STUDY

Research for the PECH Committee

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The future of the EU algae sector

Fisheries

Policy Department for Structural and Cohesion Policies
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RESEARCH FOR PECH COMMITTEE

The future of the EU algae sector

Abstract

This study examines the EU Algae Initiative of the European Commission and gives an overview of the European algae sector in terms of production, applications, opportunities and barriers. The 23 targeted actions proposed by the Commission have been set out with the goal of unlocking the vast potential of algae for the EU's Blue Bioeconomy, addressing key challenges, such as food security and climate change mitigation. For successfully developing the sector, a set of barriers will need to be overcome. This requires a collective effort by policymakers, at Member State and EU level, as well as industry stakeholders, scientific community, administration and others.

This document was submitted to the European Parliament's Committee on Fisheries.

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DISCLAIMER

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LIST OF ABBREVIATIONS

AAM	Aquaculture Assistance Mechanism
CEN	European Committee for Standardization
CFP	Common Fisheries Policy
DG AGRI	The European Commission's Directorate-General for Agriculture and Rural Development
DG GROW	The European Commission's Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
DG MARE	The European Commission's Directorate-General for Maritime Affairs and Fisheries
DG RTD	The European Commission's Directorate-General for Research and Innovation
DG SANTE	The European Commission's Directorate-General for Health and Food Safety
EGD	European Green Deal
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data Network
ENER	The European Commission's Directorate-General for Energy
EUMOFA	European Market Observatory for fisheries and aquaculture (EUMOFA)
FAO	Food and Agriculture Organization of the United Nations
IMTA	Integrated Multi-Tropic Aquaculture
MSP	Maritime Spatial Planning
PBR	Photobioreactor
PECH	European Parliament's Committee on Fisheries
R&I	Research and Innovation
SMEs	Small and Medium-sized Enterprises
Sp.	Species
TFEU	Treaty on the Functioning of the European Union

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EXECUTIVE SUMMARY

This paper gives an overview of European algae production, including applications, opportunities and barriers (Section 2), provides an outline of the European and global algae sector development (Section 3), and summarises the main aspects of the Commission's EU Algae Initiative (Section 4).

a. European algae production

The European algae sector produced a total of 287 390 tonnes in 2019, representing 0.8% of the global production. The vast majority of this production is based on macroalgae with a small fraction of less than 1 % originating from microalgae. In the EU, **France, Ireland and Spain** are the top three countries in terms of turnover, employment and number of **macroalgae** companies. The top four Member States with the highest number of **microalgae** companies are **Spain, Germany, France and Italy**.

European macroalgae production is predominantly based in the **North Atlantic**. It mainly relies on **wild stock harvesting** as the most common production method. The most common seaweed **applications** include food, food-related products, as well as cosmetics and well-being. **Seaweed aquaculture** production is well positioned to play a key role for sustainable production operations, food security and climate change mitigation. Conversely, increasing sustainability issues with wild harvesting, high production costs and a limited market demand, are some of the **key barriers** hampering the macroalgae sector in its development.

Microalgae production in Europe is **land-based** and occurs in photobioreactors (71%), ponds (19%) and fermenters (10%). Common microalgae **applications** include food supplements and nutraceuticals, cosmetics and wellbeing products, as well as feed. Given the common use of photobioreactors for production, the European microalgae sector is in a unique position for producing high-value algae-based products, such as nutraceuticals, with a variety of additional potential applications under development. Limited capacity to increase production using reactors, high production costs, as well as administrative barriers, are some of the **main challenges** associated with the sector.

b. Global algae sector

Global algae production has increased from 0.56 million tonnes in 1950 to 35.82 million tonnes in 2019. Over **97% of all production comes from Asia** with Chinese production accounting for 57% globally. Besides China, Indonesia (27% of global production), South Korea (5%) and the Philippines (4%) are major producers. Macroalgae account for over 99% of global algae production. As mirrored by European production patterns, ***Saccharina*** is the most commonly produced macroalgae group globally, accounting for 36% of the total production. For the microalgae sector, **green microalgae** are the most commonly produced group, although when including cyanobacteria with microalgae, **Spirulina** dominates production in Europe and globally. The substantial growth of global algae production is not reflected by European production patterns, which have remained relatively flat. Nevertheless, the highest number of seaweed start-ups and equity investments in the algae sector occur in Europe. **France and Norway** are generally seen as the frontrunners of the European algae sector, having substantially increased production levels since 2018.

c. EU Algae Initiative

On 15 November 2022, the European Commission published its communication "**Towards a Strong and Sustainable EU Algae Sector**", also known as the **EU Algae Initiative**. This initiative sets out a strategic approach for **developing algae production** and associated value chains in the Union. The

communication follows up on different Commission reports, publications and policy initiatives, largely associated with the **European Green Deal**. The aim of the initiative is to unlock the potential of algae production as part of the **Blue Bioeconomy**. To this end, benefits and challenges related to the current setup and future projections of the algae sector are described (Figure 1), accompanied by action areas for growing the industry.

Figure 1: Summary of benefits and challenges presented in the EU Algae Initiative

Benefits	Challenges

• Food security
• European Green Deal
• Source of alternative protein
• EU Blue Bioeconomy development
• Various commercial applications
• Low-carbon aquaculture
• Sustainable food and feed products
	• Fragmented governance framework
	• Low production levels
	• Low consumer awareness and acceptance
	• Knowledge gaps, such as:
	  ○ Environmental impacts/benefits
	  ○ Harvesting, processing and cultivation techniques

Source: EU Algae Initiative

The four overarching aims of the initiative are improving **governance framework, business environment, R&I and market development**. The implementation of these aims is to be achieved by completing **23 targeted actions.** The implementation period of these actions is generally set between 2023 and 2027, with **seven actions** containing specific end dates. The Commission announced a final evaluation of the progress in implementing this initiative for the end of 2027.

1. INTRODUCTION

The **European Green Deal** is one of the six policy priorities of the von der Leyen Commission for 2019-2024, setting out packages for achieving climate neutrality by 2050 and developing a resource-efficient economy[1]. In the European Green Deal communication, "**seafood based on algae**" is mentioned as an example for "innovative food and feed products" as part of the Farm to Fork Strategy. Additional policy drivers associated with the development of the EU algae sector are the updated **Bioeconomy Strategy** and the **Sustainable Blue Economy** communication[2].

As a key element of marine ecosystems, algae not only generate most marine **primary production** (approximately half of all photosynthesis globally), but also provide essential **ecosystem services** (e.g. food source, water quality and biological regulation).[3] Distinguished between macroalgae (seaweeds) and microalgae (phytoplankton), over 70 000 species are estimated to exist, 50 of which are commercially exploited.[4] Using algae as a source of food, feed, and even energy, dates back to over half a century. Algae consumption is most prevalent in **South-East Asia**, where over 90% of the global production occurs. Some European countries like Ireland have a long history of seaweed collection and processing for consumption (e.g. red alga *Palmaria palmata*), playing an important **cultural and socio-economic role** (Mouritsen et al., 2020).

On 15 November 2022, the Commission released the communication '**Towards a Strong and Sustainable EU Algae Sector**' (Figure 2)[5]. This communication sets up the framework for **unlocking the potential of algae production as part of the Blue Bioeconomy**. The present study gives an overview of European algae production, including applications, opportunities and barriers (Section 2), provides an outline of the European and global algae sector development (Section 3), and summarises the main aspects of the Commission's Algae Initiative (Section 4).

1 European Commission, The European Green Deal
2 European Commission, A sustainable Bioeconomy for Europe;
European Commission, Transforming the EU's Blue Economy for a Sustainable Future
3 National Oceanic and Atmospheric Administration, Arctic Ocean Primary Productivity;
Hydrobiologia, Ecosystem services provided by marine and freshwater phytoplankton;
European Commission, State of knowledge regarding the potential of macroalgae cultivation in providing climate-related and other ecosystem services
4 Journal of Phycology, How many species of algae are there?;
European Algae Biomass Association, What are Algae?
5 European Commission, Towards a Strong and Sustainable EU Algae Sector

Figure 2: Word cloud created from European Commission's communication "Towards a Strong and Sustainable EU Algae Sector"

Source: EU Algae Initiative

2. EUROPEAN ALGAE PRODUCTION

KEY FINDINGS

- European **macroalgae** production is predominantly based in the **North Atlantic**. It relies on **wild harvesting** as the **preferred production method** (68% of total production).
- The most common **seaweed applications** include **food, food-related** products, as well as **cosmetics** and **wellbeing**.
- **Seaweed production**, particularly aquaculture, is well positioned to play a **key role** for **sustainable aquaculture** operations, **food security** and **climate change mitigation**.
- Conversely, increasing **sustainability issues** with wild stock harvesting, high **costs** and limited market **demand**, are some of the **key barriers** concerning the **macroalgae** sector.
- **Microalgae production** in Europe is **land-based** and occurs in photobioreactors (71%), ponds (19%) and fermenters (10%).
- Common **microalgae applications** include **food supplements** and **nutraceuticals**, **cosmetics** and **well-being** products, as well as **feed**.
- The European **microalgae** sector is in a unique position for producing **high-value algae products**, such as **nutraceuticals**, with a variety of additional potential applications under development. **Scalability limitations of reactors**, high production **costs**, as well as **administrative barriers**, are some of the main challenges associated with the sector.

KEY FACTS

Market data:

Global algae market value by revenue, 2021:	€18.5 billion (Vantage Market Research)
Global algae market value forecast for 2028:	€33.7 billion (Vantage Market Research)
Global macroalgae biomass production, 2019:	35.8 million tonnes (FAO)
➢ European share:	➢ 0.8%
Global microalgae biomass production, 2019:	56 456 tonnes (FAO)
➢ European share:	➢ 0.63%
European algae biomass production, 2019:	287 390 tonnes (FAO)
➢ Macroalgae share:	➢ 99.88%
➢ Microalgae share:	➢ 0.12%
European algae turnover, 2018:	€350 million (European Commission)
European seaweed imports, 2016:	€554 million (Seaweed for Europe)

Macroalgae production method by company in Europe:

Harvesting from wild stocks	68%
➢ Manual	➢ 85%
➢ Mechanical	➢ 15%
Macroalgae aquaculture	32%
➢ Sea-based	➢ 76%
➢ Land-based	➢ 24%

Microalgae production method by company in Europe:

Photobioreactors	71%
Ponds	19%
Fermenters	10%

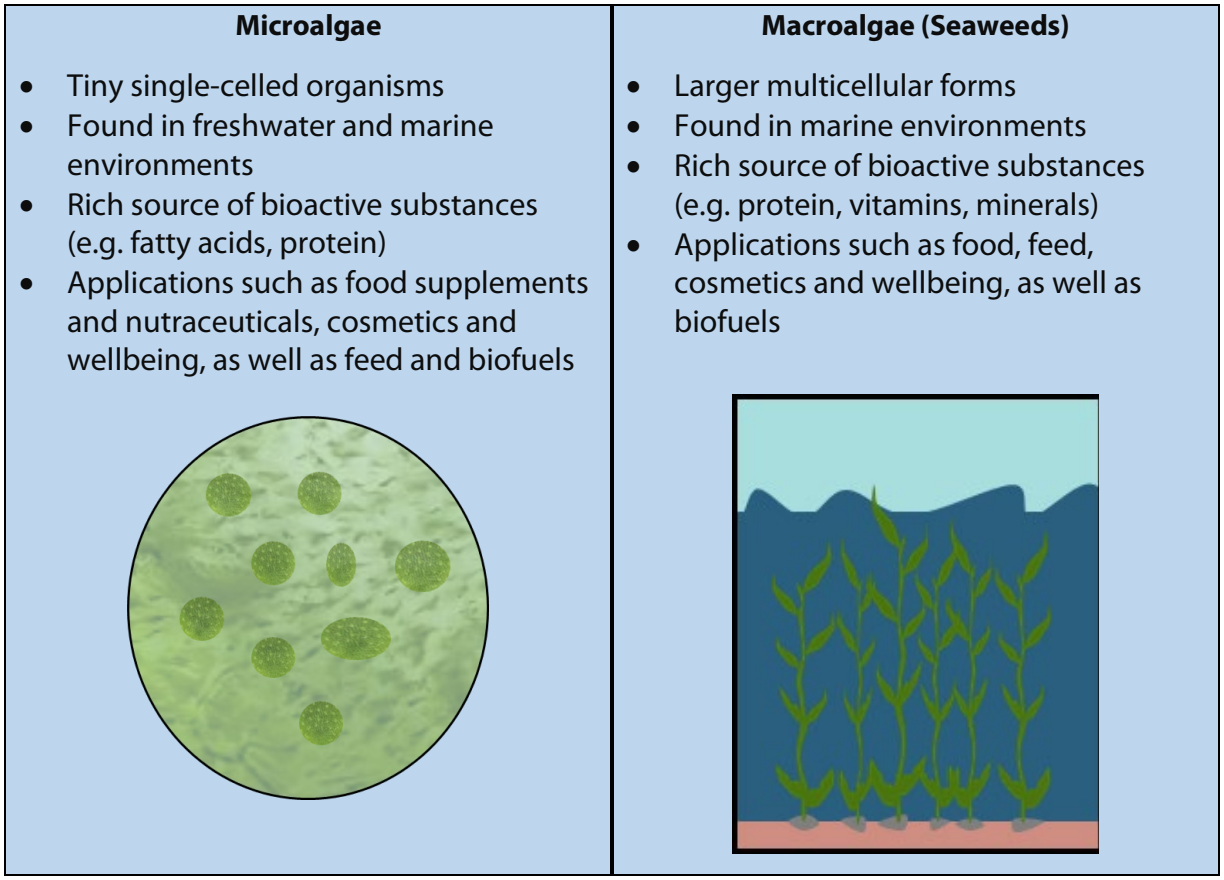
Top EU countries by number of algae companies and turnover/employment:

Macroalgae	France, Ireland and Spain
Microalgae	Spain, Germany and France/Italy
Spirulina	France, Italy and Spain
Turnover/employment (all)	France, Ireland and Spain

2.1. Background

Algae are a very diverse group of photosynthetic organisms that are found in nearly all aquatic environments. They range in size from tiny single-celled organisms (<3 µm) to large multi-cellular forms such as kelp (>30 m). Algae are classified into two main groups: Microalgae and Macroalgae (Figure 3). **Microalgae are tiny single-celled organisms** that are found in both freshwater and marine environments. They are a rich source of pigments, oils, and proteins and can be used for a wide range of applications such as food, feed, cosmetics and biofuel (Koyande et al., 2018; Mutanda et al., 2020). **Macroalgae**, also known as **seaweeds**, are **larger multicellular forms** that are found in marine environments. They are used, among others, for food, feed, and as a source of bioactive compounds (Roohinejad et al. 2017). Algae are also known for their ability to produce oxygen and absorb carbon dioxide, which makes them an important part of the global carbon cycle.

Figure 3: Key aspects of microalgae and macroalgae



Source: Own elaboration

In Europe, **seaweed production** largely relies on **harvesting wild stocks** (68% of seaweed companies), whereby **manual** collection is the most common harvest method (Figure 4). The majority of seaweed aquaculture occurs in **sea installations** (76% of seaweed aquaculture companies) with the remaining production being **land-based**. For European **microalgae production**, over two thirds of companies use **photobioreactors** (PBR) as their production method, followed by **ponds** (19%) and **fermenters** (10%).

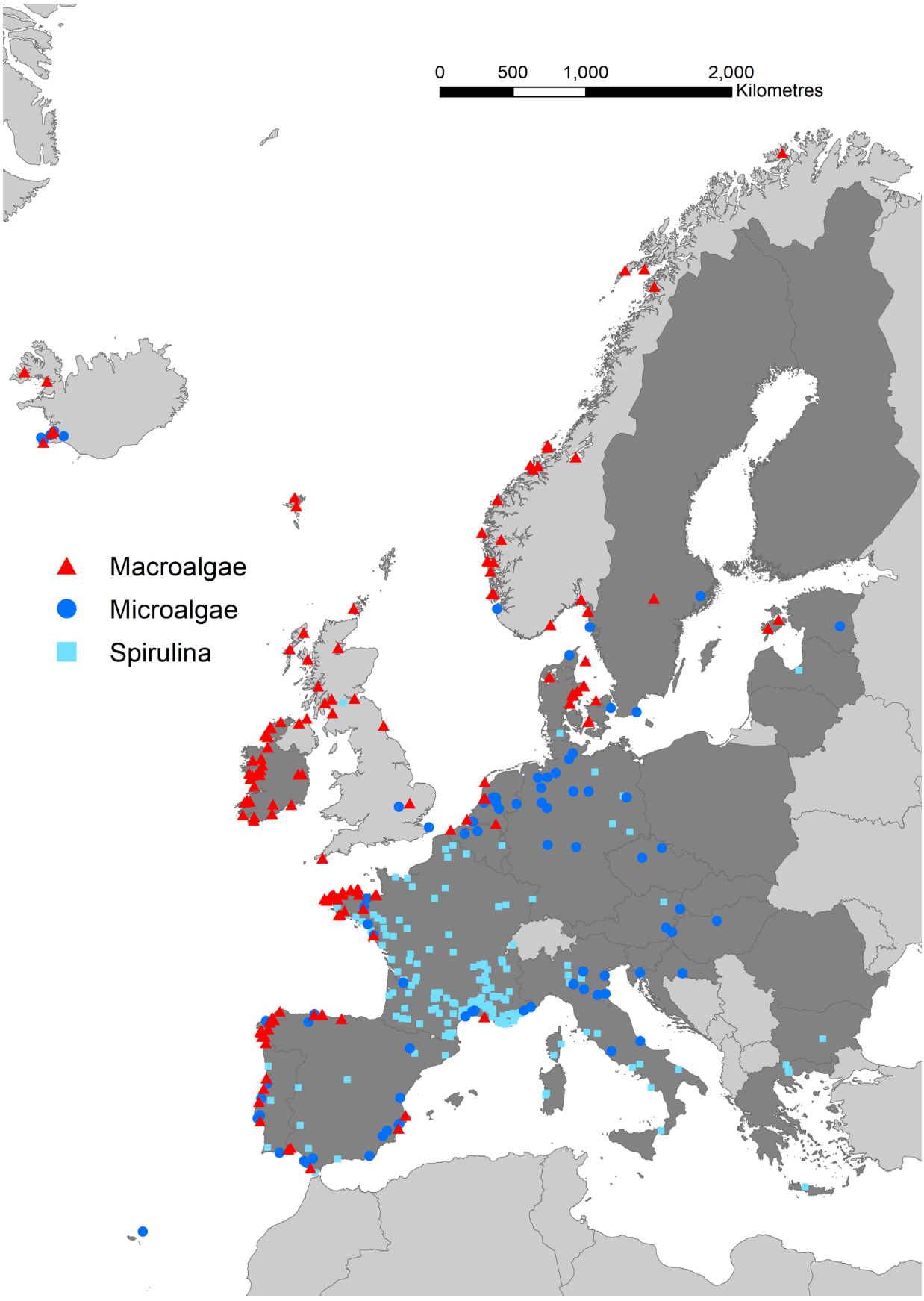
Figure 4: Main algae production methods in Europe

Source: SWD(2022) 361, p. 8

In terms of the number of EU **macroalgae** production companies, **France** (33 companies), **Ireland** (29 companies) and **Spain** (22 companies) are the most important Member States (Figure 5). With regards to the importance and share of both macroalgae/seaweeds and microalgae production, the majority of European countries have **more macroalgae** producing companies, including Denmark, France, Spain, Estonia, the United Kingdom and Norway (Figure 6).

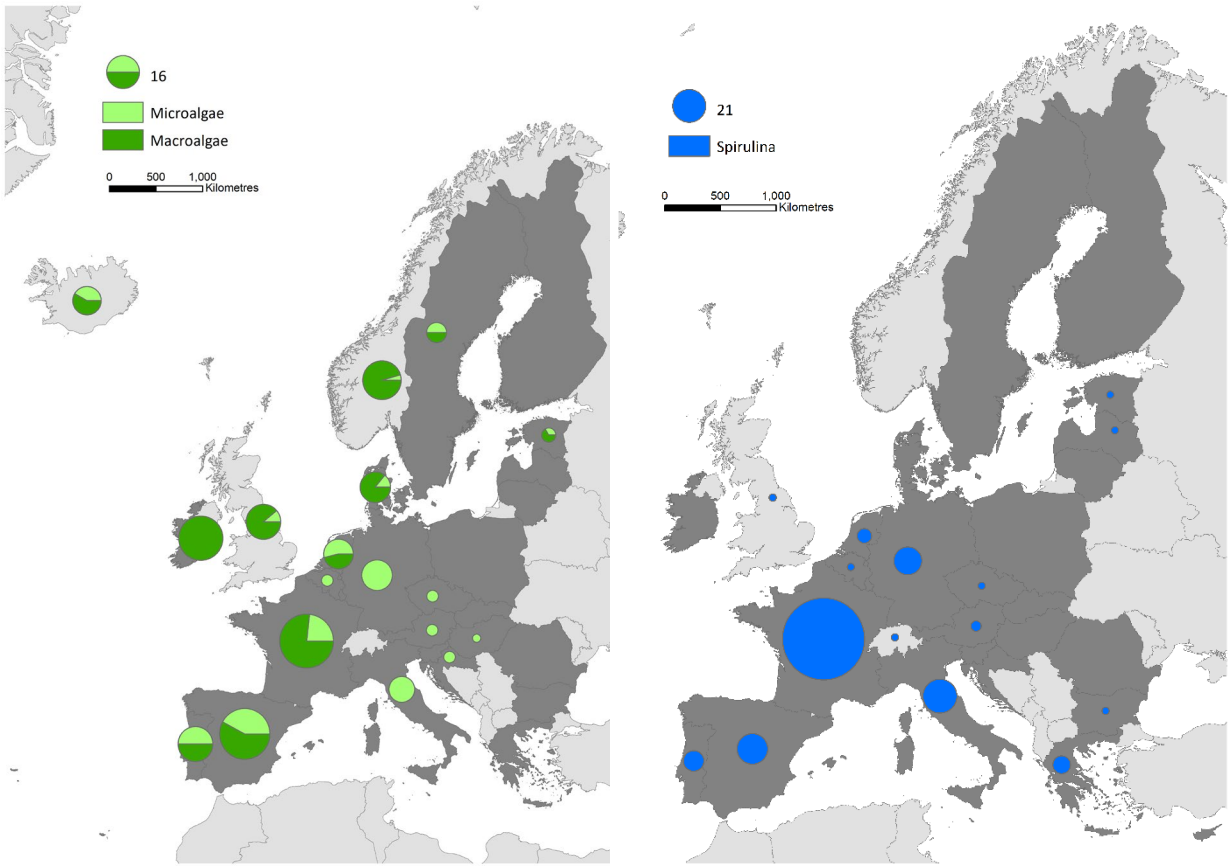
For **microalgae**, **Spain** (16 companies), **Germany** (14 companies), as well as **France** and **Italy** with 10 companies each, host the most companies in the EU. Germany, Italy, Austria, Croatia, the Czech Republic, Belgium and Hungary have microalgae and Spirulina producing companies, but they have no companies involved in seaweed production. For **Spirulina production**, the vast majority of companies are based in **France** (129 companies), followed by **Italy** (22 companies) and **Spain** (18 companies; Figure 6).

