algae production is located, the algae cultivation sector is relatively novel in the European context (Kuech et al., 2023), having emerged only in 2010 (Zhang et al., 2022).

The EU Algae Initiative is part of the European Green Deal's policy initiatives, which is working on developing algae production and its associated value chains in the European Union (Kuech et al., 2023).

Currently, 68% of macroalgae is harvested from wild stocks and 32% from macroalgae aquaculture. Due to the decreased abundance of seaweed through harvests, algae cultivation was established and scaled up. However, within the European Union, many challenges still need to be addressed, including knowledge gaps, the environmental impact of algae aquaculture, profitability, and lack of market demand (Kuech et al., 2023). Moreover, applying for licenses in the European Union takes 4-20+ months, slowing investment and growth (European Union, Maritime Forum, n.d.).

Research Question and Objectives

Wild harvesting already has an established policy framework in Iceland. Meanwhile, the emerging algae cultivation sector is still unlegislated. This gives relevance to the research question:

"What are the structural barriers and drivers to the development of the emerging sector of seaweed cultivation in Iceland on a local, regional and national level?"

This study aims to understand the state of the art in algae cultivation, identify barriers and drivers, and their influence on local, regional, and national stakeholders.

Methodology

This study uses a combination of literature review and interviews to analyze the strengths, weaknesses, opportunities and threats (SWOT analysis) to gain an in-depth understanding of the development and challenges of the emerging algae cultivation sector. Due to the scope of this thesis, the review will be limited to knowledge relevant to Europe (i.e. temperate biomes and shared policies), even though Asia holds a vast amount of knowledge and experience in the field.

Swot Analysis

The "SWOT analysis" tool is used to improve management strategies of organizations, institutions or companies (Hill & Westbrook, 1997; Baycheva-Merger & Wolfslehner, 2016). For this paper, it is used to discover and examine internal and external factors that positively or negatively influence the algae cultivation industry (see Table 1). SWOT analysis may be utilized for strategic planning and decision-making processes (Baycheva-Merger & Wolfslehner, 2016). This SWOT analysis focuses on the current situation and market.

Table 1

Table describing the criteria for the SWOT - analysis

	Positive	Negative
Internal Environment	**Strengths** Internal factors of the industry itself Additional: A strength is only a strength if it responds to an opportunity or threat (Jiang et al., 2018)	**Weaknesses** Internal factors of the industry itself
External Environment	**Opportunities** Political, institutional, social, economic, technological features which create positive potential for the industry Additional: Opportunity is opportunity if the industry has a chance to react to it (Jiang et al,. 2018)	**Threats** Political, institutional, social, economic, technological features which create negative potential for the industry

Data Collection

The literature review was started broadly, focusing on literature regarding the ecosystem benefits of macroalgae cultivation, potential challenges for macroalgae cultivation, and the state of algae aquaculture in Iceland. For this, the search engine SmartCat, the academic online library of the University of Groningen, and EU and government reports were mainly used.

To receive novel information and provide a basis for the SWOT analysis, semi-structured interviews with relevant stakeholders at three levels, Local, Regional and National, were held. The interviews were all held online except for one. The interview questions were mainly open-ended to allow participants to answer in full detail and explore the content in depth. The interview guides can be found in Appendix X2. The interviews were around 30-45 minutes long

to give enough time to accommodate potential language barriers. One participant had a translator available to ensure good communication. The data was coded with the criteria elaborated for the SWOT analysis (see Table 1).

To get a more comprehensive picture, two interviews per level were conducted. At the local level, the local seaweed company Eldey Aqua was selected for its expertise and firsthand experience in trying to establish a seaweed farm. The second local actor who works in the later version of this company, Resea Energy, joined more recently. The regional stakeholder is the Algae Association of Iceland, which works on increasing knowledge about algae in Iceland and promoting business related to algae cultivation to relevant stakeholders (Algae Association of Iceland, n.d.), as well as a member of the Sea Cluster, an organization concerned with the full utilization of sea products (Íslenski sjávarklasinn, 2024). The governmental actor was a member of parliament who is working on the establishment of the algae policies. Lastly, a member of the Ministry of Food, Agriculture and Fisheries was interviewed due to their involvement in the current legislative processes. All these actors were chosen for their expertise and engagement in the field. This allows deeper insight into the layered nature of establishing a framework for an emerging industry and how perceived challenges vary across the different levels.

Sampling of participants and ethical considerations

Interviewees were selected through convenience sampling, using online research of relevant stakeholders and recommendations from personal networks. Potential participants were contacted via email or phone. Ethical approval was obtained from the Ethics Committee of the University of Groningen. The raw data is only available to the researcher and will be stored according to the GDPR (General Data Protection Regulation) guidelines. The final capstone

document will be kept on the Y-drive of the University of Groningen server, adhering to the university GDPR legislation. Before interviews, participants read through an informed consent sheet, which outlines the study and reiterates the rights of the participants. The participants could choose to what degree their identity was revealed, and all, except one, agreed to use their name and affiliation. The interviewees could give their input on the results to ensure participant validation.

Results

Literature Review

The literature review combined scientific papers with industry and organizational reports, resulting in 48 revised documents. This allowed the identification of internal factors (strengths, weaknesses) and external factors (opportunities, threats) for Iceland's algae cultivation sector (See Table 2 and 3).

Table 2

Internal factors of the Icelandic algae cultivation industry, identified from literature

Strengths (S-factors)	Weaknesses (W-factors)
SL1. Environmental conditions	WL1. Environmental
SL2. Sustainability	WL2. Balance between ecology and economy
SL3. Provision of ecosystem services	WL3. Spatial competition with other industries
	WL4. Infrastructure
	WL5. Lack of Knowledge

Table 3

External factors of the Icelandic algae cultivation industry, identified from literature

Opportunities (O-factors)	Threats (T-factors)
OL1. Establishing a policy framework	TL1. Lack of legislation
OL2. Market trends	TL2. Impact on ecosystem
	TL3. Climate change

The results of the tables are elaborated below, the internal factors (Strengths, Weaknesses) according to Table 2, the external factors (Opportunities, Threat) according to table 3.

Strengths

Environmental conditions (SL1)

Iceland has very favorable ocean conditions that are suitable for cultivation. The cold waters around Iceland have been identified to have optimal growing conditions regarding depth, temperature range, current speed, nutrient levels, and light exposure (see Figure 2) (Boston Consulting Group, 2023). There are over 300 native species identified, indicating great commercial potential for cultivation (see Appendix 1) (Alþingi, 2023).

