Aquaculture 560 (2022) 738434

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Macroalgae production in Northern Europe: Business and government perspectives on how to regulate a novel blue bioeconomy

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ARTICLE INFO

Keywords:
Macroalgae
Cultivation
Harvesting
Licensing
Regulation
Boundary object

ABSTRACT

Macroalgae biomass production, understood as cultivation and harvesting, is a minor industry in Europe at present, but the sector is recognized as having substantial growth potential. Here, we framed the environmental license as a boundary object between business and authorities and investigated the details of macroalgal licensing procedures in seven Northern European countries (Finland, Estonia, Sweden, Germany, Norway, Iceland, and Scotland). We conducted surveys and interviews with macroalgae companies and licensing authorities to understand the challenges faced by both sides.

Generally, macroalgae production in Northern European countries is regulated by environmental and water laws and is not included in maritime spatial plans. Private actors need to apply for an environmental, water and/or fishing permit to start operations in this sector, often with several authorities involved. The companies expressed their dissatisfaction with non-specific laws and burdensome licensing procedures that may delay or even prevent the start-up. The authorities highlighted the lack of scientific environmental risk assessments of macroalgae production and the need to resolve possible conflicts with other marine sectors. Companies need the license to access markets while authorities view the license as a tool to enforce environmental legislation. As a boundary object, the license is the result of correspondence and cooperation between companies and authorities. A one-step licensing procedure for macroalgae production should be applied to encourage this business and to facilitate the compliance of legislation. In addition, macroalgae related activities should be recognized in the national maritime spatial plans to facilitate long-term planning.

1. Introduction

1.1. Global macroalgae industry

Macroalgae, also known as seaweed, have been used as food, feed, and fertilizer for centuries. The industrial use of macroalgae started in the late 17th century when ash from algae was used in glass production, and in the 19th century for extracting iodine (Aasland, 1997). At the start of the 20th century, the production of alginate started, which still is one of the key macroalgal products (Aasland, 1997). Worldwide, the majority of macroalgae biomass is cultivated nowadays, and the production is approximately 31 Mt. (wet weight) annually, whereas wild harvesting accounts for approximately 1.2 Mt. (FAO, 2018; Camia et al., 2018; Araújo et al., 2021). The global macroalgal market value in 2018 was estimated to be 8.45 billion USD and projected to grow at an annual rate of 8% (Macroalgae Market, 2019). Countries in Asia, in particular China and Indonesia, are the leading macroalgae producers, and Asia accounts for 99% of the global cultivated production. Wild harvesting has traditionally been more dispersed globally. Chile, China and Norway are the three countries with the largest harvest of naturally growing seaweed (Rebours et al., 2014; Camia et al., 2018).

1.2. European macroalgae industry

The European macroalgal biomass production has remained relatively stable during the past decades, accounting for 0.57% of the global volume in 2016 (Araújo et al., 2021 based on FAO 2019 statistics). The macroalgae industry in Europe is a small but emerging sector, as there is

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https://doi.org/10.1016/j.aquaculture.2022.738434
Received 3 December 2021; Received in revised form 27 May 2022; Accepted 28 May 2022
Available online 2 June 2022

a growing number of macroalgae producing companies, being ~150 companies in Europe in 2018 (Araújo et al., 2021). Most of these companies are located in Spain, France, and Ireland, followed by Norway, United Kingdom, and Denmark (Araújo et al., 2021).

In contrast to Asia, where cultivation dominates, wild harvesting contributes approximately 99% of the total European macroalgae biomass production (Araújo et al., 2021). Norway is the largest supplier of wild stock followed by France, Ireland, and Iceland and these countries produce 98% of the European biomass production (Camia et al., 2018). Overall, the macroalgae species the most harvested in Europe are *Laminaria* spp. and *A. nodosum* (Barbier et al., 2019), but with some harvesting of other species. Focusing on the Baltic Sea Region, only the loose form of the red algae *Furcellaria lumbricalis* is harvested for commercial purposes (Weinberger et al., 2020). The industrial harvesting of *F. lumbricalis* started in 1940s and lasted until 1960s in the Kattegat Sea area, in Danish waters, but the population decimated by intensive harvesting (Schramm, 1998). Nowadays, *F. lumbricalis* is only found in the west Estonian Archipelago Sea where the total biomass is approximately 180,000 tons (Weinberger et al., 2020).

Macroalgae cultivation in the EU and EEA (including Norway and Iceland) contributes approximately 1% to the total European macroalgal biomass production (Araújo et al., 2021). France, Denmark, and Ireland, followed by Norway and Germany, are the European countries with highest macroalgae aquaculture production (Camia et al., 2018), but more countries are currently implementing aquaculture facilities or conducting pilot trials (Camarena-Gómez and Lähteenmäki-Uutela, 2021). For instance, in Norway there is a long list of macroalgae farmers associated with the Norwegian seaweed farms association (https://www.norwegianseaweedfarms.com/), and the industry is growing in the west coast of Sweden (Camarena-Gómez and Lähteenmäki-Uutela, 2021). However, in the Baltic Sea Region, including the Swedish east coast, macroalgae cultivation remains marginal. The challenges in this estuarine catchment area are several: short growing season, low salinity, and lack of tradition (Suutari et al., 2017; Weinberger et al., 2020). The low salinity of the Baltic Sea limits the growth of kelp species (*Alaria esculenta*, *Saccharina latissima,* and *L. digitata*) or dulse (*P. palmata*), species commonly commercialized in the macroalgae industry (Barbier et al., 2019).

The cultivation of macroalgae can be conducted in land-based tanks, ponds or using open sea systems (coastal and offshore) designed with nets, ropes or rafts. Most of the European aquaculture facilities are at sea (offshore or in coastal waters), and 24% are land-based systems (Araújo et al., 2021). In sea-based systems, the cultivation can be combined with mollusc and/or fish farming in Integrated Multitrophic Aquaculture (IMTA), where macroalgae cultivation can offset the excess of nutrients released by fish farming (Kostamo et al., 2020; Belinskij et al., 2021).

1.3. Potential benefits and risks of macroalgae cultivation

Macroalgae biomass production has several socioeconomic as well as environmental benefits. The increasing global demand for human food has created a need to find new, low carbon footprint alternatives for food and feed. For instance, the red alga *Asparagopsis taxiformis*, as a feed ingredient, can reduce the release of methane emissions from cattle (Roque et al., 2021), which may enable dairy farms to reach their carbon targets (Lähteemäki-Uutela et al., 2021). Macroalgae also have health benefits for humans as they can be rich in antioxidants (Freitas et al., 2012). Indeed, macroalgae offer a broad range of uses with potentially high market value such as derived medicinal products, food and food additives, feed and feed additives, bio-fertilizers and biostimulants, and biomaterials (Lähteemäki-Uutela et al., 2021). As a positive social-economical aspect, macroalgae biomass can create new direct and indirect job opportunities based on local capacities in coastal areas and offer an alternative to the declining fisheries industry (Araújo et al., 2021). Macroalgae cultivation has the advantage of not requiring arable land, irrigation, or artificial fertilizers (Duarte et al., 2017; Wan et al., 2018; Hoegh-Guldberg et al., 2019) and can also act as a CO_2 sink (Wu et al., 2022; Duarte et al., 2017). In addition, macroalgae take up inorganic nutrients, which can mitigate eutrophication, enhance water quality and counter deoxygenation (Fei, 2004; Jiang et al., 2020; Racine et al., 2021). In IMTA systems, macroalgae cultivation can offset nutrient emissions produced by fish or mollusc farming (Kostamo et al., 2020). The macroalgae sector can thus potentially support up to seven of the UN Sustainable Development Goals.

Despite its many benefits, macroalgae cultivation cannot be allowed to expand without rules, as there are also potential environmental risks (Campbell et al., 2019). While small-scale macroalgae cultivation is considered low risk, a large-scale expansion of the industry requires greater understanding of its impacts and the balance of environmental benefits and risks. Macroalgae cultivation can potentially 1) reduce water flows and change sedimentation rate by reducing the penetration of particles from the water column to the bottom; 2) compete for nutrients with naturally occurring primary producers; 3) take up pollutants that can affect its use for human consumption; 4) release dissolved and particulate organic matter; 5) alter light conditions by shading and/or altering the physiochemical environment, which may cause changes in the benthic communities; 6) increase the risk of introduction of alien species or parasites that may change population genetics of locally occurring macroalgae; 7) change the structure of local flora and fauna, which may impact fish, birds, and marine mammals (Wood et al., 2017; Barbier et al., 2019; Campbell et al., 2019).