Figure 5: Distribution of macroalgae-, microalgae- and Spirulina production plants in Europe, February 2023



Source: Own elaboration based on data from the European Marine Observation and Data Network (EMODnet)

Figure 6: Relative distribution of macroalgae vs microalgae companies and Spirulina companies, by country



Source: Own elaboration with data from European Marine Observation and Data Network (EMODnet)
Note: The left map shows the relative distribution of microalgae and macroalgae companies by country. The size of the circle in the legend equals 16 companies. The right map shows the distribution of Spirulina production companies. The size of the circle in the legend equals 21 companies.

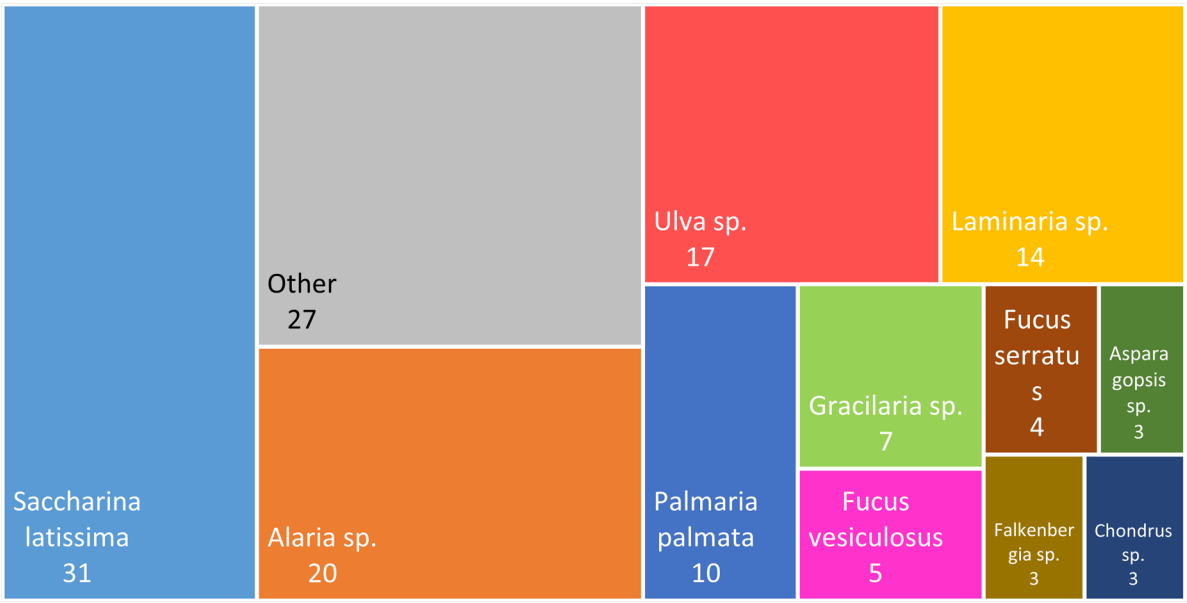
2.2. Macroalgae

2.2.1. Overview

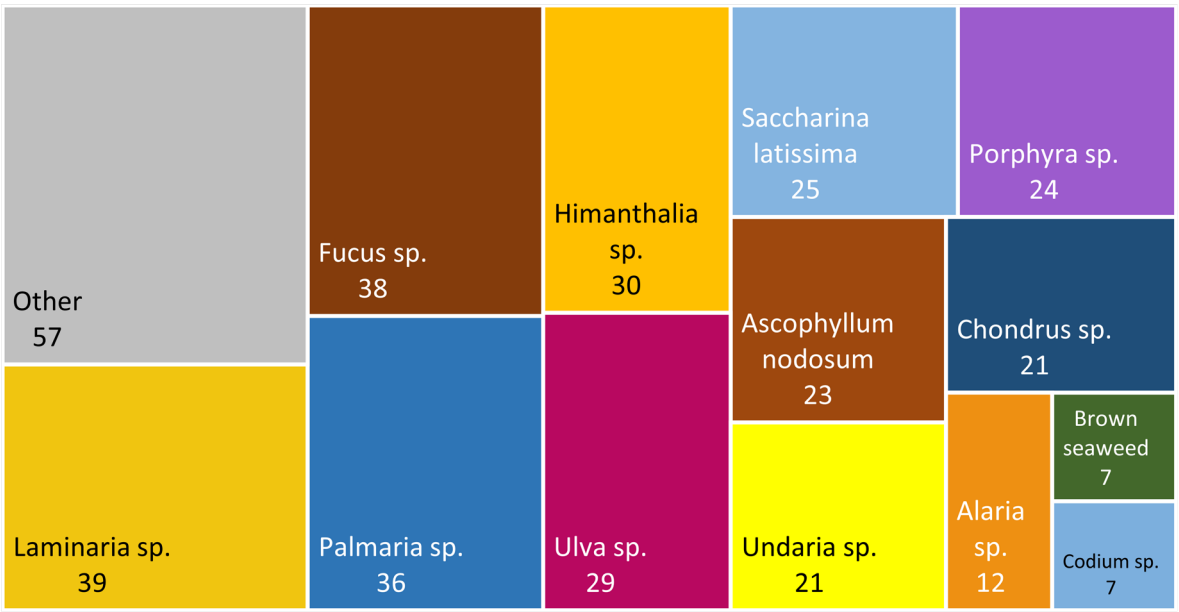
There are about 163 macroalgae producing companies in Europe, with **France, Ireland and Spain** representing the top three EU countries with over 20 companies registered in each (Figure 5). The majority of the production is located in the **North Atlantic** compared to few production sites in the Mediterranean. Over two thirds of the companies **harvest wild stocks** from the coastline, 85% of which occurs manually and 15% performed mechanically. **Aquaculture production** of macroalgae represents just 32% of the production method employed by European companies. Macroalgae aquaculture largely occurs at sea (76%) with the expansion potential for sea-based cultivation expected to be substantially higher compared to land-based operations (Araújo et al., 2021). In terms of species exploited, **kelps (*Laminaria* species)** represent the most important genus used for aquaculture and wild stock harvesting based on tonnage produced (Figure 7). For seaweed aquaculture, the majority of companies cultivate sugar kelp (*Saccharina latissima*), followed by winged kelp (*Alaria esculenta*) and the green algae *Ulva* species. Although the vast majority of wild harvesting in terms of amount collected originates from kelps, there is a larger variety of species harvested from wild stocks compared to aquaculture (Figure 7).

Figure 7: Distribution of macroalgae species produced from (A) aquaculture and (B) wild stocks by number of companies

(A) Aquaculture



(B) Wild stocks

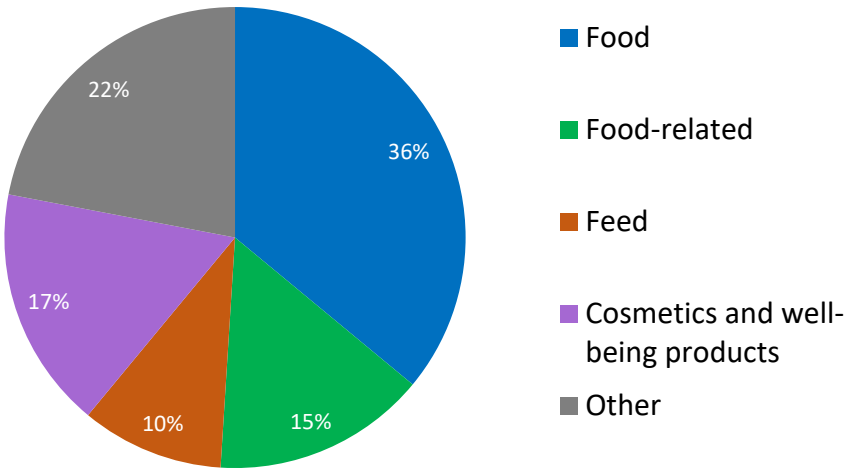


Source: Own elaboration with data from European Marine Observation and Data Network (EMODnet)

2.2.2. Applications

Seaweed biomass is a versatile resource that is used for a variety of applications in Europe (Figure 8). The largest use of seaweed biomass is for **food**, accounting for 36% of all European seaweed companies. An additional 15% of companies use it for **food-related purposes**, such as food supplements, thickening agents and preservatives. Applications for **feed products** amount to around 10% of seaweed companies. Another 17% of companies use produce in **cosmetics and well-being products**, while the remaining usage is in other applications, such as **biofuel and fertilisers.**

Figure 8: Applications for macroalgal biomass in Europe



Source: Araújo et al. (2021)

2.2.3. Opportunities and barriers

a. Opportunities

For increasing the sustainability of seaweed production, as well as reducing the environmental pressure associated with harvesting wild stock, **transitioning from wild stock harvesting to seaweed aquaculture** represents a major opportunity for developing the sector (Burrows at al., 2018; Araújo et al., 2021). Furthermore, macroalgae cultivation in aquaculture operations can play a key role for developing **Integrated Multi-Trophic Aquaculture (IMTA)** systems (used by ca. 10% of European aquaculture companies), in which multiple species of different trophic levels are cultivated simultaneously (e.g. finfish, shellfish and seaweeds integrated in a farm site; Chopin et al., 2002; Marinho et al., 2015). In addition to its current uses, the demand for consistent and high-yielding biomass is expected to increase in the future, as the variety of applications for seaweed products continues to expand (e.g. for nutraceuticals; Meng et al., 2022). Rural and coastal areas with lower economic growth could benefit from seaweed operations as a source of **income and livelihood** (Mac Monagail et al., 2017). Seaweeds, through the process of photosynthesis, absorb and store carbon, which makes them **potential contributors of blue carbon**, a term used to describe carbon sequestered and stored by coastal and marine ecosystems (Krause-Jensen et al., 2018).

b. Barriers

The harvesting of wild stock seaweeds raises **sustainability concerns**, with available data already showing a reduction in seaweed abundance and some Member States employing **strict management plans** to conserve seaweed abundance and biodiversity[6]. Although seaweed aquaculture offers more opportunities for expanding production, **unpredictable conditions at sea** could result in higher variations of yields. The most commonly used seaweed species in food products (*Palmaria palmata*, followed by *Undaria pinnatifida*) are not mirrored by the production volumes of species harvested and cultivated in Europe, therefore leading to a gap in supply and demand (North Sea Farm Foundation, 2019). Furthermore, the algae sector is associated with multiple **knowledge gaps**, such as the role of

[6] EEB Articles, Developing an environmentally and economically sustainable sugar kelp aquaculture industry in southern New England: from seed to market;
Station Biologique de Roscoff, Seaweeds fisheries management in France, Japan, Chile and Norway;
Thalassas, Economic Seaweeds of Galicia (NW Spain)

seaweeds in blue carbon and environmental impacts of seaweed aquaculture, which are holding back the expansion of the sector. The macroalgae sector's potential for profitability is crucial for attracting investment. However, at present, **consumer awareness and market opportunities** in Europe are still relatively limited. **High costs** during the seaweed production phases are a major barrier to expanding regional production (Coleman et al., 2022). In Ireland, for example, the seaweed production costs are approximately €10 273 per dry metric tonne which will need to come down to less than €75 for achieving profitability for biofuels applications. For applications as food products, the issue of **contaminant concentrations** (e.g. iodine and heavy metals) in seaweeds needs to be addressed to ensure compliance with high food safety standards (National Food Institute, 2019).