Figure 2

Table depicting the ocean growing parameters for two native algae species

Key Parameters	Considerations	
Ocean conditions		
	Saccharina latissima (Beltisþari)	Alaria esculenta (Marinkjarni)
Depth	Seeded lines placed 10-20 m below sea level, anchored at depths of 50-200m	
Temperature	5-15°C	4-10°C
Current tolerance	Moderate to heavy currents	
Nutrients	Sufficient availability of salt, carbon, nitrogen, and phosphorous	
Light	Moderate to high light exposure	
Ocean habitats and activities		
Native algae ranges	Interaction with wild populations	
Interaction with existing aquaculture	Distances between production systems	
Other ocean-based activities	Protected areas, naval routes	
Municipal considerations		
Municipal planning and interest	Coastal property rights, public opinion of aquaculture, labor force availability, infrastructure, processing facilities, access to local & export markets	

Note: Taken from the governmental report "The state and future of aquaculture in Iceland" (Boston Consulting Group, 2023)

Sustainability (SL2)

Algae is a renewable resource, with no additional inputs of freshwater, arable land and a low carbon footprint (Barrett et al., 2022; Boston Consulting Group, 2023). Some algae species have been found to reduce methane emissions of livestock when integrated into their diet (Roque et al., 2021). Wild-grown algae sequester more carbon than cultivated algae, but algae cultivation can "reduce potential pressures on wild stocks and help keep them intact as a carbon sink." (Boston Consulting Group, 2023). Thanks to Iceland's abundance of sustainable (i.e. volcanic/thermal) energy, algae farming is possible at net zero carbon emissions (Boston Consulting Group, 2023).

Provision of ecosystem services (SL3)

Macroalgae provides various ecosystem services, including provisioning, regulating, cultural, and supporting services (Schütt et al., 2023). Algae cultivation can provide services by producing algae crops and supporting the growth of other harvestable species, such as lobsters and molluscs. The regulation services could include seaweed sequestering carbon, positively impacting ocean acidification (Hasselström et al., 2018). Another important regulation service is the benefits of bioremediation. Campbell (2019) explains that algae cultivation may have positive effects if there are excess nutrients (e.g. by anthropogenic activities like salmon farming) that the algae can sequester during its growth (Campbell et al., 2019). Supporting ecosystem services are habitat formation, as wildlife can benefit from the anchoring points of the algae (Hasselström et al., 2018) or use the available surface area of the gear for shelter, spawning, attachment sites, and foraging opportunities (Forbes et al., 2022). Cultural services include cultural heritage and inspiration for coastal communities who traditionally eat algae (Hasselström et al., 2018), cognitive benefits, recreation, and notable biodiversity (Cabral et al., 2016).

Weaknesses

Environmental (WL1)

All authors mention various environmental challenges of algae farming. Lotze et al. (2019) highlight that depending on the scale, intensity, species cultivated, the gear used, and farm management and extraction practices, the ecosystem impact may vary greatly, from "changes in primary production to habitat disruption, fragmentation, food-web alterations and bycatch of non-target species" (Lotze et al., 2019, p. 1). As most macroalgae farms are situated in open

ecosystems, there are concerns regarding genetic pollution of any specimens that detach from the original site (Hasselström et al., 2018). Forbes and Campbell also highlight the dangers of algae monocultures acting as stepping stones for diseases and facilitating the dispersal of invasive species. This risk is exacerbated by commercial operations that increase the number of transport vectors for marine pests (Forbes et al., 2022; Campbell et al., 2019). Forbes also raises the critical point that farms may turn into "ecological traps", meaning that species that choose to live in the farms lose their habitat upon harvest (Forbes et al., 2022).

Balance between ecology and economy (WL2)

Forbes (2022) also concedes that it is challenging to achieve managerial practices that are not harmful to the environment because they are still under-explored. Generalizations from other places (in Iceland's case, Norway) may not apply. This makes the priorities for a commercial context, while still adhering to the values of sustainability and being economically viable, very challenging to set. Forbes et al. (2022) say that "[...] all stakeholders must decide and clarify what they want kelp farms to achieve and produce to avoid overpromising and ensure that commercial and conservation objectives are not undermined." (Forbes et al., 2022, p. 3065).

Spatial competition with other industries (WL3)

Further concerns include the space needed for cultivation (Hasselström et al., 2018). With near-shore farming activities, the industry is in "direct competition in marine spatial planning - namely tourism, shipping and fishing" (Tullberg et al., 2022, p. 2), which can lead to the local populations viewing seaweed cultivation negatively, as they may be direct or indirectly affected (Cabral et al., 2016). In offshore water, the challenge of a lower nutrient level than the coastal

zones arises, which could lead to "reduced seaweed growth rates without additional strategies" (Boston Consulting Group, 2023). To ensure similar competitivity between near-shore and offshore farming, the infrastructure for cultivation must be optimized for high productivity, low harvest and reseeding costs (Boston Consulting Group, 2023).

Infrastructure (WL4)

The infrastructure can be extensive and expensive, depending on the cultivation system. Cultivation structures must be designed to endure infrequent but severe weather events, such as storms and cyclones, and their consequential high-energy waves. Strong currents, depending on the location, must also be considered. Additionally, seaweed service vessels for harvesting, reseeding, and transport tasks need further development (Boston Consulting Group, 2023).

Lack of Knowledge (WL5)

The literature regarding algae cultivation is still not comprehensive, and drawing insights must be done carefully. Papers range from case studies to company reports to experiments with different scopes, scales and practices (Forbes et al., 2022), with no localized experience reports available. Apart from that, there is also a lack of peer-reviewed academic literature specific to Iceland. This literature and data sources for seaweed farming are difficult to come by as environmental conditions, locations, and species vary.

Opportunities

Establishing a policy framework (OL1)

Conquering the environmental, commercial, operational, and regulatory challenges is impossible without a framework. Establishing licenses can play a crucial role in doing so, as they provide a framework of regulations and rules that farmers can adhere to regarding location suitability, interaction with native stocks and environmental risks (Percy & Hishamunda, 2001), which would allow the stakeholders to start their activities (Boston Consulting Group, 2023). Iceland is still working on developing legislation regarding the regulation and definition of macroalgae farming. In 2023, a parliamentary proposal was published titled "Proposal for a parliamentary resolution about increased value creation in the utilization of algae", which concerns itself with the increased usage and value creation of algae (Alþingi, 2023), which is a step in the legislation of algae cultivation.