1.4. Legislation and licensing

A specific regulatory framework on macroalgae harvesting or cultivation is lacking in most countries, although all the general environmental regulations apply. In the EU, the main regulations are the Habitats Directive 92/43/EEC, 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, and the Environmental Impact Assessment Directive 2011/92/EU. The Organic Food Regulation 2018/848/EU has specific rules for the cultivation of organic algae (Part III: Production rules for algae and aquaculture animals, 2. Requirements for algae). When addressing the topic of food safety of macroalgae to be used as food products or ingredients, the Novel Food Regulation 2015/2283/EU applies to all species not previously consumed in Europe, and a specific Recommendation (2018/464/EU) exist to monitor the metal and iodine content in seaweed, halophytes, and products based on seaweed.

A barrier to aquaculture growth in general, and to the emerging European macroalgae industry, in particular, is social acceptability, also known as the social license to operate (Mather and Fanning, 2019; Billing et al., 2021). The social license discussion appeared in the 1990s in the mining industry (Mercer-Mapstone et al., 2017). It tries to describe how an informal process, carried out by the public, may interfere in the management of common resources and their uses for private or public purposes (van Putten et al., 2018). Macroalgae cultivation is a marine activity that may interfere with the interest of different marine sectors including the civil society. The social license to operate may depend on establishing a relationship between macroalgae producers and all stakeholders, and consulting with local people on how to best build up an operation (Billing et al., 2021).

The legal license or permit is the concrete manifestation of the social license; it is an institutional object that is collectively recognized (see e.g. Mackor, 2014). The macroalgae industry often mentions legal barriers as a limiting factor for its development (Barbier et al., 2019), mainly referring to the substantive and procedural requirements for obtaining a license to operate (Araújo et al., 2021). The environmental licensing process can be inefficient and time-consuming, depending on the socio-political context, the complexity or novelty of the technology, the fragmentation of the bureaucratic regime, and the knowledge and

resource levels of the applicant and the permitting agency (Ulibarri et al., 2017). With macroalgae, we presume that the benefits described above make the general socio-political context favourable, while the novelty of production activities and products may cause acceptance issues.

Boundary objects are considered entities, (e.g. processes, concepts, or models) that may constitute a tool for translation and collaboration between interested parties, addressing a topic from different angles (Star and Griesemer, 1989). Duncan et al. (2020) studied scientific models as boundary objects between science and policy, and Franco-Torres et al. (2020) discuss how boundary objects that bridge worldviews can have an important role in sustainability transitions. Here, we bring the concept into environmental licensing and study the legal license to operate as a boundary object. The license is a strategic object for the businesses and for the authorities, but from very different perspectives. For the business, the license is a condition for starting operations and accessing the market. From the perspective of law, the license is an abstract object created to regulate concrete, real-world behaviour (Mackor, 2014). The license is embedded in the larger legal system of water and environmental laws, which in turn is embedded in higher-level principles of sustainable development. As the license is where business strategies and societal interests become concrete and interact, it is a major object defining blue bioeconomy development.

Here, we investigated macroalgae production licensing in Northern European countries, including countries from the Baltic Sea and the North Atlantic regions. Our aim was to identify the specific issues that cause the challenges or difficulties in macroalgae legal licensing. Specifically, we addressed the questions:

- What do macroalgae biomass production businesses expect from government regulation and from the licensing authorities?
- What do government regulators and licensing authorities expect from the macroalgae biomass production businesses?

2. Materials and methods

Case studies of stakeholder opinions on macroalgae biomass production were carried in six different countries, covering the Baltic Sea region (Finland, Germany and Estonia) and the North Atlantic Ocean (Norway, Iceland and Sweden). Sweden is in the latter group as macroalgae operations take place in its west coast. The countries were chosen as case studies to facilitate the comparison between a range of countries from no commercial macroalgae biomass production (Finland) to countries where there has been a long tradition of harvesting and use of macroalgae (Norway and Iceland).

In the case study approach, we gathered triangulated qualitative data from A) a literature review, B) surveys and C) interviews (Bryman, 2016). At the first stage, we conducted a literature review of academic literature, policy documents and marine strategy documents at the EU and national levels in Finland, Estonia, Germany, Norway, Sweden, Iceland, and Scotland (Fig. 1). We included Scotland as it is a country with a well-defined macroalgae legislation, although its macroalgae related activities are still at small-scale (Billing et al., 2021). Through the literature review, we defined the background of our study. The study was complemented with secondary sources from a qualitative survey of macroalgae biomass producers (companies, S1a) and government stakeholders (authorities, S1b), followed by semi-structured interviews of the companies. The interviews were based on the survey questions. All the countries participated in the licensing survey/interview study, except Scotland. To conduct the survey/interview study, we first gathered information of macroalgae companies from their websites, from September to October 2020, to obtain basic information of their location, activity, and species they cultivate/harvest. Then, we selected 34 macroalgae companies and 15 national authorities, and contacted them via email to ask them to participate in our study by answering the survey (S1a, b), from November 2020 to January 2021. In total, 10 companies and 8 authorities answered our survey (Table 1). Finally, we interviewed the companies that answered the survey to deepen the information obtained from the survey (February to March 2021). All the interviews were conducted virtually and held in English. They were recorded, with consent, for further analysis, and the interviewees agreed to be mentioned in this study. From the survey/interviews, we gathered licensing experiences from the companies and from the government stakeholders and their opinions on how the macroalgae industry could

Fig. 1. Summary of the methodology followed in this the case study. Qualitative data were collected from different sources: Literature review of different documents (A), survey (B) and interview (C) data from macroalgae companies. National authorities only participated in the survey study. Countries (Finland, Estonia, Germany, Norway, Sweden, and Iceland) were selected as case studies. From Scotland, only the literature review was conducted. The () symbol indicates the number of participants in each case.

Table 1
List of companies and authorities that participated in the survey/interview case study.

Case studies	Number of answers	Companies	Authorities
Finland	4	Origin by Ocean	Regional State Administrative Agency (AVI) Centre for Economic Development, Transport and the Environment (ELY) MSP Coordinator
Sweden	2	Nordic Sea Farm	Land and Environmental court
Estonia	4	EstAgar Tinurek OÜ Vetik OÜ	Ministry of Environment
Germany	1	Kieler-Meeresfarm GmbH & Co. KG	
Norway	5	Leroy Ocean Harvest/Ocean Forest AS	County Administration of Agder
		Seaweed Solutions AS TANGO Seaweed AS	Ministry of Trade Industry and Fisheries
Iceland	2	Thorverk	Ministry of Industries and Innovation

All the companies answered first the survey, followed by an interview. National authorities only answered the survey.

be improved in terms of regulation and licensing. These data provided more background support to the information collected during the literature review and formed the answers to our research questions. The survey/interviews were analysed separately per case study and compared with the findings from the literature review. The literature review and survey/interview data were analysed by systematically searching through all the data for emerging themes.

We present our findings as follows. Section 3 presents the regulatory and strategic frameworks in each case study (country), based on literature review and document analysis. Section 4 discusses the perspectives of businesses and authorities in each country, derived from survey and interview data. Section 5 presents overall conclusions and recommendations.

3. Macroalgae regulatory framework in Northern European countries: regulations, licensing process, blue strategies, and marine management plans

Macroalgae biomass production is generally regulated by environmental and/or water laws, lacking a specific regulatory framework and considered, in most cases, as water operation (Table 2). However, macroalgae production is mentioned in some national strategies, programs, and in some of the national Maritime Spatial Plans (MSP) and marine management plans (Table 3).

Table 2
Macroalgae-related activities, permits, laws, and authorities involved in the licensing process in the studied countries (Finland, Sweden, Germany, Estonia, Iceland, Norway and Scotland).