Figure 9: Summary of opportunities and barriers concerning the European macroalgae sector

Opportunities	Barriers
• Transition from harvesting wild stocks to seaweed aquaculture for increasing sustainability and production volumes • Key role for development of Integrated Multi-Trophic Aquaculture (IMTA) systems • Meet demand for various products and biomass processing • Increased potential of mechanical harvesting • Source of income for coastal and rural areas • Potential contribution to carbon sequestration • Further underexplored applications	• Sustainability concerns for harvesting seaweed from wild stock • Uncertainties regarding sea-based cultivation (particularly offshore) • Discrepancy between the species in highest demand and the species produced in greatest volumes • Knowledge gaps associated with the sector (detailed in Section 4.2.2., Figure 23) • Limited market demand and consumer awareness • High costs associated with cultivation, processing, infrastructure and operations • High concentrations of iodine and heavy metals

Source: Own elaboration

2.3. Microalgae and Spirulina

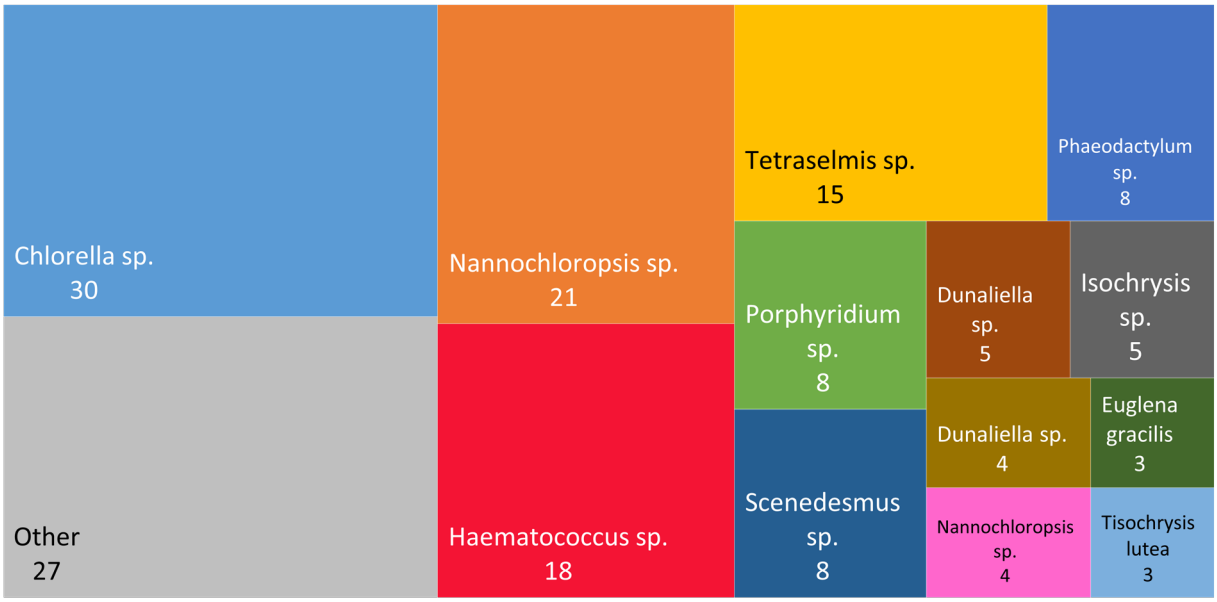
2.3.1. Overview

In Europe, the number of companies involved in **microalgae** production is lower compared to macroalgae (89 compared to 151 for macroalgae), with **Spain, Germany and France/Italy** being the countries with the highest number of companies (Figure 5). Producers of the cyanobacteria **Spirulina** are largely located in **France** (over 60%), **Italy and Spain** (Figure 6). As opposed to the majority of macroalgae production, microalgae and Spirulina production methods are **land-based**, including photobioreactors (71%), ponds (19%) and fermenters (10%). In contrast to the widespread use of photobioreactors (PBR) for microalgae production, the majority of Spirulina production (83%) takes place in ponds, with the remaining production being attributed to PBRs. The two main production methods of PBRs and ponds differ in investment needs and operational costs. PBRs require significant investments and have **high operational costs**, with the resulting biomass typically targeted for **high-value products** such as nutraceuticals, cosmetics, and pharmaceuticals. Biomass for low-value

products is largely produced in ponds, a production method that requires lower investment and comes with lower operational costs while producing higher quantities of biomass.

The most commonly cultivated microalgae species in Europe in terms of companies involved in the production are ***Chlorella* sp.**, followed by *Nannochloropsis* sp., and *Haematococcus pluvialis* (Figure 10). When considering the production of dry weight biomass, *Chlorella* has the highest output, followed by *Haematococcus pluvialis* and *Nannochloropsis*. This selection is also mirrored internationally, whereby *Chlorella* and Spirulina production are the two most widely produced groups (Vigani et al., 2015; Mobin & Alam, 2017).

Figure 10: Distribution of microalgae species by number of companies

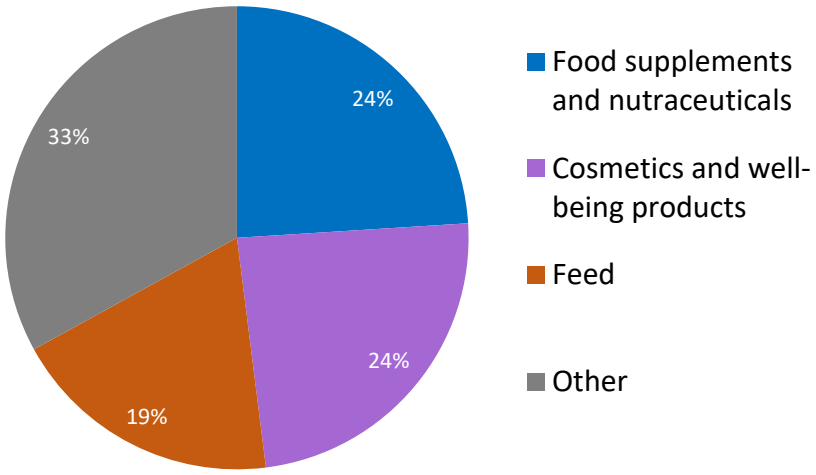


Source: Own elaboration with data from European Marine Observation and Data Network (EMODnet)

2.3.2. Applications

Microalgae are used for a variety of industrial and commercial applications. In Europe, companies use microalgae biomass primarily for the **food supplement and nutraceuticals** sector (24%), the **cosmetics and well-being** industry (24%) and for **feed** (19%). Other applications, such as **biofuels and pharmaceuticals**, have been a focal point for research and industry, although the number of companies using the biomass for these areas is currently low. To fully exploit the potential of microalgae biomass for biofuels, **technological advancements** and corresponding cost reductions have been identified as essential (Zhang et al., 2014). For Spirulina, food, food supplements and nutraceuticals represent the most common applications by companies (75%).

Figure 11: Applications for microalgae biomass in Europe



Source: Araújo et al. (2021)

2.3.3. Opportunities and barriers

a. Opportunities

Photobioreactors (PBRs) are the most widely employed production method for microalgae, allowing **precise control of production** by regulating environmental conditions. Therefore, advancing production systems with PBRs are expected to increase consistency and productivity of microalgae production (Benner et al., 2022). The European sector is well placed for contributing to the market of **high-value products** using PBRs. The wide range of applications for microalgae are an opportunity for the sector to **diversify commercial applications** in areas such as biofuels, bioplastics, and other bioproducts (Onen Cinar et al., 2020; Sivaramakrishnan et al., 2022). Furthermore, microalgae have a high nutritional value and thus, are well placed for taking a growing share in areas such as the nutraceutical industry (Koyande et al., 2019). Microalgae production is generally associated with lower environmental impacts compared to traditional forms of agriculture (Usher et al., 2014). Additional research into **adapted strains** could improve the scalability by using strains with lower environmental requirements and higher production outputs. Microalgae are effective at removing pollutants and heavy metals from water, therefore having the potential to contribute to **wastewater treatment and bioremediation** (Sutherland & Ralph, 2019).

b. Barriers

The disadvantage of relying on the **PBR production method** is a **lack of scalability** for increasing production output, as well as high investment and **operational costs** associated with the reactors (Kumar & Jain, 2014). Technological innovation will be essential for increasing productivity as current production costs make it difficult for companies to achieve **profitability** (Waycott, 2020). The process of utilising new microalgae species is impeded by **bureaucratic obstacles**, such as the requirement for any new species to comply with the EU's Novel Food regulation[7]. Upscaling **outdoor microalgae production** will be limited by climate conditions as cultures will be exposed to external weather changes (de Vree, 2016). There are a variety of **knowledge gaps** associated with microalgae

[7] European Commission, Novel foods regulation

production, such as methods for extracting valuable compounds (e.g. lipids and pigments), algae strain selection, algae-bacteria interactions, heavy metal concentrations and others (Mathimani et al., 2019).