Market trends (OL2)

Iceland predicts the growth of the algae market due to its newfound popularity in various industries and environmental applications, including as a source of sustainable nutrition, an alternative to traditional animal feed, its ability to mitigate the ecological impacts of fish aquaculture, and its potential to lower carbon alternative for aquaculture and animal feed (Barrett et al., 2022, Boston Consulting Group, 2023). It also finds application uses in the emerging markets of sustainable bioplastics, fuel and fabrics (Tullberg et al., 2022). This is also why investments in infrastructure and equipment to increase processing capacity are made despite the need for more specific legislation. Iceland has identified their niche in the market for nutrient-dense algae species *(e.g. Laminaria sp./klóþang and Saccharina latissima/* beltisþari*)*

that differ from those in the Asian market, avoiding competition with commoditized seaweed products due to their good reputation, especially in the Northern Hemisphere (Boston Consulting Group, 2023).

Threats

Lack of legislative system (TL1)

Iceland lacks sector-specific government guidance and regulation, resulting in slow sector expansion, delays in license approvals, and halting investments. Economic activity cannot commence as it is illegal to farm without a license. Some macroalgae cultivators have partnered with fish aquaculture for farming trials. However, this does not close the legislative gap, as the legislation for salmon is mostly not applicable to algae aquaculture, as they are two species with different infrastructure needs (Boston Consulting Group, 2023).

Additional challenges include the lack of clarity regarding location suitability, interactions with native stocks and other aquaculture, and environmental risks due to the absence of research activity. Much of the research on these factors has not been conducted in Icelandic contexts but rather estimated through comparisons with Norway (Boston Consulting Group, 2023).

Impact on ecosystem (TL2)

The fish farming industry in Iceland has left a significant environmental footprint, with negative impacts ranging from genetic blending to the adverse effects of pharmaceuticals, increased nutrient waste, and diseases (Boston Consulting Group, 2023). In Asia, diseases like the "Ice-ice" disease are on the rise due to the large-scale nature of their operations (Campbell, Kambey, et al., 2019). In Europe, the lack of biosecurity for macroalgae is a concern, as there is

limited epidemiologic knowledge of seaweed pathogens (Campbell et al., 2019). The known detrimental effects of poorly located large-scale aquaculture farms include shading, physical obstruction, altered hydrodynamics, nutrient depletion, benthic enrichment, and modified biochemical interactions (Forbes et al., 2022).

Climate change (TL3)

The implications of climate change are an anticipated threat for Iceland, with potential negative effects on ocean conditions and, consequently, the environmental suitability for algae cultivation. Due to temperature increases and ocean acidification, the optimal growing conditions may shift, potentially affecting native cultivated species (Boston Consulting Group, 2023).

Interviews

The first local interviewee worked in the "Eldey Aqua" company, which later became "Resea Energy". The initial mission of Eldey Aqua was to build up a small, sustainable algae cultivation farm in the Westfjords. The second local interviewee is from Resea Energy and is focused on identifying what needs to be added to the algae cultivation industry's funding and facilitation ecosystem, evaluating the needs of the companies operating in the field, and getting investors into the sector. The first regional actor is the Algae Association of Iceland, which combines more than 40 different entities of Iceland working with algae. The second regional actor comes from the Iceland Ocean Cluster, an organization concerned with fully utilizing marine resources. The governmental stakeholder was a parliamentary member of Iceland, working at the forefront of making algae aquaculture and cultivation policy. Lastly, a members of the Ministry of Food and Agriculture and Fisheries was interviewed, as they are the main ministry involved in legislation

making for aquaculture. All except one of the participants were proficient in English. A translator was used to overcome the language barrier. The following table will explain the abbreviations used in the results section for easier understanding. The "I" stands for "interviewee", and the subsequent "L, R or G" for local, regional and governmental, the 1 and 2 indicating which actor specifically.

Table 4

Explanations of the abbreviations used in the results section

Abbreviation	Affiliation
IL1	Eldey Aqua
IL2	Resea Energy
IR1	Algae Association of Iceland
IR2	Iceland Ocean Cluster
IG1	Parliamentary member of Althingi
IG2	Member of ministry of Food, Agriculture and Fisheries

Table 5

Internal factors of the Icelandic algae cultivation industry, identified from interviews

Strengths (S-factors)	Weaknesses (W-factors)
S1. Sustainability	W1. Lack of legislation
S2. Citizen participation	W2. Lack of long-term vision and investment
S3. Environmental conditions	W3. Lack of market demand
S4. Networks	W4. Logistics
S5. Visibility	W5. Lack of knowledge and direction
	W6. Time pressure

Table 6

Internal factors of the Icelandic algae cultivation industry, identified from interviews

Opportunities (O-factors)	Threats (T-factors)
O1. Establishment of a framework O2. Appeal of the industry O3. Comparison to other countries O4. Driving forces O5. Participating in the legislation advisement process	T1. Lack of legislation and consequential financing issues T2. Non-prioritization T3. Climate change T4. Social license

The results of the tables are elaborated below, the internal factors (Strengths, Weaknesses) according to Table 5, the external factors (Opportunities, Threat) according to table 6.

Strengths

Sustainability (S1)

Across all levels, sustainability emerges as a value and strength for the industry. IR1 says:

> First of all, you are sustainably harvesting, meaning that you take care of the harvesting ground. You do not revisit the same harvesting ground unless it is more than recovered in sustainable harvesting. In the others [cultivation], you are using an already seeded line in a certain territory, and you also take care that it is not affecting the environment except in a positive way.

Both governmental actors are aware of the adverse effects of fish farming and are prioritizing sustainability in their work. Lessons from previous fish farming are taken, which is also why some people in the government want to invest more time into research about algae concerning

the conservation of the species and nature to minimize harmful impacts. IR2 mentions that the industry's sustainability is also related to its ability to use existing vulcanic energy for production and further processes.

Citizen participation/Legislation making (S2)

IL1 was a driver in pushing for the establishment of legislation and managed (along with other stakeholders) to move the issue of algae cultivation more into the political sphere. They remarked that this engagement makes putting forward the algae agenda easier than six years ago when they initially established themselves. The process of making algae legislation is primarily in the hands of the concerned ministries, their staff, and members of parliament. Still, they also include relevant parties of interest. When advising the Boston Consulting Group, IL1 affirms that they were firm on including locality and long-term planning. IR1 mentioned that they have been more involved with the Ministry of Food and the Board of Development of Industries, who are essential decision-makers in algae cultivation. Alongside this, IG1 says they are also actively in "[...] very open discourse about any legislature [with other countries] because we try to gain inspiration from other countries.". IG1 mentions that this enables them to take lessons from other countries to develop good legislation, which can be especially important for them regarding adherence to EEA standards (e.g. health).