Case study	Activity	Permits	Regulation	Authorities
FINLAND Cultivation*	- Water resource management issue	Water and environmental permit	- Water Act - Environmental protection Act	- Centre for Economic, development, Transport and Environment (ELY) - Regional State Administrative Agency (AVI)
SWEDEN Cultivation	- Water operation	Water permit (> 0.3 ha)	Environmental Code Act 1998/812	- Land and Environmental Court - County Administrative Board
GERMANY Cultivation	- Water operation	Water and shipping policy permit	- Federal Waterways Act - Water Acts of the Länder	- Federal Waterways and Shipping - Agency + state authorities
ESTONIA Harvesting	Aquatic plant collection	Fishing permit	- Fishing Act	- Agriculture and Food Board
Cultivation*	- Water operation	Superficies, building, and water permits	- Water Act - Natural Conservation Act	- Consumer Protection and Technical Regulatory Agency - Environmental Board
ICELAND Harvesting	- Acquisition of seaweed for commercial purposes	Contract from landowner	- Regulation no 90/2018	- Directorate of Fisheries
NORWAY Harvesting	- Management of wild living marine resources - Harvesting of seaweed and sea tangle	Harvesting permit	Marine Resources Act FOR-2004-11-26-1526 FOR-2018-09-10-1310 FOR-2019-09-26-1274	Directorate of Fisheries
Cultivation	- Production of aquatic organisms	- Fishing, water, discharge, and seaweed permits - Environmental assessment for >10 ha	- Aquaculture Act - FOR-2004–12-22-1799 - Pollution Control Act	- State Administrator - Directorate of Fisheries - Coastal Administration
SCOTLAND Harvesting	- Traditional beach-cast - Wild harvesting for commercial purpose: large scale - Vessel-based harvesting	- Not permit needed - Crown Estates Harvest License Option process - Marine license +environmental assessment	- The Crofters Act 1993 - Environmental Assessment Act 2005 - Marine Act 2010	- NatureScot - Crown Estates Scotland - Marine Scotland
Cultivation	- LOA - Cultivation inshore region - Offshore cultivation - Large operation	- Temporary permit[1] - Marine license[2] Pre-consultation + Marine license[2] + Aquaculture lease[3]	- Marine Act 2010 - Water Environment 2013 - Marine and Coastal Access Act 2009 - Marine Licensing Regulation 2013 - Scottish Crown Estate Act 2019	- Crown Estate Scotland - MS-LOT - MS-LOT - Crown Estate Scotland

The symbol (*) indicates the licensing processes that are under development. Superscripts included in the table (Scotland) are as follow: [1]Temporary permit (LOA) includes business plan and project description. [2]Marine license includes project description, mitigation plan and application fee. [3]Aquaculture lease includes business plan, marine license, and the project description.

Table 3
Marine management plans and marine strategies in the studied countries (Finland, Sweden, Germany, Estonia, Iceland, Norway and Scotland).

Case study	Marine management plans	Marine strategies	Macroalgae included
FINLAND	*Maritime Spatial Plan 2030	National Aquaculture Strategy 2022	*Potential in blue biotechnology (Vision 2030)
		*Finnish Bioeconomy Strategy	*Potential in energy production
SWEDEN	*Marine Spatial Plans for Gulf of Bothnia, Baltic Sea, and North Sea	*Maritime Strategy National Food Strategy	*Macro- and microalgae, potential in food production and fertilizer. Potential as eutrophication remediation
			*Macro- and microalgae, potential in aquaculture activity
GERMANY	Maritime Spatial Plan 2021	*National Bioeconomy Strategy 2030	*Potential raw materials for different industries
ESTONIA	*Under preparation: Estonia Maritime Spatial Plan	Sustainable Estonia 21 and Estonia 35	*Potential as aquaculture activity.
		Agriculture and Fisheries Development Plan until 2030	*Potential cluster-solutions combining fish and algae farms
ICELAND	In process: Marine spatial planning for Westfjords and East fjords		Not included
NORWAY	Integrated Marine Management Plans for Barents Sea, Norwegian Sea, and North Sea and Skagerrak	Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry 2009	Not included
		Ocean Strategy 2019	
SCOTLAND	*National Marine Plan 2015		*Potential in aquaculture sector.
			*Potential for reducing nutrients in IMTA systems

The third column shows whether macroalgae is mentioned in the marine management plans (black symbol *) and/or in the marine strategies (red symbol *).

3.1. Finland

In Finland, there is currently no commercial macroalgal cultivation, nor harvesting of wild macroalgae, but there are some small-scale cultivation trials conducted by research organizations and companies. Thus, there is not a specific macroalgae regulation and licensing process defined in Finland. All aquaculture activities, known as *water resource management issues*, are subject to the Water Act 587/2011 (Vesilaki 587/2011) and the Environmental Protection Act 527/2014 (Ympäristönsuojelulaki 527/2014, Table 2). Projects conducted in the water are subject to a permit if they may cause changes in the quality and quantity of the water bodies (Water Act 3) and the benefits to public or private interests are weighed against disadvantages or losses (Water Act 3:4§). The applicant must have the right to use the water area based on ownership or contract (Water Act 2:12–13§). If there is a risk of harming the environment, an environmental permit is required according to the Environmental Protection Act, which may lengthen the licensing process. In Natura 2000 areas, the conditions must be evaluated according to the Nature Conservation Act (Luonnonsuojelulaki 1096/1996). Short-term activities on an experimental basis or for testing purposes may be exempted from the environmental permit under the conditions that there are no serious environmental impacts (Environmental Protection Act 4:31§). Typically, macroalgae cultivation is not presumed to harm the environment, and the need for an environmental permit, or other permits such as water permit, is still under discussion. The Centre for Economic Development, Transport and the Environment (Elinkeino-, liikenne- ja ympäristökeskus, ELY) makes the decision on the need for a permit, and the Regional State Administrative Agency (Aluehallintovirasto, AVI) processes the applications for aquaculture operations. The applicant may also need to consult the Transport Infrastructure Agency (Väylävirasto) to confirm whether the macroalgae cultivation activity is affecting sea traffic.

Relevant Finnish strategies are the *National Aquaculture Strategy 2022* and the *Finnish Bioeconomy Strategy*. Only the *Bioeconomy Strategy* mentions "algal aquaculture" with potential in the energy industry that may support developing the bioeconomy (Finnish Government, 2014). The bioeconomy strategy is currently being updated. In addition, microalgae and macroalgae cultivation are mentioned in the recently approved Finnish MSP 2030 for the areas Gulf of Finland, Archipelago Sea and southern Bothnian Sea and Norther Bothnian Sea, Quark and Bothnian Bay (Marine Spatial Planning, 2020). Algae are mentioned within the Blue Biotechnology sector, included in the Vision 2030 document, and emphasizes the potential uses of algae in food, wellbeing products, and pharmaceuticals. The plan also recognizes algae as an energy source and their ability to improve the marine environment by removing nutrients.

3.2. Sweden

In Sweden, macroalgae are commercially cultivated on the west coast (Camarena-Gómez and Lähteenmäki-Uutela, 2021). There is some collection of beach cast, but harvest of wild stock is not occurring. Although there is macroalgae biomass production, a lack of specific macroalgae legislation, and even aquaculture laws in Sweden, is observed. For macroalgae cultivation, the Environmental Code Ds 2000:61 (Swedish Government, 2015a) and the Act 1998/812 with Special Provisions on Water Activities (Lag 1998:812 med särskilda bestämmelser om vattenverksamhet, Swedish Government, 1998) applies. These activities are considered as *water operations,* apart from the cultivation of fish, mussels and crayfish (Environmental Code; Chapter 11. Water operations, section 9). For cultivation, a water permit is needed, and it is granted by the County Administrative Board (Länsstyrelse), after judgment by the Land and Environmental Court (Mark- och miljödomstolen; Environmental Code; Chapter 20). The County may classify the operation as high environmental impact, and then the applicant must perform a more complex environmental impact assessment, which may lengthen the process. Besides, access to the water area is based on ownership or contract. Operations smaller than 0.3 ha do not require a water permit but must be notified to the County Administrative Board. For aquaculture close to a beach, an exemption from the beach protection regulations is required. If the area is in a national park, nature reserve, biotope protection or Natura 2000 area, the exemption is applied from the County Administrative Board. For unprotected areas, an exemption can be granted by the municipality where the operation is planned.