Figure 12: Summary of opportunities and barriers concerning the European microalgae sector

Opportunities	Barriers
• Controlled production in PBRs • Potential of European sector for developing high-value product markets • Applications in biotechnology and biorefinieries, ranging from food, feed, to cosmetics, bioremoval and biofuel • Nutritional value (source of essential nutrients such as vitamins, minerals, antioxidants, and amino acids) • Low environmental impact • Potential for adapted microalgae strains to meet specific requirements for different applications and environments	• Technological advancements needed to scale sector • Low scalability with PBR production • Climatic limitations for expanding outside production • Administrative limitations for developing applications for new species • Significant production and operational costs • Knowledge gaps • High concentrations of contaminants (e.g. heavy metals) in some algae

Source: Own elaboration

3. ECONOMIC DEVELOPMENT OF THE ALGAE SECTOR

KEY FINDINGS

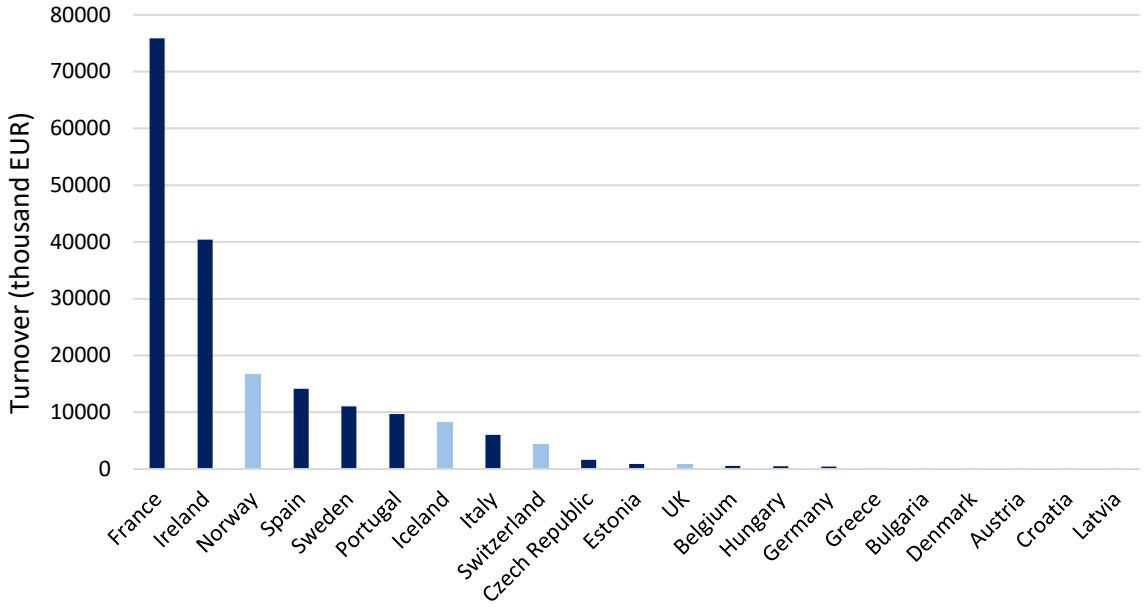
- In Europe, **France, Ireland, Norway** and **Spain** lead the chart in terms of employment and turnover generated in the algae sector.
- Global algae **production has increased** from **0.56** million tonnes in 1950 to **35.82 million tonnes** in 2019. **Over 97%** all production comes **from Asia**, with Chinese production accounting for 57% globally.
- Besides **China**, **Indonesia** (27% of global production), **South Korea** (5%) and the **Philippines** (4%) are major producers, contrasted by the low share of global production coming from Europe (<1%).
- The substantial growth of global algae production is not reflected by **European production patterns**, which have remained **relatively flat.**
- There is an **increasing interest** on the international stage for **growing regional algae sectors** (e.g. proposed SEAfood Act in the United States).

3.1. Economic development of the European algae sector

France, Ireland, Norway and Spain are the leading countries in terms of average **turnover** generated by algae companies in Europe, with 76, 40, 17 and 14 thousand euro annual turnover generated respectively (Figure 13). The majority of sales are derived from **macroalgae** (68%), followed by microalgae (17%) and Spirulina (11%). The sector turnover is mirrored by employment figures, with **France, Ireland, Spain and Portugal** having the highest share of **employees** in the algae sector at 478, 385, 225 and 163 employees respectively (Figure 14). Furthermore, the majority of employees are involved in the producing and processing steps of the value chain (approximately 1 161 employees)[8]. Half of employees in the European algae sector are involved in the **macroalgae value chain**, compared to 25% for microalgae, 13% for combined microalgae and *Spirulina*, and 10% for only *Spirulina*.

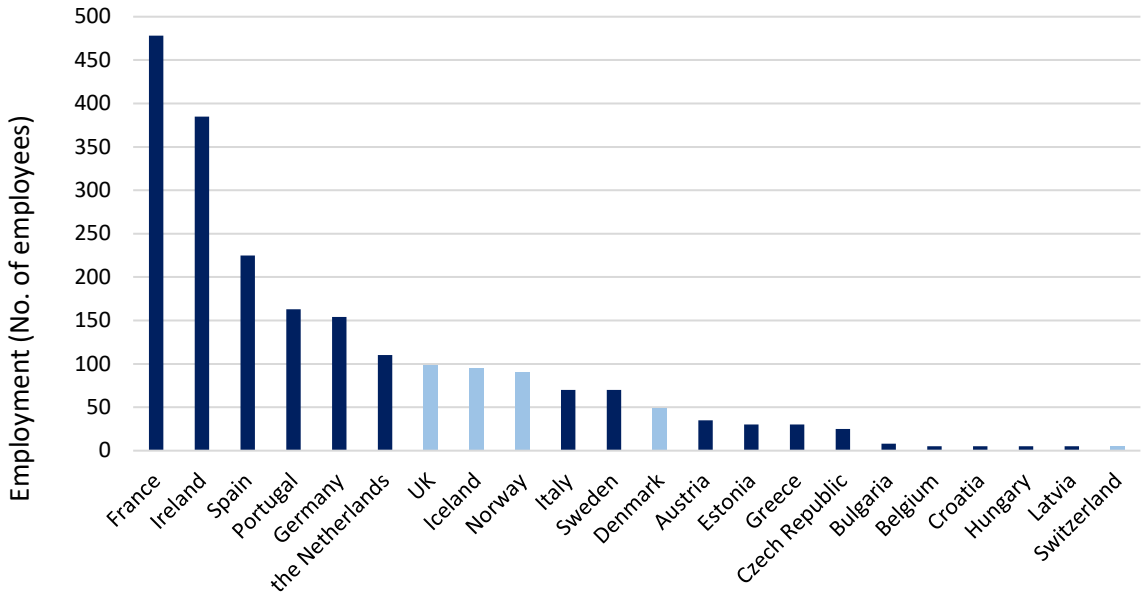
[8] European Commission, An overview of the algae industry in Europe

Figure 13: Average annual turnover by country, 2016-2020



Source: European Commission

Figure 14: Average annual employment by country, 2016-2020



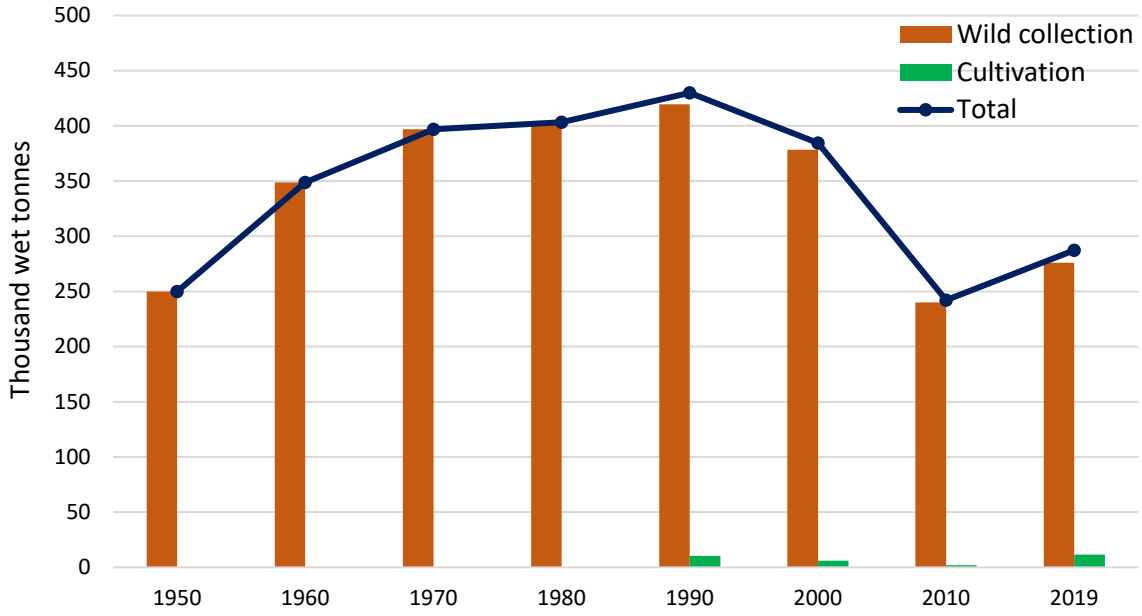
Source: European Commission

In comparison to the increasing global algae production, production patterns in Europe have remained relatively flat (Figure 15 & 17), whereby **Spirulina** production dominates the microalgae sector and **brown seaweeds** dominate the macroalgae sector. Although European algae production levels account for less than 1% of global production, the highest number of **seaweed start-ups** and **equity investments** occur in Europe (Figure 16)[9]. In the European seaweed sector, **France and Norway** are

[9] Phyconomy, A database of seaweed organisations

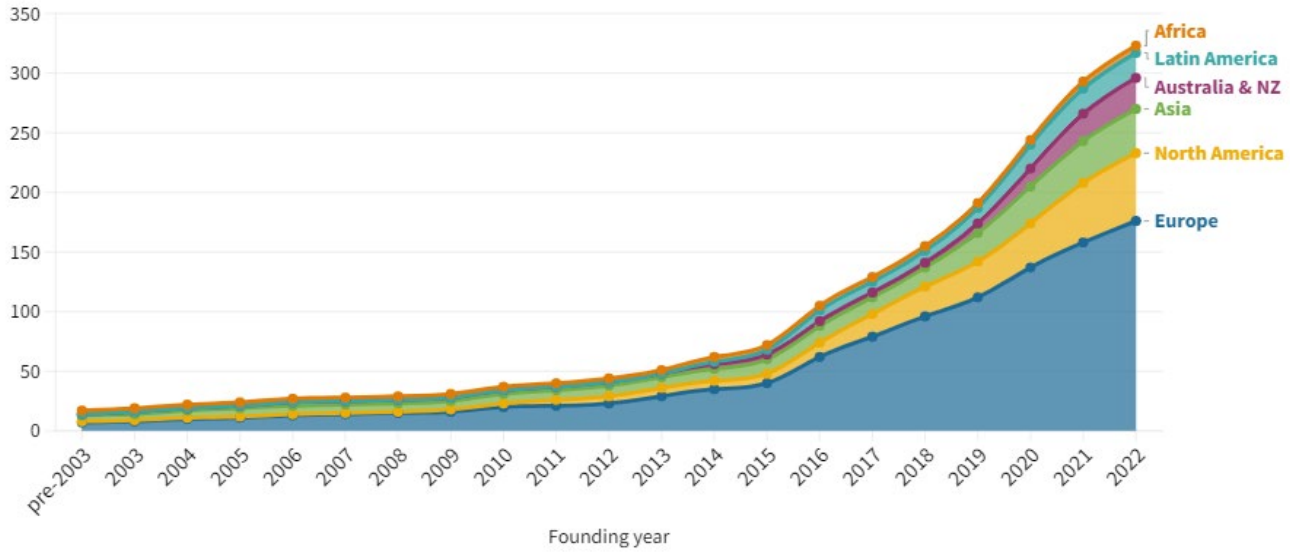
seen as the frontrunners with French seaweed production increasing by 260% between 2018 and 2022 and Norwegian production tripling over the same period[10].