Environmental conditions (S3)

Across all levels, there is agreement that the environmental conditions are good. IL1 and IR1 remark on the success of their small-scale cultivation trials. IR2 echoes this, confirming that the ecological conditions for seaweed aquaculture are good. IG1 is similarly of the "[...] opinion that

the opportunities are very promising in the field of algae agriculture and algae harvesting as well.".

Networks (S4)

IR1 and IL1 deem their robust networks to be essential tools for the development of the industry. For IL1, this includes people from academia, different levels of government and a group of advisors. IR1 is the intersection of 40 organizations, from individuals to companies to institutions. They mention that it allows them to join the interests of various stakeholders concerning algae, which helps strengthen their ability to represent their interests during consultations with the government. IR2 also remarks on their ability to be a platform for different projects to support works related to the blue economy. If someone has a working prototype, IR2 are the entity bridging the gap between the research and implementation. IG1 and IG2 explain that they have ambitions to include “relevant stakeholders” in the legislation-making.

Visibility (S5)

Another strength the algae industry has gained is presence and awareness in the civilian and commercial spheres. IL1 made algae more visible, frequently appearing across different media outlets (television, radio, and newspaper). This increased the general awareness of citizens and gained the interest of foreign companies, who had an enormous interest in collaborating with them. They became popular to the point that they were "[...] actually able to choose collaborators."

Weaknesses

Lack of legislation (W1)

Across all three levels, the interviewees mention that the main weakness of the industry is the current lack of legislation. IL1 explains that the lack of involvement of the governing bodies on the local, regional, and national levels limited their efforts to push for legislation. While they were hopeful and "[…] in the spirit of making it happen [...]", the congresspeople were "[...] at the same time, most definitely not focused on making it happen.". They reflect that a contributing factor is that politicians and municipalities have limited timeframes, leading to deprioritization of new topics.

According to IR1, the pressure to move the industry forward comes from the people themselves. However, as few people have been in the seaweed industry, that pressure has been limited. This is reitereated by IR2, who says that the government is dropping their plans for algae legislation because there is too little pressure from the people and because the algae business, although with some successful companies, is not as profitable as fish farming.

IG2 explains that the government dropped the legislative plans for algae due to "[...] the complexities of the legislation, and the fear of algae aquaculture getting lost in the discussion about fish farming". The situation regarding laws becomes even more complex, as they must consider the "[...] EEA regulation as well. We cannot have conflicts". IL2 considers that the unsustainable use of the ecosystems for fish farming is the reason the establishment of the legislation is faltering, as the ecosystem lobby retains high pressure on the government to create good legislation.

Lack of long-term vision and investment (W2)

IG1 identifies the lack of legislature as a reason algae are not as big as it could be. According to IL1, the need for more legislation and long-term planning makes it challenging to get financing into the industry and gain a competitive edge in a market they could dominate. IL1 says: "[…] we were in discussion with partners, but when it came to the lack of long-term governmental plan or framework, it is also preventing financing from other countries because you cannot invest in a question mark.". IL2 explains:

> Here are some [companies] that are getting investment, absolutely, but it is hard to scale the cultivation companies because there isn't demand for the seaweed, because the companies that should generate demand, they haven't gotten far enough [due to lack of legislation] to scale up the research and development to start by (bio)refineries that can process mass scale.

IR1 reiterates this, as uncertainty, e.g., regarding licensing for cultivation, is a challenge because "without getting proper licenses, investments can be eliminated. You cannot get or attract investors if you don't have the legal framework." IR2 questions what and how establishing a framework and licensing could solve this. They reflect, "[...] there are all these questions that have not been addressed yet." Lastly, IL2 mentions that the reactionary approaches to issues lead to abusive industries, and the mistakes are also on a large scale.

Lack of market demand (W3)

IR2 identifies that people in Iceland have lost the habit of eating seaweed, indicating that the market might initially struggle to take to the people. As for the biofuel industry, IR2 says that the market also has an uncertain outlook, as it is currently much cheaper to rely on the natural energy IL2 mentions that the lack of demand and the developing nature of the industry deter potential investors. The fish farming industry experienced high demand from the start, with investments guaranteed. This growth opportunity prompted the government to recognize the "[...] need to start zoning ocean space for an industry" and to work on risk and benefit assessments.

Logistics (W4)

The harsh waters of Iceland necessitate robust infrastructure, especially for offshore farming. IL1 says the equipment is heavy and expensive and must be deployed "[…] quite accurately. It is not something that you can do on goodwill and good faith." Piggybacking off or collaborating with fish farmers to co-share infrastructure (e.g., boats) may be successful but may also result in greenwashing.Transportation infrastructure must also be considered: IL1 and IR2 explain that the freshly harvested algae cannot be transported far, as it spoils quickly after harvest, but that there are no spatial considerations yet to include close-by coastal processing plants.

Lack of knowledge and direction (W5)

IL2 mentions that it still needs to be fully mapped out where algae would be well or ill-suited for cultivation and the ecosystem risks. They compare it to the salmon aquaculture industry, where "[...] there was considerably more information available", as well as resources, which made it much easier to proceed and invest time and money, not only for the government but also for

private entities. According to IL2, more research is needed to assess whether using seaweed to mitigate the negative consequences of fish farming would be viable. At some point, the government investigated using the same legislation for shellfish, although it is a different species, which IL1 found to be "very irresponsible". Lastly, IL2 identifies that there is also "[...] not a consensus about what sustainability means, which is a problem. But it's a better problem than there not being a consensus that sustainability is important.". "[...] We don't necessarily have the groundwork," explains IG2, referring to the fact that algae are still underexplored as a resource. Neither governmental stakeholders use a specific definition for sustainability nor work towards achieving a particular aquaculture model (i.e. regenerative, stock-enhancing, commercial)

Time pressure (W6)

Both local stakeholders mention their perceived lack of time. IL2 says there is an urgency to establish the industry, as algae can be part of the solution to climate change. To do this, they state that trade-offs must be made and risks with ecosystems taken, as "There is no time to fully evaluate the long-term impacts of industrial buildup in ecosystems.". IL1 thinks the industry needs to hurry to establish itself, though it is more concerned about the lack of long-term spatial planning.