The Swedish Government has published the *Maritime Strategy* (Swedish Government, 2015b) and the *National Food Strategy* (Swedish Government, 2017), both emphasizing the importance of aquaculture to cultivate fish, shellfish, and mussels in a more sustainable way. The *Maritime Strategy* mentions micro- and macroalgae and highlights their strong development potential in the aquaculture industry. Also, the recently approved (February 2022) Swedish MSP for the Gulf of Bothnia, Baltic Sea, and North Sea (Havsplaner för Bottniska viken, Östersjön och Västerhavet) mentions macroalgae cultivation as an aquaculture activity that can be considered in their maritime spatial planning (Swedish Government, 2022). The Swedish MSP emphasizes the potential products that can be obtained from algae like oils, vitamins and proteins, and can produce ingredients for food, feed, medicine and fuels, recognizing

the environmental benefits of algae by reducing eutrophication.

3.3. Germany

In Germany, there are some trials and also small-scale commercial cultivation of macroalgae at the Baltic Sea coast, but no specific regulations are defined for macroalgae cultivation (Camarena-Gómez and Lähteenmäki-Uutela, 2021). They are considered *water operations*, and the applicable laws are the Federal Waterways Act 2007, § 31, Waterways and shipping police approval (Bundeswasserstraßengesetz 2007, § 31 Strom- und schifffahrtspolizeiliche Genehmigung), last amended in August 2021 (Article 3, German Government, 2021), and the Water Acts of the Länder. For cultivation, a federal-level water and shipping policy permit (Wasser-und Schifffahrtspolizeiliche Genehmigung) is needed, and the issuing authority is the Waterways and Shipping Administration (Wasserstraßen- und Schifffahrtsverwaltung, WSA). After obtaining the water permit, the WSA offers a contract to lease the water area and the applicant is allowed to use the defined water area. In addition to the federal-level water permit, state-level permits are required in case of coastal protected areas (Camarena-Gómez and Lähteenmäki-Uutela, 2021).

The Federal Government of Germany has approved the *National Bioeconomy Strategy 2030,* where algae are recognized as a potential source of raw material with many different applications in medicine, industry, agricultural ecology, and environment (Federal Government of Germany, 2020). The Strategy 2030 emphasizes the need for more research to improve the whole production chain. However, macroalgae cultivation is not mentioned in the MSP for the Baltic Sea nor for the North Sea, which were recently approved by the Federal Government and entered into force in 2021 (Camarena-Gómez and Lähteenmäki-Uutela, 2021).

3.4. Estonia

In Estonia, there is no macroalgal cultivation yet, but naturally growing *F. lumbricalis* is harvested in its loose form for the extraction of furcellaran (Kersen et al., 2017; Camarena-Gómez and Lähteenmäki-Uutela, 2021). This is the only aquatic "plant" that can be harvested as *aquatic plant collection,* being regulated through the Fishing Act (Kalapüügiseadus) 2015, last amended in 2021 (Estonian Government, 2021). In its natural habitat, this red macroalgae is owned by the state but when washed ashore, the ownership is obtained by the owner of the shoreline. In order to avoid the overexploitation of the algae, the Fishing Act sets the rules on the harvesting areas and harvesting frequency of the algae, including a rotation system for harvesting areas. In addition, there is a monitoring program to follow the recovering of the algal population. The Agriculture and Food Board (Põllumajanduse ja Toiduamet) at the Ministry of Rural Affairs (Maaeluministeerium) grants a 1-year permit for harvesting purposes. In the permit are stipulated the harvesting locations, maximum quantities harvested (normally 2000 tons per year), and gear allowed for this type of activity. During the last 30 years, the licenses have been bought by two companies, and it is not possible to apply for new licenses for natural stock preservation reasons (Camarena-Gómez and Lähteenmäki-Uutela, 2021). The collection of beach-cast does not, however, require a license.

Cultivation of macroalgae is subject to the Water Act 2019 (Veeseadus 2019) and several licenses are required: Superficies license, building permit, and possibly a water permit for the special use of water (Estonian Government, 2019). The superficies and building permits are issued by the Consumer Protection and Technical Regulatory Authority (Tarbijakaitse ja Tehnilise Järelevalve Amet), whereas the Environmental Board (Keskkonnaament), under the Ministry of Environment (Keskkonnaministeerium), is the authority that handles the water permit. There are other authorities that evaluate the application if needed: The Ministry of Defence, the Ministry of Rural Affairs or the Heritage Protection Agency. The Nature Conservation Act (Looduskaitseseadus) 2004 sets the requirements on operations in the Natura 2000 areas and if non-native species are introduced.

Several sustainability strategies have been adopted by the Estonian Government during the last decades, for instance the *Sustainable Estonia 21* and *Estonia 35*, which are based on the Sustainable Development Goals defined by the United Nations (Camarena-Gómez and Lähteenmäki-Uutela, 2021). Recently, an Agriculture and Fisheries Development Plan until 2030 was presented to the Estonia Parliament (Riigikogu) with the aim to promote the sustainable development of fisheries and aquaculture and to maintain a good environmental status in terrestrial and aquatic ecosystems. In the development plan, the focus on macroalgal cultivation is limited (Camarena-Gómez and Lähteenmäki-Uutela, 2021). Conversely, the proposed Estonian MSP includes macroalgae in the aquaculture chapter as a potential activity in the growing blue economy sector (Estonia Government, 2019). The MSP does not define algae cultivation areas, but it provides guidelines and conditions for the development of macroalgae farming, including mapping the natural growth potential of algae and suitable areas for cultivation. The MSP expects that aquaculture and energy development plans will have positive synergies. It also supports IMTA systems, combining nutrient-emitting fish farms at sea with the nutrient-removing algae and/or shellfish farms, as "cluster solutions". It is clearly specified that macroalgae farming must be distinguished from fish farming when discussing the need for environmental impact assessments. The final MSP is expected to be adopted in 2022.

3.5. Iceland

Iceland has a long tradition of wild harvesting of macroalgae conducted by local communities, and the activity is still ongoing in areas such as the Bay of Breiðafjörður, mainly based on the brown algae *Ascophyllum nodosum* (Maack, 2019). For commercial harvest, the Regulation No 90/2018 on the acquisition of seaweed applies (Reglugerð um öflun sjávargróðurs í atvinnuskyni No 90/2018) (Regluderdasafn, 2018). The regulation is issued by the Directorate of Fisheries under the Ministry of Industries and Innovation. Different aspects are defined in the regulation: harvesting, permitting, inspections, registration, and penalties. In brief, the regulation stipulates that access to harvesting areas is subject to an agreement or signed contract with the landowners and the Directorate of Fisheries facilitates this agreement. In addition, an annual plan indicating the location (GPS outline) of harvesting must be submitted and the amount of the harvested biomass must be weighed and registered as marine catch. There is a rotation system for harvesting areas to avoid overexploitation. The permit can be revoked in case of violations. For each vessel, a permit from the Directorate of Fisheries must be acquired, and the vessels must be seaworthy, based on the Fisheries Management Act No 116/2006, Art. 15, Chapter A. *Seaweed* (Lög um stjórn fiskveiða 2006 nr. 116 10. Ágúst. 15 g. II. Kafli A. *Sjávargróður*). Currently, there is a bill in the parliament to amend the Fisheries Management Act and the Act of Fishing Fees (Procurement of Seaweed for Commercial Purposes), case 350. The Nature Conservation Act No 60/2013 (Lögumnáttúruvernd2013, nr. 60 10. Apríl) may also apply to macroalgae harvesting (Camarena-Gómez and Lähteenmäki-Uutela, 2021). Contrary to harvesting, commercial macroalgae cultivation does not yet exist in Iceland, and there is no legal framework for this activity (Frank, 2020). Currently, a proposal on an Action plan for the utilization of algae (um aðgerðaáætlun um nýtingu þörunga) is in the parliament process (Camarena-Gómez and Lähteenmäki-Uutela, 2021).

Iceland is working on the first Marine spatial planning for Westfjords and Eastfjords. For that, the National Planning Agency (Skipulagsstofnun) has developed a *National Planning Strategy* (Landsskipulagsáætlun) for 2015–2026 (Skipulagsstofnun, 2013), based on the Planning and Building Act (No. 73/19997, no.135/1997and no. 58/1999) and the Regulation 1001/2011 on National Planning Policy (Reglugerðnr. 1001/2011 um landsskipulagsstefnu). The National Planning Strategy is the first legal document in Iceland integrating ocean

and coastal management (Lehwald, 2020).