Figure 15: Development of algae production in Europe, 1950 - 2019



Source: FAO

Figure 16: Global development of algae start-ups by founding year, 2003 - 2022



Source: Phyconomy

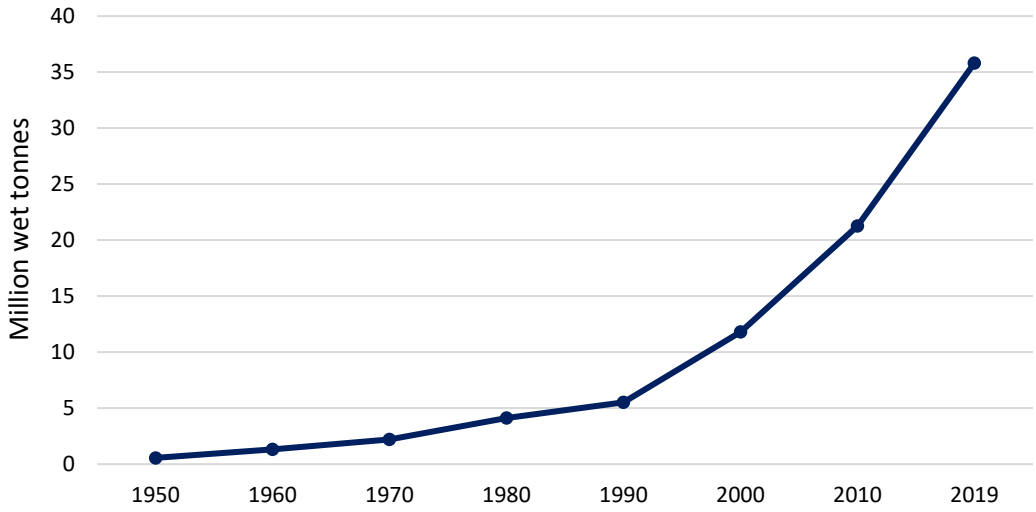
3.2. Global algae production

Global algae production has increased substantially in the past 30 years (Figure 17). However, researchers have identified discrepancies in estimates for Indonesia and the Philippines (Porse & Rudolph, 2017; Langford et al., 2022). Of the over 35 million tonnes of algae produced in 2019, **seaweeds** account for **99% of total production**, whereby microalgae account for less than 1% (56,456

[10] Phyconomy, 2023 Seaweed State of the Industry

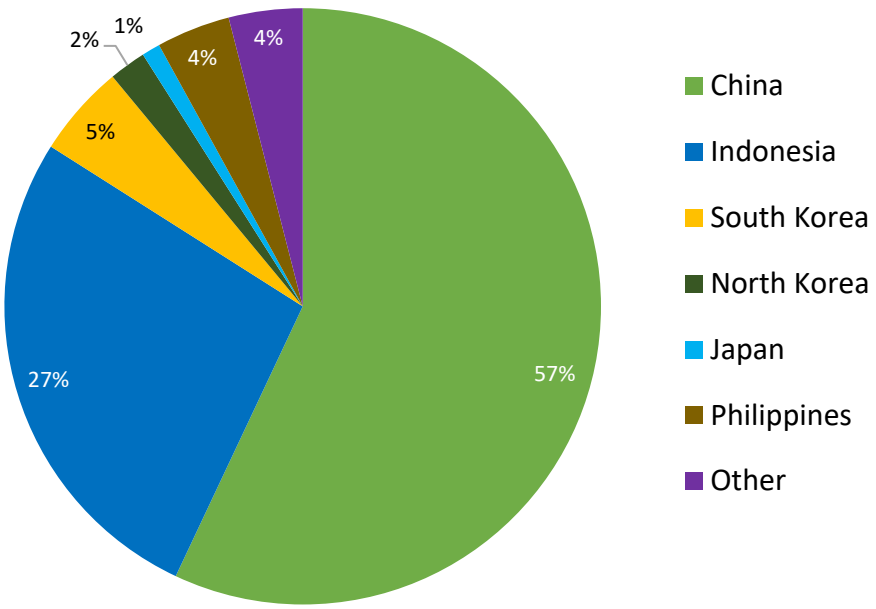
tonnes). Over 97% of global algae production occurs in **Asia**, with **China** accounting for 57% (FAO, 2021). In comparison, the **European algae sector** accounts for **0.8% of global production**. As displayed in Figure 18, China accounts for 57% of all seaweed production, followed by Indonesia (27%) and South Korea (5%). When counting microalgae and cyanobacteria together, Chinese production accounts for 97% of global yield, with substantially higher Spirulina and Arthrospira production compared to other microalgae. Green microalgae production equalled approximately 248 tonnes in 2019 (<1% of global algae production). The **brown algae genus *Saccharina*** is the most widely produced macroalgae group (36% of global production; Figure 19), followed by the tropical red algae *Kappaphycus* and *Eucheuma* (28%) and the red algae *Gracilaria* (15%).

Figure 17: Global algae production, 1950 - 2019



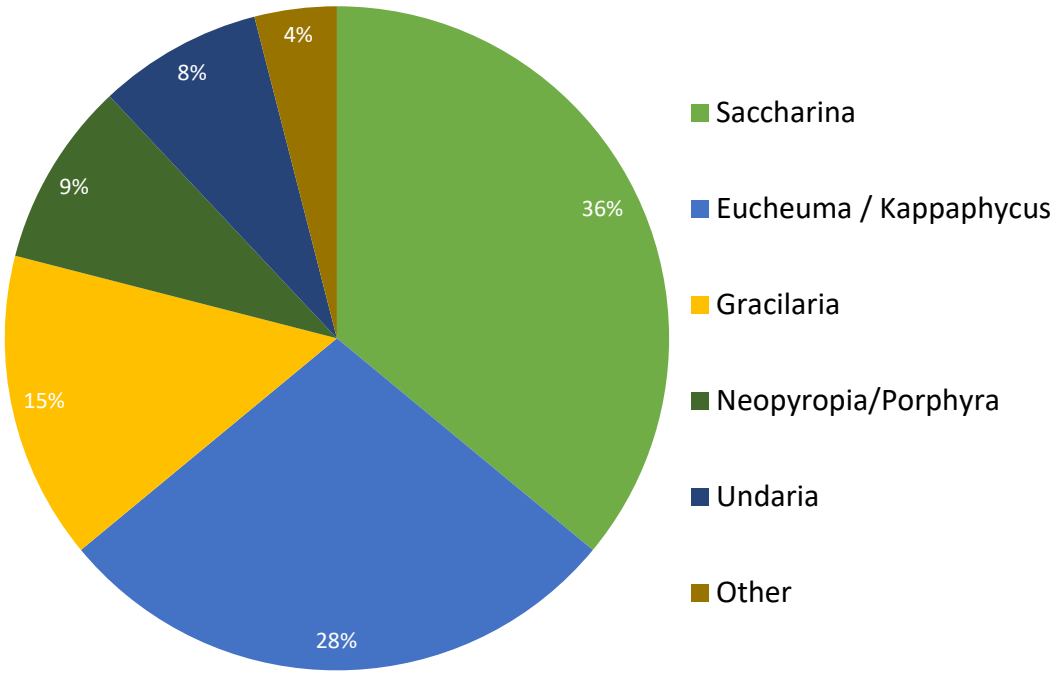
Source: FAO

Figure 18: Global seaweed production shares by main producing countries, 2020



Source: FAO

Figure 19: Global seaweed production by species, 2020



Source: FAO

Other countries with a largely underexplored algae sector outside the Asian region have also initiated strategies for developing regional production. The proposed **SEAfood Act in the United States**, for example, includes provisions for unlocking the potential of offshore aquaculture[11]. Furthermore, the upcoming update of the **US National Aquaculture Development Plan** is expected to include strategic plans focused on growing aquaculture, particularly shellfish and seaweed production[12]. In 2019, the United States share of global algae production was 0.1%, with a total production of 3 394 tonnes.

[11] The Fish Site, Can the SEAfood Act kick-start US offshore aquaculture?
[12] Aquaculture North America, Bright horizons: Seaweed and shellfish 2023 outlook

4. EU ALGAE INITIATIVE

KEY FINDINGS

- The European Commission's **EU Algae Initiative** communication sets out **actions for unlocking the potential** of algae production as part of the Blue Bioeconomy.
- The communication **describes the benefits** associated with growing the algae sector while acknowledging the **existence of limitations** preventing the development of the industry.
- The communication proposes **four overarching aims**, including governance framework, business, R&I and market development, accompanied by **23 targeted actions**.
- A **progress report** regarding the implementation of the proposed actions is announced for the **end of 2027**.

4.1. Commission activities relating to EU algae production

A report on "**Food from the oceans**", published by the Commission in 2017, explicitly mentions the importance of harvesting species of lower trophic levels, such as seaweeds, to increase ocean food production[13]. Subsequently, the production expansion potential of algae was picked up in the **European Green Deal** communication (2019), specifically referring to algae as part of "innovative food and feed products"[14]. The **Farm to Fork Strategy** (2020), one of the key elements presented as part of the European Green Deal, includes provisions setting out "a well-targeted support for the algae industry, as algae should become an important source of alternative protein for a sustainable food system and global food security"[15]. Under the "**Decarbonising our waters, ocean and seas**" mission objective, increasing EU algae production by 100% by 2025 is listed as an action to decrease the environmental footprint of aquaculture along with increasing consumption of sustainable alternative sources of protein by 70% by 2030[16]. In addition, the report describes a job creation potential in the EU algae sector of 15 000 jobs. The "Food from the Ocean and Freshwater Resources" pathway for action in the **Food 2030 Pathways for Action report**, specifically refers to algae farming as "[might be] the next big thing for food and feed production"[17]. Furthermore, the **Sustainable Blue Economy** and **Sustainable Carbon Cycles** communications released in 2021 mention algae production as an untapped source for developing a sustainable food sector while providing a nature-based solution to the climate crisis ("blue carbon farming")[18].

The build-up of the aforementioned files culminated in the publication of the Commission's communication "**Towards a Strong and Sustainable EU Algae Sector**" in November 2022 (Table 1). This communication provides the framework under which specific initiatives, platforms and research

[13] European Commission, Food from the oceans
[14] European Commission, The European Green Deal
[15] European Commission, A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system
[16] European Commission, Mission Starfish 2030: Restore our Ocean and Waters
[17] European Commission, Food 2030 pathways for action
[18] European Commission, Transforming the EU's Blue Economy for a Sustainable Future; European Commission, Sustainable Carbon Cycles

activities are to be implemented with the **overarching aim of growing the EU algae sector**. In addition, the communication on the future of the Common Fisheries Policy (CFP) published in February 2023 describes the "**aquaculture farm of the future**" based on increasing production of lower trophic species, such as shellfish and algae[19].