Opportunities

Establishment of a framework (O1)

The overarching opportunity for all levels is the establishment of a long-term framework. IL1 reflects that this would "kickstart the industry". This opportunity presents itself for IG1 to pass

the legislation surrounding fish aquaculture so that they can concentrate their efforts on algae aquaculture, a sentiment echoed by IG2, who agrees that without licenses, the industry cannot move forward. IG1 says, "[...] the current government still plans on making legislation and choosing a directive for the future of algae aquaculture that is in the agreement that the current government has signed by all three parties.". The government is currently working on this new legislation for algae cultivation, with the prediction that the process will be finished by the coming winter (2024). The establishment of a framework would also allow for "[...] centralized long-term planning of making and preparing industrial zones for municipalities[...]," according to IL2. IG2 mentions that this already happens in the form of a coastal spatial plan. IG1 aims to develop an industry where "the legislator ensures that the businesses can grow and blossom here in Iceland and the wide world." This is why the government does not employ a copy-paste method for other legislation. Instead, the government invests in making legislation tailored explicitly to Iceland as "Different challenges call for different legislation or at least different research around probable issues that maybe people in Norway wouldn't have faced.".

Appeal of the industry (O2)

IG1 and IG2 also identify opportunities for the industry to lie within the "benefits for smaller communities.. The Progressive Party of Iceland is committed to "the interest[s] of these smaller communities […] and what could benefit them, what kind of industry would benefit them, what kind of companies could start their business in these smaller communities resulting in jobs and more inhabitants' '. IR2 echoes this, noting that the seaweed industry has the potential to strengthen the communities because processing sites must be close to the coast because "seaweed needs to be processed very quickly after being harvested or collected" as it spoils easily. This

means "[...] jobs for the communities, which is very important". IR2 also mentioned that Iceland plans to decentralize their economy from Reykjavik to maintain "happy, prosperous communities all around the island. And I think definitely processing seaweed will have to be done on the coast. And so, therefore, providing activities in like some kind of dynamic, economic dynamic areas as well.".

IR2 also sees an opportunity for seaweed to diversify food production. They explain it has the potential for "[...] not only sustainability but self-sufficiency to some extent, having a diversity of farming is very important." Iceland also has a history of eating seaweed, so IR2 thinks that after rebranding and re-popularizing seaweed as a food source, it could establish itself again and create a market. This is also repeated by IG2, who asserts that seaweed could become "massive" with proper marketing. According to IR1, another appealing factor could be carbon binding. They make clear that:

> It's not going to be what drives the industry in a way that does not make a huge profit for the farmer itself, but it could be a potential way of development for the country in reducing the carbon footprint for the whole nation.

IR2 also sees much potential regarding the industry uses for algae. The organization is predominantly concerned with the full utilization of fish but plans to expand to algae. For this, it is beneficial that algae used to be traditionally eaten. They also see the potential in extracting high-value compounds from the algae, as "[...] that's where you have the most margin.". IG1 says that these products may become globally popular.

IL1 also mentions the potential of algae aquaculture to mediate the effects of fish aquaculture, although it must be taken into account that it may be overmarketed and be misused as "[...] a greenwashing thing, like an image or PR thing to be part of some sustainable practices.". However, if algae aquaculture/mediation is done well, IL2 remarks that the industry can be "[...] the right thing for the environment".

Comparison to other countries (O3)

Iceland gains inspiration and lessons from comparison with other countries and industries for their legislation, according to IL1. They were checking out processes in the Faroe Islands or Norway. For the Faroe Islands, IL1 was inspired by the "[...] grey zone for startups to transfer from research to production, and then they would adjust the legislation to it afterwards.". They explain that to "[..] have a research license and then that the research license would apply to both sustainable harvesting as well as potential cultivation." It could also be a means to establish the industry. IR2 describes how Iceland looks at Norway for inspiration and lessons, although primarily for fish farming. They conclude, "[...] there's much to learn from how Norway set up their farms in general.". IR1 suggested that what the Faroe Islands are doing could be an opportunity for Iceland. IG1 is very aware of the "[...] pros and cons and past experiences from other countries when we are making a legislature here. We primarily look at Denmark, Norway, and other Scandinavian countries, but we have also, in some cases, looked at Britain or Sweden.". IG1 says that comparing to fish farming can point to important lessons, as fish farming is a "[...] very big topic of discussion right now in Iceland for various reasons, mostly related to sustainability."

Driving forces (O4)

According to IL2, what would "really facilitate them scaling up would be to have guaranteed offtake agreements. So, like, have some guarantees that for the biomass that they [cultivators] cultivate, somebody will buy it. IR1 sees it as helpful to lower the threshold to start in the industry of algae in order to potentially have more people enter the industry and increase pressure on policymakers. They also value their position in combining interests they can jointly put forward. IR2 also sees Iceland's favourable energy sector as an opportunity for the industry. Energy in Iceland is quite cheap, which is great for an industry that is "[...] very demanding in terms of infrastructure and energy.". This also ties into her assessment that the only limiting factor is the actual production of algae, not energy. According to them, some production plants are self-sufficient in energy and could scale up production if the law and resources allow it. IL1 says that they are attempting to

> [...] move away from this venture capital model of investing in specific companies, but rather like identifying whole value chains that can be invested in and set up that can then sustain each other, sort of like from the cultivation to the production of some valuable products, where if we facilitate the establishment of the value chain in the same geography, they can then grow symbiotically and get more traditional funding.

which they believe can increase funding from abroad and drive the industry forward.

Participating in the legislation advisement process (O5)

For the IL1, it was a big chance to advise the Boston consulting group, as they are working with the government and are involved with the framework-making. This allowed IL1 to be "[...] quite heavy on the inclusion of locality, or restrictiveness so that we would not get a wild west

scenario as we have with salmon farms.". IL1 sees good legislation as an essential factor to prevent the exploitation of local communities. IR1 was also an advisor, giving suggestions on how legislation should look like. IL2 mentions that the government asked for feedback by inviting all "identified industry entities to come and give thoughts" about the proposal for a parliamentary resolution about increased value creation in the utilization of algae. IG2 mentions that to make the legislation, they would organize citizen participation groups for the industry stakeholders.