3.6. Norway

The harvesting of wild macroalgae in Norway has taken place for centuries, but the present industry started in the 1960s, and approximately 150,000 tons of *Laminaria hyperborea* and 15,000 tons of *A. nodosum* are harvested every year for the extraction of alginate and other products (Meland and Rebours, 2012; Stévant et al., 2017). Currently, there are two companies commercially harvesting macroalgae in Norway (Camarena-Gómez and Lähteenmäki-Uutela, 2021). Harvesting takes place in the western coast of Norway (Rogaland to Trøndelag). For that, the coast is divided into different zones that are harvested on a 5-year cycle and only from 5 to 20 m depth based on the current regulation (see below). Harvesting of kelp or *Laminaria* spp. is subject to the Marine Resource Act 2008 that regulates the *management of wild living marine resources* (Norwegian Government, 2015). This act is issued by the Directorate of Fisheries (Ministry of Trade, Industry and Fisheries), and it requires a license. The harvesting of macroalgae is also regulated by the Decree No. 642 of 1995 to regulate the harvesting of seaweed and kelp (FOR-1995-07-13-642, Forskrift om høsting av. tang og tare) in the inner waters on Norway, the territorial waters, and the economic zone (LOVDATA, 2022a), amended by the regulation FOR-2004-11-26-1526 (LOVDATA, 2022b). The purpose of the regulation is to ensure a sustainable utilization of the macroalgae by conducting the activity during harvesting seasons and forbidding the activity in waters deeper than 20 m (§ 3. Definisjon). The right to harvest macroalgae belongs to the State but a permission can be granted to actors based on regional regulation (§ 4. Retten til høsting av. tang og tare). There are two specific regional regulations for macroalgae harvesting in Norway: Regulation for Rogaland, Hordaland and Sogn og Fjordane (FOR-2018-09-10-1310, Forskrift om høsting av. tare, Rogaland, Hordaland og Sogn og Fjordane) valid until 2023, and the regulation for Møre og Romsdal and Trøndelag (FOR-2019-09-26-1274, Forskrift om høsting av. tare, Møre og Romsdal og Trøndelag) valid until 2024. The regional regulations define the periods and the areas allowed for harvesting.

Aquaculture is a large industry in Norway, in particular salmon production (Young et al., 2019), but it is also the country in Europe with most macroalgae cultivation companies, in total sixteen companies held a license for cultivation in 2016 (Araújo et al., 2021; Stévant et al., 2017). All aquaculture activities in Norway, including macroalgae cultivation, are regulated by the Aquaculture Act 2005. Macroalgae cultivation requires a license for the *production of aquatic organisms* based on the Regulation on permits for aquaculture of species other than salmon, trout and rainbow trout 2004 (FOR-2004–12-22-1799, Forskrift om tillatelse av. andre arter enn laks, ørret og regnbueørret 2004) (LOVDATA, 2022c). The license includes a water permit, granted by the Coastal Administration, species-specific macroalgae permit, granted by the Directorate of Fisheries, and a permit under the Pollution Act 1981 (articles §11 and §16), granted by the State Administrator (Statsforvalteren), previously County Governor (FOR-2020-12-18-3041, Forskrift om endring i forskrifter gitt med hjemmel i akvakulturloven som følge av. nytt navn på fylkesmannen). It is required that the cultivated species already grow naturally in the cultivation area. The State Administrator is the regulatory body that processes the license and evaluates the location of the farm and the possible conflicts with other marine sectors or users. Indeed, all the interested parties that use the water area must give permission to develop macroalgae farms (Camarena-Gómez and Lähteenmäki-Uutela, 2021). The Directorate of Fisheries is the appeal body of the license. There are more administrations that evaluates the application for macroalgae cultivation licenses: Food Safety Authority, Norwegian Water Resources and Energy Directorate, Municipality and Public. For activities larger than 10 ha, it is required to perform an Environmental assessment (miljøundersøkelse) to prove the sustainability of the operation.

The former Norwegian Ministry of Fisheries and Coastal Affairs adopted the *Strategy for an Environmentally Sustainable Norwegian Aquaculture Industry* (Norwegian Government, 2009). This Strategy provided a guideline to current aquaculture policies and contributed to develop the Resent Blue Opportunities (Norwegian Government, 2019). Although macroalgae cultivation is not fully elaborated in these strategies, their adoption contributed to develop a macroalgae bioeconomy-based production in Norway and contributed to the success of this industry (Stévant et al., 2017; Araújo et al., 2019. On the contrary, macroalgae farms are not mentioned in the Integrated Marine Management Plans defined for the three EEZs: Barents Sea and Lofoten, the Norwegian Sea, and the North Sea and Skagerrak, although fisheries and aquaculture are mentioned (Norwegian Government, 2021; Young et al., 2019). For coastal zones, the Integrated Coastal Zone Planning integrates the protection and conservation, recreation and uses of the coastal zone, and addresses the possible conflicts among users and uses of the coastal zone (Tiller et al., 2012).

3.7. Scotland

In Scotland, wild harvested macroalgae has been used for feed and fertilizer since the 18th century (Angus, 2017). Nowadays, it is concentrated at the west coast (Outer Hebrides islands) where a large-scale harvesting operation of *A. nodosum* takes place at an area of 31.5 km^2 by the Hebridean Seaweed Company (Burrows et al., 2018; Crown Estate Scotland, 2021). At much smaller scale, *Laminaria* spp. and *P. palmata* are harvested by hand or collected from beach-cast (Burrows et al., 2018). A recent assessment on macroalgae harvesting and cultivation conducted by the Scottish Government has estimated a potential annual harvesting biomass of ca. 15,000 t per year (Scottish Government, 2020a). This assessment shows the potential macroalgae species and locations for harvesting in the Scottish waters. Cultivation also occurs at a relatively small scale and there is only one company with commercial cultivation, with additionally a few companies with pilot-scale operations, covering ~0.9 km^2 in total (Crown Estate Scotland, 2021). The species cultivated are *S. latissima* and *A. esculenta,* and at smaller scale L. *digitata, Saccorhiza polyschides* and *L. hyperborea* (Kerrison et al., 2016). There are also experimental cultivation trials of *Ulva* spp. and *P. palmata* (Barbier et al., 2019). The total asset value of Scottish macroalgae biomass production in 2020 was £0.1 m (Crown Estate Scotland, 2021).

Despite the small-scale biomass production, there is a growing interest in macroalgae-related activities due to the potential uses of the macroalgae products in different industries and their environmental benefits. This is reflected in the increase of members registered in the Scottish Seaweed Industry Association in the last 5 years. The Scottish government is aware of the fast-growing macroalgae sector and the opportunities that can bring to the Scottish economy, society, and the environment (Crown Estate Scotland, 2021). At the same time, the government is also concerned about the adverse effects of large-scale mechanical harvesting on the environment, and the potential risks of macroalgae cultivation by introducing non-native species, other impacts on surrounding ecosystems, and conflicts with other marine sectors. Consequently, the Scottish government introduced the Marine (Scotland) Act 2010 with the aim to manage the marine environment (Scottish Government, 2010). In 2019, the Marie Scotland Directorate created the *"Seaweed Review Steering Group"* to review the current situation of macroalgae-related activities and its regulation, to define the future management of this growing industry and to improve the regulatory framework that will befit to the purpose (Scottish Government, 2019a).

Focusing on harvesting, the Scottish Government published a Strategic Environmental Assessment (SEA) report in 2016 entitled *"Wild Seaweed Harvesting"* under the Environmental Assessment (Scotland) Act 2005 (Scottish Government, 2016). The SEA report provides information about the diversity of macroalgae and their distribution, their ecological functions, and the effects of harvesting, among other topics. A summary on the current regulation and licensing process of wild

macroalgae harvesting can be found in the SEA report (Scottish Government, 2016). In brief, the need of a license and the information required from the applicant will always depends on the scale of the harvesting activity (Scottish Government, 2016). The traditional *harvesting of beach-cast* macroalgae in small quantities by crofters is exempt of a license or permission from the landowner under The Crofters Act 1993, and a stock assessment is not needed. However, *wild harvesting activity* for commercial purposes requires a lease issued by the Crown Estate as a landowner, with previous consultation to the NatureScot, former name Scottish Natural Heritage. Large-scale proposals (>90 t wet weight p/a) of harvesting that are not subject to statutory licensing, are subject to the *"Crown Estates Harvest Licence Option"* process, a full application that requires detailed information of the location, species and volume harvested (monitoring strategies), a sustainable harvesting strategy and business plan (INMARA, 2019). *Vessel-based harvesting* activities require a Marine license under the Marine (Scotland) Act 2010, issue by the Marine Scotland (MS) directorate. Besides, a confirmation from the relevant environmental authority stating that the activity is sustainable and will not provoke adverse effects on the environment must be provided together with the license application. The SEA report specifies that there is a risk of adverse effects on kelp and wrack forests when conducting mechanical harvesting. Currently, there is a moratorium on the removal of certain wild kelp species from the seabed for commercial uses defined in the Scottish Crown Estate Act 2019, section 15 (Scottish Government, 2019b). The moratorium limits the number of granted licenses for harvesting when the removal inhibits the regrowth of the macroalgae. The Scottish Government adopted this regulation as a response to the widespread reaction of local people and other voices objecting a harvesting project submitted by a company aiming to harvest 33,000 tons of kelp per year (Billing et al., 2021). Several Scottish laws and EU regulations comprise the current policy framework for licensing wild harvesting activities in Scotland, which are summarised in the SEA report (Scottish Government, 2016).