Table 1: Overview of European Commission documents relating to the EU algae sector

Commission document	Relevant content	Publication date
Food from the oceans – Scientific opinion no. 3/2017 – Publication by DG RTD	"Mariculture is closest to a realisation of this [obtain significantly more food and biomass] because macroalgae and molluscs are at the lowest trophic levels, but also because plants now make up a substantial fraction (up to 70%) of the feed of finfish and crustacean mariculture."	29/11/2017
The European Green Deal, COM(2019) 640	"The Farm to Fork Strategy will [...] launch a process to identify new innovative food and feed products, such as seafood based on algae."	11/12/2019
Roadmap for the Blue Bioeconomy – Publication by DG MARE	Report concluding consultations with stakeholders and desk research regarding challenges associated with the Blue Bioeconomy sector, including micro- and macroalgae applications.	03/02/2020
Farm to Fork Strategy, COM(2020) 381	"[The Commission will also] set out well-targeted support for the algae industry, as algae should become an important source of alternative protein for a sustainable food system and global food security."	20/05/2020
Regenerating our ocean and waters by 2030 – Interim report – Publication by DG RTD	Interim report by the Mission Board Healthy Oceans, Seas, Coastal and Inland Waters describing objectives and actions for restoring and regenerating European oceans. Increasing algae production listed as a key target as part of zero-/low-carbon aquaculture.	24/06/2020
Food 2030 pathways for action – Publication by DG RTD	"Pathway 3 – Food from the ocean and freshwater resources" lists algae farming as an R&I need.	12/11/2020
Strategic guidelines for EU Aquaculture (2021-2030), COM(2021) 236	"...specific initiative to support the production, safe consumption and innovative use of algae. This initiative will address the challenges and opportunities of algae farming and propose concrete actions"	12/05/2021
Sustainable Blue Economy, COM(2021) 240	The communication sets out the development of the Algae Initiative as an action for building sustainable food systems.	17/05/2021
Sustainable Carbon Cycles, COM(2021) 800	"The development of blue carbon initiatives would lead to multiple co-benefits, such as ocean regeneration and oxygen production, food security by bringing algae-based proteins to the market or new green and local job opportunities."	15/12/2021
Towards a Strong and Sustainable EU Algae Sector, COM(2022) 592	This communication sets up the framework envisaged for unlocking the potential of algae production as part of the EU's Blue Bioeconomy.	15/11/2022
The common fisheries policy today and tomorrow: a Fisheries and Oceans Pact towards sustainable, science-based, innovative and inclusive fisheries management, COM(2023) 103	"The Commission Calls on Member States to support innovation and promote good practices in aquaculture, as well as low-trophic aquaculture production such as molluscs and algae farming and integrated multitrophic aquaculture (IMTA) systems."	21/02/2023

Source: Own elaboration

[19] European Commission, The common fisheries policy today and tomorrow: a Fisheries and Oceans Pact towards sustainable, science-based, innovative and inclusive fisheries management

4.2. Benefits and challenges

4.2.1. Benefits

An overview of the potential benefits from developing the EU algae sector is visualised in Figure 20. One of the key benefits mentioned in the Commission's communication is the contribution to **food security** by providing an alternative plant-based source of protein. Algae-based aquaculture could potentially provide the total global protein demand in the year 2050, in addition to representing a high-quality nutritional food source containing essential amino acids and vitamins (Greene at al., 2022). The World Resources Institute identified a 56% food gap between current crop calorie production levels and calorie demand expected in 2050 (assuming no change in current production levels)[20]. Algae-derived food sources have the potential to contribute to filling this gap. In addition, marine habitats are largely underutilised for human food production with 71% of earth's surface being saltwater yet only 2% of the world's food supply in terms of calories derived from the oceans (FAO, 2016). **Plant-based food markets** are steadily increasing and are expected to represent nearly 8% of the global protein market in the year 2030 (Bloomberg, 2021). In Europe alone, the consumption of plant-based food increased by 49% between 2018 and 2020[21].

Another opportunity highlighted in the communication is the production of sustainable **food and feed products** in conjunction with promoting the transition to **zero-/low-carbon aquaculture**. Algae cultivation has been found to contribute to **regenerating the oceans** and seas by removing excess nutrients and preventing eutrophication, in addition to acting as a nature-based solution to the climate crisis by **removing carbon from the atmosphere**[22]. With the Commission's proposal for establishing a **Union certification framework for carbon removals** published in November 2022, algae cultivation may be included in certification schemes with attributed carbon removal units[23]. With regards to the proposed Nature Restoration Law, seaweed cultivation may play a crucial part in restoring marine ecosystems (Article 5 of regulation proposal) by **improving water quality and removing excess nutrients**[24].

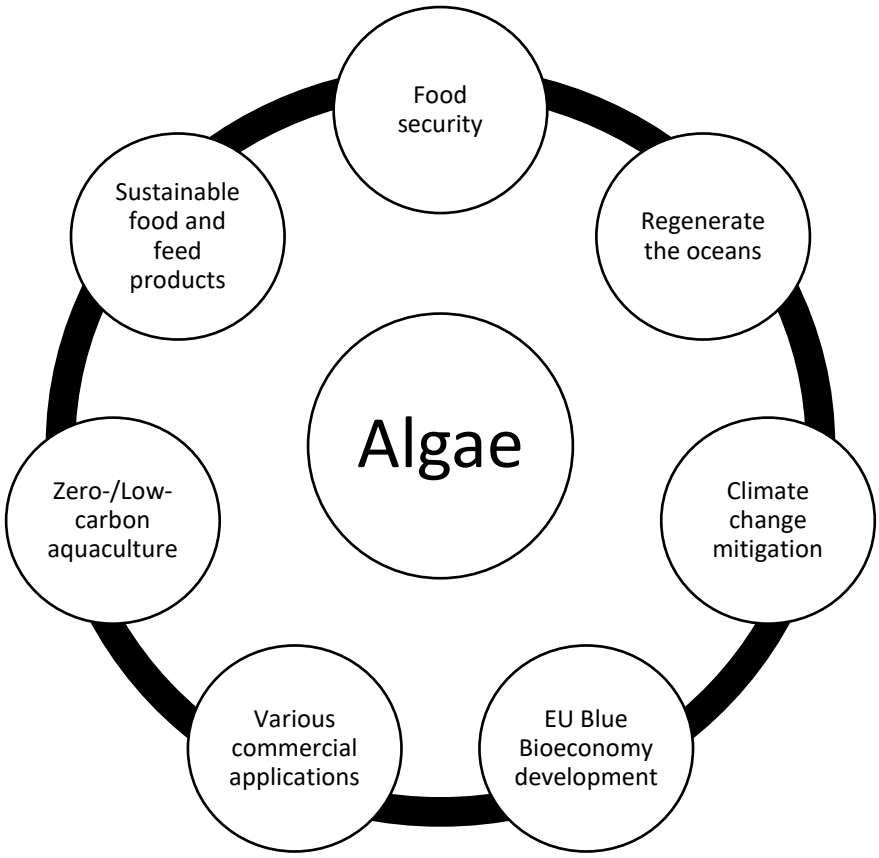
The idea of cultivating multiple marine species of varying trophic levels, also known as **integrated multi-trophic aquaculture** (IMTA), cannot only increase sustainability and regenerate coastlines but also improve profitability of aquaculture operations[25]. The Commission's latest communication on the future of the Common Fisheries Policy (CFP) specifically calls for Member States to "promote good practices in [...] algae farming and integrated multitrophic aquaculture (IMTA) systems"[26]. A guidance document on the environmental performance of algae farming with regards to implementing the Strategic guidelines for EU Aquaculture (2021-2030)[27], was announced as part of the CFP update. The

[20] World Resources Institute, World Resources Report: Creating a Sustainable Food Future
[21] European Commission, Europe's plant-based food industry shows record-level growth
[22] Marine Policy, A case for seaweed aquaculture inclusion in U.S. nutrient pollution management;
The Nature Conservancy, Global Principles of Restorative Aquaculture
[23] European Commission, Certification of carbon removals
[24] European Commission, Proposal for a Nature Restoration Law
[25] Journal of Phycology, Integrating seaweeds into marine aquaculture systems: a key toward sustainability;
Aquaculture, Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture;
Reviews in Aquaculture, The economics of Integrated Multi-Trophic Aquaculture: where are we now and where do we need to go?
[26] European Commission, The common fisheries policy today and tomorrow: a Fisheries and Oceans Pact towards sustainable, science-based, innovative and inclusive fisheries management
[27] European Commission, Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030

expansion of algae production for animal feed is expected to contribute to **reducing the pressure on wild-caught fish**, whereby currently approximately a third of the world fish caught is processed for animal feed[28].

According to the algae communication, growing sustainable algae sector value chains would contribute to the **EU Blue Bioeconomy** development as set out in the European Green Deal. The EU's Bioeconomy strategy mentions the potential of ocean farming, particularly with regards to the algal sector, which is expected to become a significant part of the Blue Bioeconomy[29]. There are many **algae biomass applications** ranging from algae-based novel foods to pharmaceutical and cosmetic products. Algae have the potential to play a role as part of sustainable biofuels, identified as "**drop-in biofuels**" in the recent communication by the Commission "On the Energy Transition of the EU Fisheries and Aquaculture sector"[30]. However, in a review by the International Energy Agency (IEA) algae bioenergy applications are summarised as "not foreseen to be economically viable in the near to intermediate term" (IEA, 2017). The various commercial applications of micro- and macroalgal products are expected to increase opportunities in coastal communities and contribute to economic development.

Figure 20: Main benefits of algae production listed in EU Algae Initiative communication



Source: Own elaboration with information from EU Algae Initiative

[28] International Food Policy Research Institute, The future of fish;
Journal of Marine Science and Engineering, Seaweed Potential in the Animal Feed: A Review
[29] European Commission, Roadmap for the blue bioeconomy
[30] European Commission, On the Energy Transition of the EU Fisheries and Aquaculture sector

4.2.2. Challenges

a. Fragmented governance framework

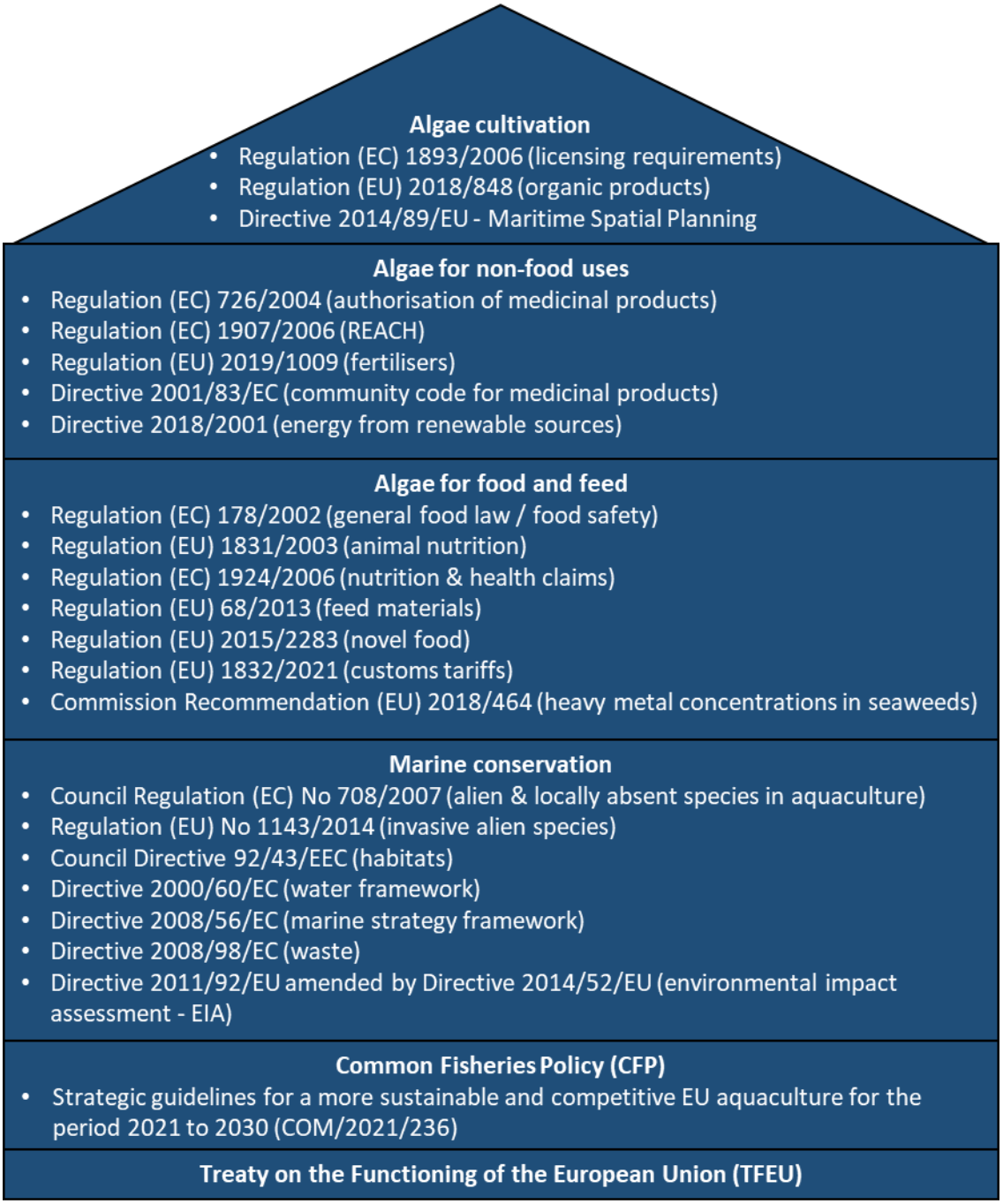
The EU Algae Initiative also describes a set of challenges preventing the development of the sector, identifying a **fragmented governance framework** as one of the key obstacles. An overview of the present EU governance framework is summarised in Figure 21. Based on the TFEU and the Common Fisheries Policy a large number of Regulations, Directives and recommendations regulate the production of algae in EU Member States, with the latter most recently complemented with the "Strategic guidelines for EU Aquaculture (2021-2030)"[31]. The EU Aquaculture guidelines proposed the creation of **"one-stop-shop" systems** for aquaculture licences as a solution to fragmented and complicated licensing procedures.