Threats

Lack of legislation and consequential financing issues (T1)

The biggest threat to all three levels is the lack of a legislative frame and the consequential issues with financing. IL1 explains that "[…] without clear legislation or at least defined grey zones, it is impossible to get financing into an industry. Without long-term financing, even short-term financing, it is impossible to make plans." This stifles the emerging industry. IR2 also contemplates that , "[…] there's too little plans" and no legislation. IR1 remarks, "If the industry is to develop, then the legislation frame has to be clear because, without proper licenses, investments can be eliminated. You cannot get or attract investors if you don't have the legal framework.". On the same topic, IL2 deliberates that it is hard for traditional investment philosophies and investors to "[...] rationalize putting money into these ventures" without strong demand. IL2 explains that a policy was laid out that private entities could undertake research endeavours (e.g., ecosystem assessments) but that cultivation companies could not stem from this financial responsibility. IL2 explains:

> I mean, there are some that are getting investment, absolutely, but basically there is, it's hard to scale the cultivation companies because there isn't demand for the seaweed, because the companies that should generate demand, they haven't gotten far enough to like actually scale up the research and development to start by (bio) refineries that can process mass scale.

They acknowledge that there is "[...] funding on the production side, but not enough funding on the cultivation side because that doesn't really fit the venture capital model.".

IL2 explains that municipalities are also part of why the legislation is not advancing, as they do not make decisions regarding climate change, are no experts on the matter, and do not know how to create and implement climate infrastructure. What makes the legislation-making even more complex for IG1 is that "there's a big issue here that sometimes there's a conflict of newer and older laws", meaning it is "important as well to make sure that the new legislation around our algae aquaculture wouldn't conflict with older laws", as well as the added difficulty of also making sure it adheres to the EEA standards of e.g. health.

IL2 remarks that Iceland does not do long-term planning, instead mostly engaging in "[...] purely opportunistic [...]" behaviour. This is re-emphasized by IL1, who clarifies that legislation-making is reactionary and not long-term oriented, which they say leads to poor legislation and frameworks and abusive industries.

Non-prioritization (T2)

Furthermore, IR1 affirms that the non-prioritization of algae and prioritization of fish aquaculture is a significant obstacle to the industry; IR2 hypothesizes that this is because the industry has yet

to be profitable. They remark, "Unfortunately, the way this world works [that it] has to be profitable to work.". IL1 also sees this threat. They mention that the priorities are lying elsewhere, namely salmon farming. This issue is also worsened by "governmental shifts, […] leaning from right to left every four years. So you can't push the project that your successor might oppose.". Additionally, many meetings meant to advance the agenda were instead spent on defining terms because the legislators were underprepared. Moreover, they often prioritized other matters, partly because their funding sometimes depended on those priorities, according to IL1. The government also mentioned that fish aquaculture is being prioritized over algae partly because of the current issues within the fish industry. The legislators said they had "the fear of algae aquaculture getting lost in the discussion about fish farming,[so] it was decided not to include it at this point", as the debate surrounding fish farming is already highly complex.

Climate change (T3)

IG1 mentions that climate change and the consequential ocean acidification are risk factors for the algae industry. In their opinion, their effects on life below water must be further researched to allow for long-term plans to be established.

Social license (T4)

Another threat identified by the IR1 is the mentality of "just not in my backyard." Although sentiments towards algae are generally positive and their development is supported, people are generally disinclined to have any operations close to their homes.

Discussion

The structural barriers and drivers for the development of the emerging macroalgae sector at the local, regional, and national levels fall into environmental, social, commercial, operational, and regulatory categories. These categories have emerged as overarching themes from the results of the SWOT analysis from the literature review and results.

Environmental & Social

According to the Boston Consulting Group Report, the environmental conditions were deemed good, a sentiment shared in all three levels. However, it must be acknowledged that the trials were small-scale experiments primarily used to assess whether the growth conditions were optimal. As Hasselström et al. (2018) and Lotze et al. (2019) voice concerns over large-scale operations, investing in ecosystem assessments that evaluate potential ecosystem benefits, carrying capacity or ecological effects of large-scale operations becomes imperative. Knowledge production emerges as a priority, as the literature urges to make case-to-case assessments (Tullberg et al., 2022), especially as ecosystem services can only be obtained under favourable conditions, with the proper managerial practices, modes of production, scale, intensity and proper species cultivated (Hasselström et al., 2018; Krause‐Jensen et al., 2018; Forbes et al., 2022). This also applies to the necessity of exploring which of the 300 algae species of Iceland holds commercial potential or finding the ones most capable of mitigating fish farming. The hope that algae cultivation can be made attractive with carbon sequestering must be nurtured carefully, as the ability to sequester carbon depends on further processing steps and use (Hasselström et al., 2018).

Similarly, research on managerial practices must be conducted to achieve positive ecosystem outcomes (Forbes et al. (2022). Although farms do not replicate or replace natural habitats, they still offer some regenerative/restorative properties to buffer negative climate impacts (Schütt et al., 2023). Currently, Iceland is passing more fish aquaculture laws to address similar issues. This raises the importance of being cautious of the environmental consequences that algae may have. This is also why Barbier (2020) says that until population dynamics and genetics are better understood, only native species cultivation is acceptable (Barbier et al., 2020).

Knowledge production can be achieved through collaboration, consulting knowledge holders (e.g. local/regional stakeholders, academics), understanding the needs and challenges of the industry, and a shared understanding of the mission and values (Zurba et al., 2021)

Across all levels, the interviewees agree that the algae industry has the potential to benefit smaller communities, as the production and processing must be in the same place. Freshly harvested algae must be processed quickly (Roque et al., 2021), making it impossible to move the processing to a central location. This can be beneficial in creating workplaces in rural areas. However, this once again raises concerns about achieving a social license, lest the local population think negatively of algae cultivation.

Commercial

Algae products can be used in a broad range of industries, which should make it easy to gain traction in the market. However, currently, there is still little market demand for cultivated algae. This is caused by the complex interplay of the industry being underfinanced and underregulated due to a lack of long-term planning. This uncertainty makes it difficult for all local, governmental and outside actors to invest time and money into the development of the industry.

Contrary to the fish farming industry, which had investors ready to invest as soon as the legislation was established, algae cultivation lacks this popularity due to the current lack of profitability and certainty surrounding the industry. IR2 proposes that sustainable harvesting must be exhausted before cultivation fills the gap. Additionally, few people are in the industry, as there are huge obstacles to overcome, which decreases the government's political pressure to establish legislation. This slows down governmental actions like zoning areas for production and processing spaces or creating a licensing framework. IL2 mentioned that the government expects the research to be privately funded, which, from their perspective, is a high financial burden on an industry that has yet to emerge. IG1 and IG2 hope that passing the fish-aquaculture bill in winter will allow them to reprioritize the algae legislation. On the investment side, scaling up cultivation, increasing productivity, and lowering operational costs (Greene & Scott-Buechler, 2022) may also give algae a chance to become competitive and more attractive to outside investors. Lastly, rebranding and good marketing could help gain the industry's footing inside and outside Iceland, according to the IR2 and IG2.