Regarding macroalgae cultivation, Scotland has a complete system of rules in anticipation of macroalgae industry growth. The MS directorate defined in 2017 a macroalgae cultivation policy entitled *"Seaweed Cultivation Policy Statement"* (SCPS) after a consultation process to different public bodies (Scottish Government, 2017). The SCPS, including six policies for macroalgae commercial cultivation and IMTA systems and offers guidelines to potential farmers, aims to boost growth of the macroalgae industry by supporting small-medium scale farms developed in a sustainable manner. The SCPS defines two development sizes for macroalgae farms: Small-medium scale cultivation areas (0–50 × 200 m), are considered to have limited environmental impact, but potential negative impact in the case of 30–100 × 200 m areas. Larger areas (>50 × 200 m) are still not considered. Before starting the process for obtaining the necessary permits for macroalgae cultivation, the applicant may apply to a *"Lease Option Agreement"* (LOA). The LOA temporary reserves the seabed area for pending full applications (explained below) and is granted by the Crown Estate Scotland for 3 years, free of charge. The LOA requires a business plan and a project description, which includes the equipment needed, the total area of the farm, the start date of installation and the exact location with latitude and longitude co-ordinates. For Scottish *inshore regions* (up to 12 nm offshore), macroalgae cultivation is considered a "*licensable activity*" due to the need to install equipment into the sea, based on the Marine (Scotland) Act 2010. Farmers need to conduct a full application for a marine license by filling a *"Marine License Application for Algal Farms"* (Scottish Government, 2020b). General guidance on marine licensing can be found on the Marine, fisheries and seal licensing policy section at the Scottish Government website (https://www.gov.scot/policies/marine-and-fisheries-licensing/marine-licensing/). The marine license is issued by the Marine Scotland-Licensing Operations Team (MS-LOT), on behalf of the Scottish government. An applicant for a marine license is required to include the project description, a mitigation plan in response to potential impacts and an application fee that must be paid upfront to MS-LOT. Farmers must consider the Scottish National Marine Plan (NMP) when defining the appropriate location of the farm. The SCPS also recommends setting the macroalgae farm in shellfish waters, defined as clean waters in The Water Environment (Shellfish Water Protected Areas: Designation) (Scotland) Order 2013, to reduce the contamination risk for human consumption. The marine license application process may take 14 weeks and the validity of the license is 6 years. *Offshore regions* (12 to 200 nm offshore) are regulated under the Marine and Coastal Access Act 2009. *Large operations* (>1000 m^2) must conduct a pre-application consultation prior to the marine licensing decision, including consultation to statutory consultees and public consultation event that has been advertised locally based on the Marine licensing (Pre-application Consultation) (Scotland) Regulations 2013. Once the marine license is granted, permission from the Crown Estate Scotland is needed to conduct aquaculture activities on Crown land, based on the Scottish Crown Estate Act 2019. For that, an application for leasing the seabed (Aquaculture leases) must be submitted, including the business plan, the marine license, and the project description. The aquaculture lease is free of charge.

The NMP was adopted in 2015 to provide a policy framework for the management of the inshore and offshore waters (Scottish Government, 2015). The plan enables the sustainable development and use of the marine areas by protecting the marine environment while fostering existing and emerging industries like macroalgae cultivation. Aquaculture is one of the sectors included in the NMP, with fish and shellfish has target biomass to grow. Some of the objectives for this sector are to build a sustainable aquaculture industry, that is economically viable and contributes to food security whilst minimizing environmental impact. In the Aquaculture sector, there is a section for *"Supporting Economically Productive Activity"*, on which macroalgae production is mentioned for the various products that can be obtained and for the nutrient recycling capabilities of macroalgae when combined with IMTA systems (NMP 2015; Aquaculture, Part 3: Other opportunities to grow and diversify the sector). There are also Regional Marine Plans in development that involve consultation with local stakeholders to discuss marine uses, including macroalgae cultivation.

4. Business and government perspectives on the regulation and licensing procedures for macroalgae cultivation

4.1. Finnish macroalgae licensing experience

Origin by Ocean (ObO), founded in 2019, is the first company in Finland planning to conduct macro- and microalgae related activities for commercial purposes, and the first company that has applied for a macroalgae cultivation license. The aim of the company is to establish a biorefinery business extracting sustainable biomolecules from algae, which can be potentially used for pharmaceutical supplies, food, cosmetics, and detergents. For that, they intend to use different raw materials obtained by different methods: cultivation at sea of *Fucus vesiculosus*, harvesting of blue-green algae (cyanobacteria), and use of *Sargassum* sp. shipped from the Caribbean. The biomass production of *F. vesiculosus* and blue-green algae (cyanobacteria) is planned locally. They are also developing the seeding technology for *F. vesiculosus.*

Due to the lack of previous macroalgae cultivation applications in Finland, the macroalgae licensing process is still undefined. ObO was asked by the corresponding authority ELY to fill out a questionnaire, which is an environmental and water management permit application for fish farming (Ympäristö-ja vesitalouslupahakemus kalankasvatukselle). The company was informed to fill out only the parts that apply to macroalgae farming. To date, ObO is in the process to obtain the corresponding permits, being still under discussion whether they need environmental and/or water permits for their operation.

During the interview, ObO mentioned *"we are building the market in Finland"* and they have recognized the gaps in the regulation and licensing process with non-specific licensing applications for macroalgae

cultivation. ObO also observed the difficulties to obtain the appropriate information when several authorities are involved in the decision-licensing process. Although the licensing could have been easier, ObO are "*optimistic*" about the macroalgae industry due to its potential in the blue bioeconomy sector and said, *"macroalgae cultivation can bring work opportunities to local people"*. The company added, *"considering macroalgae cultivation in the Finnish MSP may help to develop this industry"*. ObO are also aware of the Baltic Sea eutrophication problems and they believe that macroalgae cultivation has a "*great potential*" as a nutrient removal measurement to further improve the environmental conditions of this catchment area.

The authorities (ELY and AVI) involved in the licensing process in Finland have expressed their interest in improving the regulation on macroalgae cultivation, but they mentioned that "*more experience in this type of operation would be needed to improve the licensing process"*. They believe that the way to start is by granting first an experimental permit to obtain more information about the potential of macroalgae farming and to know more about the possible risks to the environment. The Finnish MSP planners and stakeholders have "*recognized the potential of the macroalgae industry in the blue economy*" and there is interest to consider macroalgae in future MSPs.

4.2. Sweden macroalgae licensing experience

Nordic Seafarm, founded in 2016, is the largest company conducting commercial macroalgae aquaculture in Sweden, and they cultivate sugar kelp (*S. latissima*), oarweed (*L. digitata*) and sea lettuce (*Ulva intestinalis*) at the Swedish west coast. They produce their own seeding material on ropes, which is also sold to other companies. The raw biomass is mainly sold to the food industry, being present in many food products like vegan burgers, beers and gin, and they collaborate with known chefs. They are also collaborating with other companies to produce biomaterials from macroalgae with different applications, e.g. construction material and bioplastic.

Although the Nordic Seafarm products are present in different industrial sectors, the company emphasize the need to "*improve the market by organizing business-to-business meetings*" with food producers, chefs, and retailers, as well as events to meet the public. Nordic Seafarm also mentioned during the interview "*we are building the market*", like ObO, and thus, they observed similar regulatory problems such as unspecific regulation of macroalgae cultivation and complex licensing process. For Nordic Seafarm, the Environmental Court evaluation of the application and the conduction of an environmental impact assessment, considered macroalgae cultivation as high environmental impact, was their main legal barrier for obtaining the macroalgae cultivation license that ultimately prolonged the licensing process. The timeframe for Nordic Seafarm to obtain the cultivation license was 15 months, even though they were familiar with the complexity of the application process. Small operations are exempted from the Court revision, but for Nordic Seafarm this type of operations are too small to be profitable and are suitable only for testing purposes. Although, they identified legal and business barriers, Nordic Seafarm believe that "*the market is promising and once the market is built, the authorities will be eager to regulate it"*.

The national authority Land and Environmental Court pointed out several environmental issues related to macroalgae cultivation. The Court stated *"Macroalgae cultivation may cause disturbances for sensitive habitats and animals. Also, deposition of detritus from cultivation areas may cause oxygen deficit problems in the bottoms"*. Thus, the Court considers macroalgae cultivation to have high environmental impact and consequently, it may require a more complex environmental impact assessment before the commencement of the operations. However, the Court recognized that the evaluation process is complicated and stated, *"considering the low environmental impact of macroalgae cultivation compared with other water activities and the small conflicts with other interests, macroalgae cultivation could be handled through a notification process to the County Administrative Board"*. The Court recognized that macroalgae cultivation has big opportunities since *"it corresponds to many common sustainability goals for Sweden"*.

4.3. German macroalgae licensing experience

Kieler Meeresfarm GmbH & Co. KG (KM) is a German company founded in Rebours et al., 2014 that extended their operation in 2020 with a permit to run an IMTA system. Currently, they cultivate *S. latissima* and mussels, and they are aiming to introduce sea trout into the farm. With this IMTA system, the company will achieve a nutrient neutral cultivation farm where macroalgae cultivation is recognized as a compensation measure for nutrients released by fish aquaculture. In Germany, cultivating only macroalgae is not recognized as a compensatory method of nutrients released elsewhere, it must be combined with other activities such as fish farming to count as a compensatory measure. KM is also running initial trials to cultivate *F. vesiculosus*. The cultivated biomass is sold to OceanBASIS, a sister company specialized in the extraction of active ingredients for cosmetics. KM is the first German company with an IMTA permit that was obtained after a 4-year licensing process.

During the interview, KM mentioned that *"the most complex and tedious step was to find all the authorities that need to be contacted during the licensing process"*. However, KM found support from the administration personnel who offered assistance in writing the proposal. The company must keep informing the authorities to obtain the permits and approvals to conduct the IMTA activity. Besides all the environmental permits (see Section 3.3), they also had to apply to the federal Government (water owner) to conduct a survey that determines the possible existence of bombs from WWII in the cultivation area. Another barrier mentioned by KM was economic*: "It is difficult to obtain funding for this type of operations at the EU level"*. The company also recognizes that "*the interest in macroalgae is increasing but the market is still small, and the production costs are high"*.

4.4. Estonian macroalgae licensing experience

In Estonia, there are several companies that use the red algae *F. lumbricalis* for different commercial purposes. Tinurek OÜ, founded in 2009, is the only company with harvesting license in Estonia. They are currently harvesting macroalgae in the Saarema area and supply the dry material to EstAgar AS and to Vetik OÜ, a sister company of Tinurek OÜ founded in 2017. Tinurek OÜ/ Vetik OÜ uses the raw material to extract the red pigment phycoerythrin for food and cosmetic applications. The biomass collected in Estonia is relatively low (~1000–1500 tons ww per year) due to market barriers.

They are seeking new ways to valorise the macroalgae industry with a biorefinery approach. EstAgar AS, founded in 1997, extracts carrageenan (Furcellaran) from the algae and sells it to different clients within the food and cosmetic industries. EstAgar AS is also interested in exploring new production lines, such as the extraction of the pigment phycoerythrin.

Tinurek OÜ mentioned in the interview that one of the barriers in the macroalgae business is at the market level: *"cultivation is still an expensive activity due to the low price and underdeveloped market for this species"*. Thus, Tinurek OÜ believes that further *"valorization of the biomass by creating a specific biorefinery process"* and *"organization and participation of events"* will contribute to promote the macroalgae industry in Estonia. The company EstAgar AS is in the process of obtaining the cultivation license which they started in 2018. They are satisfied with the harvesting regulation, but they observed issues in the cultivation licensing process and stated that *"the lack of a specific regulation and the complex evaluation of the application is causing the lengthening of the process"*. However, EstAgar AS observed that the Ministry of Rural Affairs is starting to support aquaculture activities in Estonia and they stated, "*this can contribute to improve the current situation*" and added, "*the new MSP for Estonia may help*".

The Ministry of Environment has communicated that the lack of macroalgae farming regulation is due to the current absence of macroalgae farming activities in Estonia and thus, there has not been a need for regulation until now. The ministry has identified some challenges with macroalgae farming: *"potential conflict with coastal fisheries and potential environmental risk at local level"*. Authorities have observed inadequate project applications from some stakeholders, with unsuitable species or lack of environmental information. The environmental impact assessment of macroalgae farming may be challenging due to missing previous cases. As a potential benefit, they mentioned that *"macroalgae can reduce the nutrient loads in the Baltic Sea, we have enough area for farming"*. They have recognized the potential of the biorefinery industry but with a further improvement of the marketing and product development.

4.5. Icelandic macroalgae licensing experience

The Icelandic company Thorverk hf. was founded in 1975 at Reykhólar, a small village mainly focused on the macroalgae harvesting and drying. Thorverk hf. is the only large-scale wild harvesting company in Iceland. In the past, the company harvested *A. nodosum,* L. *digitata* and *L. hyperborean*. Currently, *A. nodosum* is the main harvested species by the company with an annual harvest of 15,000–20,000 t per year (Maack, 2019). To conduct the activity, the company applied for a harvesting license and for an exemption of weighing macroalgae on a certified port-scale, due to difficulties adhering to regulations. The permit was granted in 2020 and there is a certified person who carries out the weighing and reporting. The company pays a resource rent to the landowner and the corresponding tax to the Government for harvesting *A. nodosum*. Thorverk hf. has not observed any difficulties in obtaining the harvesting license, it is a well-defined process, and the biomass is not a limitation yet. The company is positive about the growing macroalgae market.

The Ministry of Industries and Innovation pointed out several potential barriers for the development of macroalgae cultivation. As environmental barrier, the Ministry mentioned, *"there is a potential risk for natural communities by shading the species below the cultivation facility"*, and thus, the areas with natural macroalgae stands should be avoided for cultivation. The Ministry mentioned one social-economic barrier: "*Extensive macroalgae aquaculture may also cause conflicts with other marine sectors like navigation"*. As a positive aspect, the Ministry sees the potential of macroalgae cultivation at sea as a source of products for food and industrial uses, or as part of integrated aquaculture facilities.

4.6. Norwegian macroalgae licensing experience

The Norwegian company Tango Seaweed AS (TS), founded in 2016, cultivates *S. latissima* and *A. esculenta* on ropes outside Herøy, on the west coast of Norway. They sell their dry material as condiments and as food ingredients to other food producers. They work closely with Hortimare, a company specialized in macroalgae propagation of cultures by providing seeded material. TS has two licenses in two different locations, in total 46 ha, but they are currently only running a 2 ha pilot cultivation. In addition, they have licenses for 10 different macroalgae species of which they were cultivating only two in 2021. The Norwegian company Lerøy Seafood Group has a long history of capturing, selling and distributing seafood. Lerøy Group has two daughter companies conducting macroalgae-related activities: Ocean Forest AS, an R&D company founded in 2013 with the aim to develop seeding techniques, and Lerøy Ocean Harvest AS (Leroy), founded in 2018 and focused on the cultivation of *S. latissima.* The algae are fermented and sold as animal feed. Their production for human consumption is still on a small scale. The company is conducting the cultivation of fish and macroalgae in the same locations and is trying to reach a neutral nutrient system by following the "*mass balance principle*". This company has 9 licenses for macroalgae cultivation at different locations. However, one of the licenses was rejected due to lacking social acceptability of the macroalgae farm in one location. In Norway, the public has the right to approve or disapprove any water activities in their municipality, and in this location the cultivation activity was not approved.