The various actors all see elements that could make algae cultivation more appealing to industry and governmental stakeholders, ranging from carbon binding, maxing out production with sustainable harvesting, better marketing, the potential of decentralizing the economy, increasing economic activity in rural areas and remediation of fish aquaculture waste. Something that may help people in the industry is offtake agreements, which could incentivize people to take on the mission of scaling up their production.

Operational

From an operational perspective, there are quite some challenges to tackle.

Firstly, the issue of long-term spatial planning and its communication to the stakeholders. Due to the short shelf-life of freshly harvested algae, the processing plants must be situated close to the coast. Thus, for the industry to develop, there must be long-term spatial planning, mapping out zones for production and processing. The local level shares frustration over the lack of such planning. However, IG2 has access to spatial planning maps, indicating that there might be an information mismatch between the actors.

Secondly, there may be conflicts within different industries (e.g. shipping, tourism, fishing, processing) (Tullberg et al., 2022), which can already be seen in the "not-in-my-backyard" mentality IR1 describes. This could make it more challenging to achieve a social license. Media visibility may be beneficial to mitigate this. When the local stakeholder increased their visibility, the general public awareness increased, allowing people to get familiar with the concept and benefits of algae cultivation. However, scepticism due to environmental concerns or aesthetic purposes may always remain. According to IG2, the municipalities have a vote in the coastal planning plans, which, if combined with citizen participation panels, may be a tool to achieve a social license.

Thirdly, the municipalities generally suffer from a lack of trained personnel at the local level. This makes long-term planning and climate solutions challenging to introduce and implement. Something that may counteract this is the involvement of bigger commercial entities, who can help the municipalities with planning. Interestingly, one of the local stakeholders views this in a positive light, as they say, that the businesses have the financial capacity, as well as labour, to help. However, the other local stakeholders mentioned they were concerned that the industry

would take on a more industrial approach instead of a societal one. Meeting to discuss these concerns and establishing guidelines for all actors is vital in mitigating differing views.

Fourth, when scaling up the industry operations, decisions on infrastructure, spacing, selection of species and resource management must be made in order to minimize environmental impact (Vijayaram et al., 2024; Percy & Hishamunda, 2001). According to IL2, there is currently a lack regarding most of the factors above, necessitating more research.

Lastly, IL1 and IR2 mention that the harsh water of Iceland poses another challenge, as the industry necessitates heavy and expensive infrastructure infrastructure that can withstand the waves and currents. There is a possibility of co-using equipment from other industries (Tullberg et al., 2022), but the local level highlights that this may result in greenwashing, as algae's positive impact is overstated to justify more extensive exploitation.

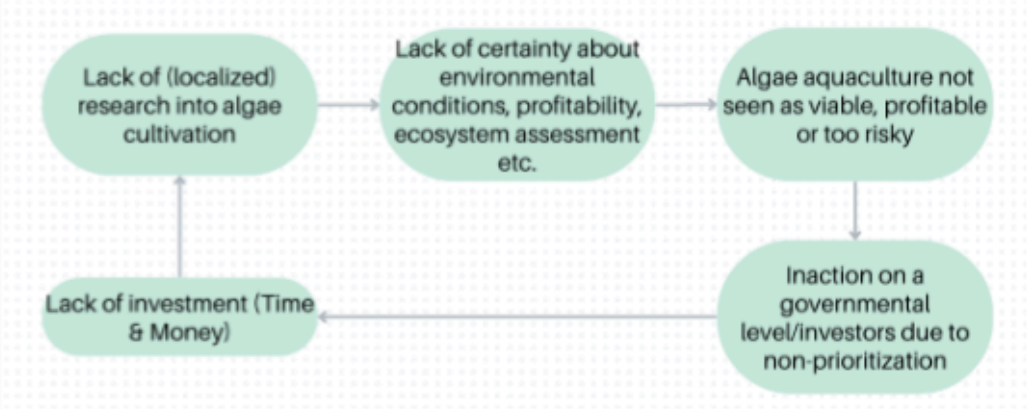
Regulatory

The government stands before the challenge of creating good legislation for algae. Due to the environmental failures in the fish farming industry, the environmental lobby has gained power over the past few years. Due to this, the parliament decided to prioritize the legislation of the fish farming industry over the establishment of the new algae industry until the fish farming legislation was passed. Multiple elements must be considered to establish a robust legislative framework, including the wanted policy framework, physical infrastructure, environmental conditions, social licenses, and market demand (OECD, 2020). However, many of these aspects still need to be explored, and more knowledge is needed. Additional factors that make the establishment of the legislation challenging are conflicts between old and new laws, as well as the government shifts from “left to right”. Further, there is a disparity between the motivation,

energy and knowledge of the local stakeholders, and governing actors that are bound by labor, time and established agendas. The combination of these factors makes it difficult to develop a long-term vision for the industry, and the lack of legislation and framework is its biggest inhibitor (See Figure 3)

Figure 3

Workflow illustrating the legislative loop that inhibits the industry



Until the legislation is passed, the government is compiling knowledge. They are collaborating with other ministers in order to learn from other countries' experiences with algae cultivation and work with feedback points for industrial stakeholders. Using knowledge/lessons from other countries is a powerful tool, especially as IG1 simultaneously acknowledges that the Icelandic context is different and thus aims to create individually fitted legislation that also adheres to the EEA. The local level perceives the engagement from the government as insufficient, remarking that the feedback point was insufficient and that they did not hear the outcome of their work. Moreover, legislative process is perceived to be slow and reactionary instead of being planned long-term, especially at the local level highlights the importance of communication across levels.

The government must increase their work on a legal framework, as the lack thereof presents a significant obstacle for those interested in advancing in the industry.

Ways forward

"Although there is room for additional wild harvest, expansion beyond current limits will likely require aquaculture.", states the Boston Consulting Report about aquaculture in the macroalgae sector (Boston Consulting Group, 2023, p. 221). For the industry to emerge sustainably, several measures must be taken. First, the legislation feedback loop needs to be broken, which will likely happen this winter after the fish legislation is passed. This gives the chance to establish a long-term plan, which makes it possible, despite possible governmental shifts, to continue to pursuit of the industry.