For both companies, TS and Leroy, the timeframe for granting the license was <1 year. The licensing process and management of macroalgae farming is adjusted to the salmon aquaculture regulation, under the Aquaculture Act, and thus, the process is well defined. The two companies were familiar with the process and with the coastal zone management from previous projects. However, both companies shared the same opinion: fish farming licensing process, based on the Aquaculture Act, is not suitable for macroalgae farming. Leroy stated, "*Having this non-specific regulation may cause delay, or even rejection of the licenses*", and TS added: "*many aspects of the application are not suitable for macroalgae farming (e.g., procedures to assess environmental impacts)"*. Leroy gave some examples of incompatibility between the current regulation and macroalgae farming. Macroalgae cultivation do not introduce organic pollutants at sea and then, the discharge permit, based on the Pollution Control Act, may not be necessary. Besides, the absence of macroalgae farming in the Norwegian marine spatial plans may cause rejections of the macroalgae license if the suggested locations are inadequate for fish farming, although they can be suitable for macroalgae farming.

Leroy is positive about the market, *"the market is growing"*, however, they also said *"we have to create the market"*. TS is optimistic about the improvement in the licensing process and stated, "*I expect changes in the process of licensing, with authorities better informed and the process adapted to macroalgae farming that may allow the harmonization of the process across the country"*. This may cause the lengthening of the licensing process, but they consider it a good and necessary development. TS also mentioned that the industry needs to be developed, "*the market needs improvement and maturation, needs to be built and informed, especially on the wide diversity of products, macroalgae species and cultivation methods"*. TS believes that macroalgae industry has a big potential for green and sustainable food production.

The Ministry of Trade, Industry and Fisheries stated the need to monitor the seabed for possible environmental impacts. The Ministry has also observed inadequate plans for process development. The authority County Administration of Agder, and also the Ministry, recognized that *"the licensing process is time-consuming due to the large number of authorities involved in the application process"*.

5. Conclusions and recommendations

Summarizing the analysis on empirical evidence, all the companies in the studied countries observed the same challenges: non-specific regulation and a complex licensing process, including several authorities involved in granting the macroalgal cultivation license. As a response, the authorities claimed that more experience and information is needed about the potential environmental risks associated with macroalgae cultivation.

Similarly to the EU level, macroalgae biomass production, and particularly cultivation, is lacking specific regulation in the Northern European countries, although the countries located in the North Atlantic have more tradition in using macroalgae (Norway, Iceland and Scotland) compared to the Baltic Sea countries. Both cultivation and harvesting of macroalgae are subject to general environmental and water laws and thus, macroalgae companies need to apply for a water, environmental or fishing permit, which involve undertaking a complex licensing process, as the rules are not yet well-established. Our study provided deeper knowledge on the legal conditions and barriers that previous literature had mentioned as an important factor for the macroalgae industry (Barbier et al., 2019; Araújo et al., 2021; Billing et al., 2021; van der Burg et al., 2021). For producers, these legal barriers are delaying or preventing the development of the macroalgae industry in the Northern European countries.

When searching for emerging themes, we discovered that all the

interviewed companies mentioned *"we are building the market"*, showing how marginal the macroalgae market is still in the Northern European countries, but also reflecting the lack of support to the companies to boost this industry. In addition to legal barriers, some companies recognize broader social-economical barriers, e.g., high production cost, funding problems, and lack of social acceptance Some companies form Norway, Sweden, and Estonia mentioned the importance of organizing business events that can visualize the variability of macroalgae products and further promote the macroalgae market. For instance, the company Dutch Weed Burger introduced in the market burgers made with macroalgae that are locally and sustainably produced and reach the consumers via restaurants and food festivals (van der Burg et al., 2021). When searching for new consumers, good taste but also local and environmentally friendly production seem to be major preconditions for tasters to eat macroalgae products (Birch et al., 2019; Kulikowski et al., 2021). As another way of improvement, the companies from Estonia and Finland believe that introducing macroalgae cultivation as a new sector in the national maritime spatial plans can help to develop this industry. On the other side, all the national authorities highlighted that more experience and research on macroalgae cultivation are needed to assess the potential environmental impact of this type of activity on marine ecosystems. In addition, some authorities were concerned about possible conflicts with other water users when introducing this new sector in marine spatial plans, for instance, the effect on tourism (Wood et al., 2017). However, some policy makers and regulatory authorities were positive and recognized the potential of macroalgae in different industrial sectors like energy, food and feed production.

As answers to our research questions, we concluded that a) businesses expect authorities to understand the specifics of the macroalgae industry, including the environmental benefits of macroalgae cultivation, to differentiate macroalgae cultivation from fish farming, and to define clear and speedy licensing procedures and b) authorities expect the businesses to evaluate the environmental risks of their operations. Businesses and authorities are the two main parties shaping this relatively new field of blue bioeconomy. The markets are embedded in rules, which businesses and authorities build together, both relying on science. Well-informed judgment by experienced regulators is crucial. Due to the potential environmental, employment and health benefits, sustainable macroalgae biomass production needs to be promoted by clarifying the licensing procedures and the conditions for obtaining the license. The expansion of macroalgae production has caught government regulatory and monitoring bodies unprepared with some exceptions. In Scotland, the Scottish Government has quickly responded to the need to build a regulatory framework, with well-defined legislation and licensing process that can foster the development of this industry.

We framed macroalgae production license as a *boundary object* between business and authorities. The license is the boundary object that defines the conditions for conducting the operation (Table 4). For the companies, the license is the precondition for starting and expanding the business, and thus an important basis for blue business strategies. For the authorities, the license is a tool to realize their duty to balance societal interests and to protect the environment by enforcing the legislation. The goals of the parties and the broader society are balanced and resolved in the license. The license, considered as a boundary object, should serve as a tool to facilitate the cooperation between companies and authorities.

Both parties, business and authorities, have good grounds for their expectations. Through collaboration they can develop a fair and efficient regulatory framework (see Ulibarri et al., 2017). The authorities cannot grant licenses without scientific risk assessments. However, macroalgae farmers are aware of the potential social-economic and environmental benefits of the macroalgae cultivation. As macroalgae farming has positive impacts and is less risky than fish farming and less complicated than IMTA, it should benefit from simplified procedures and harmonized regulation. To develop a macroalgae regulatory framework with well-defined procedures for cultivation and harvesting we recommend:

Table 4
Macroalgae license defined as boundary object.

Business	The license	Authorities
The license as a condition for business and basis for strategy	The boundary object that defines the conditions for operation	The license as a tool for realizing administrative duties based on legislation

1. Incorporate macroalgae cultivation in the national MSPs to facilitate long-term planning.
2. Streamline and simplify the licensing process by defining one-step and specific macroalgae permit, without the need to contact several different authorities.

Macroalgae farming may become an important part of climate mitigation strategies (FAO, 2018). Macroalgae can function as a carbon sink (Krause-Jensen and Duarte, 2016) and its cultivation could be one of the ocean carbon removal strategies (Webb et al., 2021). Economic compensation for climate services associated with macroalgae farming would help generate new markets for macroalgae production while also creating incentives to reduce further the carbon footprint of macroalgae aquaculture (Duarte et al., 2017). Similarly to how trade is expanding in carbon offsets, operators can be encouraged to trade in nutrient offsets (Kostamo et al., 2020). Nutrient offset markets have already been created in some places, for example in Denmark (Kostamo et al., 2020). Fish farmers can buy offsets from algae farmers, or both types of aquacultures can be combined under IMTA systems (Belinskij et al., 2021).

Realizing the carbon and nutrient removal potential of macroalgae production should be developed simultaneously with the development of novel macroalgae products such as foods, bioactive compounds, and biomaterials. Authorities has by default a much-needed focus on potential negative environmental impacts of marine aquaculture, but when it comes to macroalgae, there should be a way to quantify the potential positive effects as well. For macroalgae cultivation to move forward, a key issue will be to have a sustainable expansion of the industry with close collaboration between all stakeholders involved.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Open access funding provided by Finnish Environment Institute (SYKE). This work was supported by the EU Interreg Baltic Sea Region program under the European Regional Development Fund and by the Nordic Council of Ministers through the projects: Growing algae sustainably in the Baltic Sea (GRASS) and Sustainable cultivation of seaweed (SUSCULT), respectively.

We would like to thank all the companies and authorities that contributed to this study and all partners involved in the GRASS and SUSCULT projects and the SUBMARINER Network secretariate.

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