Much like Alleyway states: "[...] for aquatic environments, and in fact many food industries, clear description and agreement on the meaning and intent of these practices, and the extent of the environmental opportunity associated with their use, is lacking" (Alleway et al., 2023, p. 2), Iceland is currently similarly lacking direction when developing their legislative framework. However, the regulatory environment must be led with a clear vision. It must be clearly outlined and communicated to local stakeholders which zones are suitable for seaweed farming, where local biophysical limits lie and how to reap most benefits without detriment to local communities and environments. Following Barbier's (2020) advice and only cultivating native species until population dynamics and genetics are better understood could help minimize environmental risks (Barbier et al., 2020).

Anticipatory governance (Quay, 2010) can be a potent tool, prioritizing foresight to reduce risks, setting policy aims, and enhancing the capacity to respond to events early on, rather than when

they are well underway. This is achieved through the development of knowledge sources, demand management, and cost and risk assessments to minimize harm to society and the environment (Quay, 2010). Given the uncertain nature of the field, it is crucial for the government to be accountable and flexible in supporting actors in the field when they encounter unexpected obstacles.

Another way to move forward is to increase funding for research and development. The industry could increase the speed at which it emerges if it received adequate support until its place in the market is established and at a point where either outside investors finance it or it can finance itself. To establish the industry holistically and equitably for all stakeholders (including nature!), stakeholder panels can be a helpful tool, especially as all actors prove to be very motivated. The government should use the robust networks that already exist within the algae aquaculture industry. The algae association of Iceland may be utilized to organize panels and discussion rounds combining cultivators, citizens, regional and governmental organizations, local knowledge holders (for ecosystem dynamics, sustainable aquaculture, local governance systems), and academics (e.g. ecologists) to advise the government jointly. This allows the stakeholders to combine their viewpoints, knowledge and values, come to conclusions via compromise, and allow the industry to emerge in a way that satisfies all parties.

A major flaw is that there is no standard definition of sustainability. The Ministry of Food currently does not orient its work after a specific definition, and neither does the work of the parliament, which chooses to stick to a general definition that sustainability balances "economic, social and environmental factors, in line with the UN sustainable development goals" (Icelandic Government, n.d.). Unless a shared vision is achieved, the legislation may become impractical to implement or adversely affect the communities or ecosystems. Pernet and Browman (2021)

propose that sustainable development of the seaweed industry must not develop "along the path of traditional economies" that make cost-driven decisions but instead develop alongside the values of circularity and sustainability (Pernet & Browman, 2021, p. 1).

Conclusion

The emerging algae cultivation industry in Iceland has the potential to provide a versatile bioresource that aligns with the European blue bioeconomy strategy. The Icelandic government is confident about the potential of algae, aiming to scale up within the next ten years. However, before the industry can establish itself, some environmental, commercial, operational and regulatory challenges exist. The first issue concerns breaking the legislative loop, which stifles the industry due to a lack of legislation and a consequential lack of planning, investment and incentives to enter the industry. For this, legislation on fish must be passed to redirect the focus to the algae industry. The second issue deals with Iceland's lack of localized knowledge. Although the environmental conditions seem optimal, it must be assessed how scaled-up operations would influence the ecosystem, understand the mitigation potential of algae for fish farming and explore best managerial practices to reap, minimize harm and maximize the benefits that algae cultivation could have. The potential for society is deemed positive, as the rural communities could benefit from increased economic activities, making it a key driver for the local and governmental stakeholders. To scale up the industry sustainably, citizen participation becomes a powerful tool to have unified definitions of their values and success. The third issue is the lack of market demand, which marketing could tackle. It becomes essential that algae is not an additional product in the market; instead, it should offer a more carbon-friendly alternative or even replacement, adhering to the values of circularity and sustainability. The industry holds

plenty of potential, including its application in varied industry uses, climate and ecosystem mitigation potential, decentralizing the economy, and remediating the fish industry.

To move forward, increased funding for research and development and utilizing localized knowledge will help align the industry's growth with local community and environmental needs. Lastly, adopting a shared definition of sustainability that emphasizes circularity and aligns with UN sustainable development goals will guide the sector's development along a sustainable path. By achieving a standard definition of sustainability and setting clear goals for the industry, the macroalgae sector can reap significant benefits and contribute to Iceland's transition to a sustainable economy. Ultimately, Iceland has all of the necessary tools at its disposal to move forward, with motivated actors ready to set up if given the opportunity, resources and knowledge platforms.

Limitations and further research

The limitations of this work include my language barrier. I was confined to the availability of English documents (especially the Boston Consulting Report) or translations of documents, which narrowed my view. A much more comprehensive overview of the issue could have been achieved by advancing my reach to environmental organizations and citizens. Further some of the elements in the SWOT-analysis may emerge to be a different category, as the knowledge and literature progresses. Participant validation was not achieved for two participants due to time constraints. For the same reasons, further participants recommended by interviewees could not be considered, like environmental organizations and local actors in Breiðafjörður. Working

together with Resea Energy may have influenced my views, which I acknowledge. Future research should also address the knowledge gaps regarding the ecosystem assessment to uncover suitable seaweed species, species dynamics, and managerial best practices to reap ecosystem benefits in the context of Iceland, as well as the effects of monoculture practices on marine ecosystems.

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Appendix

Appendix 1: Full list of native Icelandic species (Gunnarson, K., & Jónsson, S. (2001). Benthic marine algae of Iceland: révisée! checklist. In *Cryptogamie* (Vols. 131–158, pp. 131–158) [Journal-article]. Retrieved June 5, 2024, from https://sciencepress.mnhn.fr/sites/default/files/articles/pdf/cryptogamie-algologie2002v23f2a11.pdf

Appendix 2: Interview guides

Local actor:

1. What is the mission of your company?
2. What barriers are you facing during the licensing process?
3. Have you been involved in the process of establishment of licenses?
4. Are there already known environmental/social conditions that have to be met?

Regional actor (dependent on the actor)

1. How does your work relate/how do you contribute to the establishment of the licensing process?
2. What barriers/ obstacles do you encounter?
3. What are the lessons learnt from SUSCULT?
4. What are the priorities/concerns of the stakeholders regarding the establishment of a licensing framework?

National actor:

1. How would you describe the current state of licensing in Iceland?
2. What type of aquaculture are you aiming for? (Commercial/restorative/stock enhancement/conversation aquaculture/habitat restoration)
3. What are the considerations to be taken into account for establishing a framework?
4. What are the lessons learnt from other countries?
5. What actors will be involved in the licensing process? And why? What roles do they play?