The substantial **variation in licensing procedures** and integration of seaweeds into Marine Spatial Planning (MSP) is highlighted in Figure 22. There is no uniformity between Member States in licensing for site access; therefore, the process is reliant on **national marine spatial planning procedures**. These processes and license properties (e.g. duration, cost, renewal etc.) vary substantially between Member States. In addition, several **food safety regulations** (e.g. iodine concentration thresholds) are set at a national level, leading to possible competitive disadvantages between Member States. Certain seaweeds (e.g. red algae) have been found to contain high levels of heavy metals, arsenic, iodine and other contaminants (Filippini et al., 2021). Therefore, the Commission's communication identifies "product safety and consumer protection" as a priority for allowing new algae products into the market. The Commission recommendation "on the monitoring of metals and iodine in seaweed, halophytes and products based on seaweed" sets out monitoring of relevant contaminants in seaweed products in order to determine maximum levels[32].

[31] European Commission, Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030

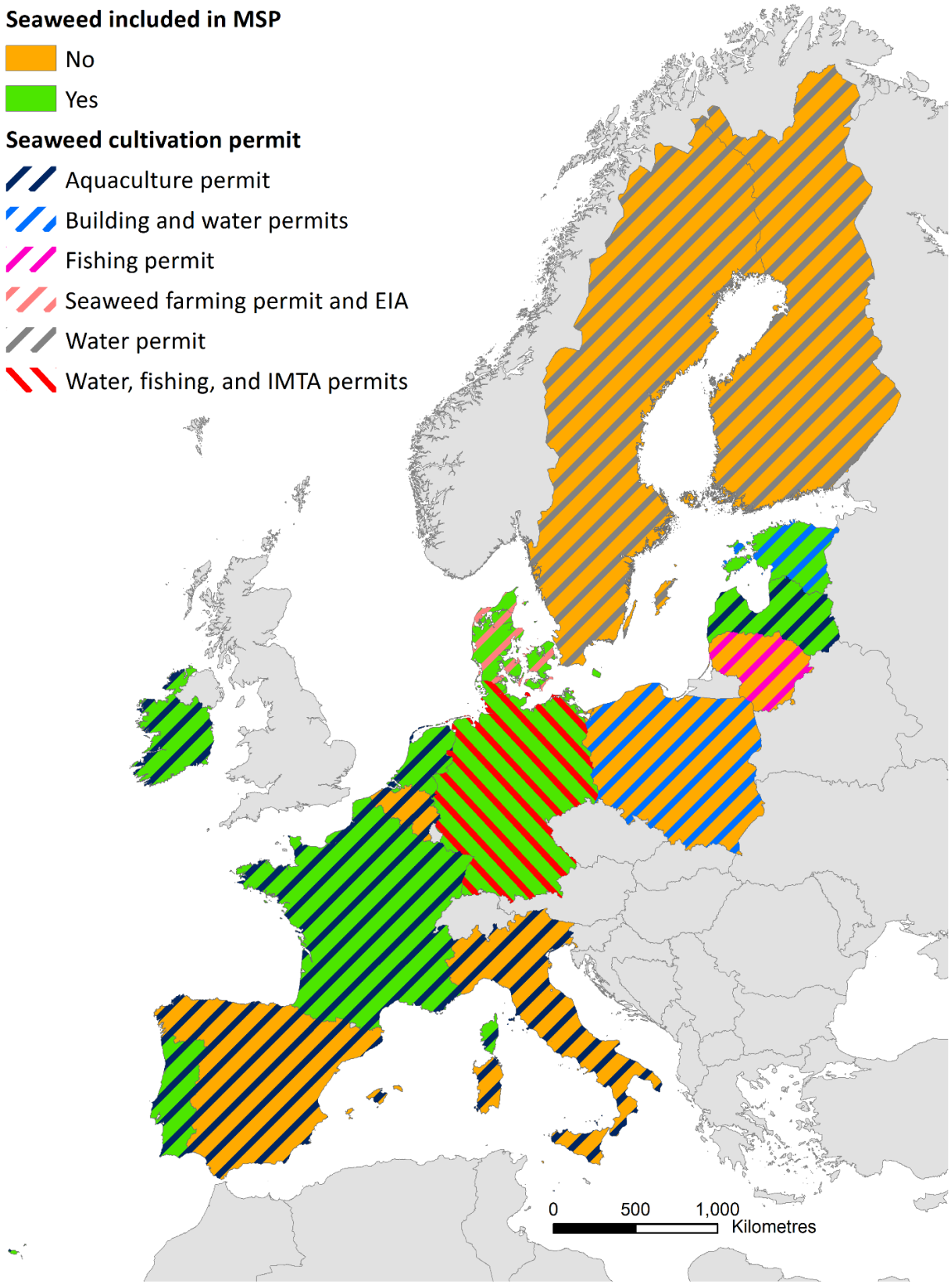
[32] European Commission, Commission Recommendation (EU) 2018/464 of 19 March 2018 on the monitoring of metals and iodine in seaweed, halophytes and products based on seaweed

Figure 21: EU governance framework of the algae sector



Source: Own elaboration with information from EU Algae Initiative

Figure 22: Overview of countries with and without seaweed included in Marine Spatial Planning (MSP), as well as the type of licensing required for seaweed cultivation



Source: European Market Observatory for fisheries and aquaculture (EUMOFA)

b. Low production levels

Another barrier to unlocking the potential of algae production in the EU are the low production levels of the sector. **Macroalgae** production is largely reliant on **harvesting biomass from wild seaweed** populations along the coastlines (68% of all production; Araújo et al. 2021). With production levels expected to increase in the future, this practice is unlikely to be sustainable. In order to reduce the reliance on wild seaweed harvesting, **sustainable seaweed aquaculture operations** need to be expanded. For this to happen, national Maritime Spatial Planning (MSP) needs to be adapted to include provisions for seaweed cultivation. The majority of **microalgae** production, on the other hand, occurs **on-land in photobioreactors** (71% of total production; Araújo et al., 2021). This practice has a high expansion potential, as no marine space is required. The main barrier identified in the communication for increasing microalgae production is the high-end technological equipment and substantial workforce needed to cultivate biomass, entailing high operational costs. Improving knowledge exchange and investing in upstream sources (e.g. research in algae genomics) were identified as options for expanding microalgae production.

c. Consumer awareness and acceptance

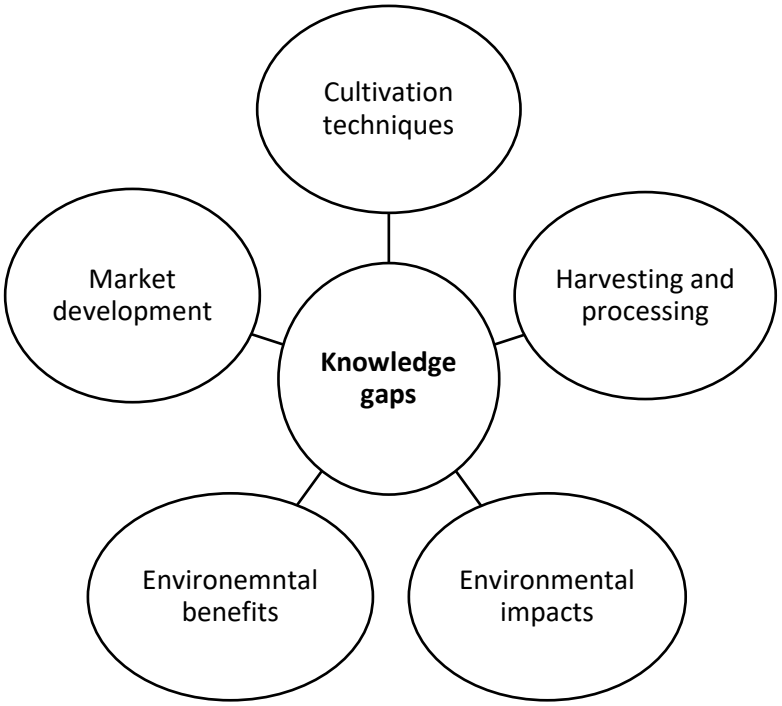
Given that the EU algae sector is still at an early stage, consumer awareness and acceptance of algae products on the European market is considered low[33]. The communication suggests increasing consumer awareness and acceptance of algae products by highlighting their benefits, such as being a **nutritious and sustainable food source**, while proactively addressing potential concerns about **heavy metal and other contaminants** in algae biomass. To promote fairness and efficiency in the industry, efforts should be made to enhance transparency in supply chain management and establish a more cohesive pricing system between suppliers and buyers.

d. Knowledge gaps

The communication identifies limited knowledge available in certain areas of the algae sector as a problem for growing the industry. The main knowledge gaps mentioned in the communication are summarised in Figure 23. One major aspect that needs to be fully addressed is the **environmental impact** of expanding seaweed aquaculture operations. This includes investigating eutrophication risks and biodiversity impacts, as well as implementing effective mitigation strategies to minimise adverse effects on the ecosystem. Conversely, **environmental benefits** of cultivating seaweed, such as potentially significant contributions to **carbon sequestration** and excess **nutrient uptake**, need to be quantified. There is a general lack of knowledge on the most efficient **cultivation techniques** for both macro- and microalgae. In addition, there is limited understanding of the most effective **methods for harvesting and processing algae**, including techniques for preserving the quality of the algae. The uncertain development of the **algae market** and consumer demand is another barrier to fully unlocking the potential of the sector.

[33] European Commission, Algae production in Europe: status, challenges and future developments

Figure 23: Knowledge gaps associated with expanded algae production



Source: Own elaboration with information from EU Algae Initiative

4.3. Aims and actions of the initiative

In order to unlock the full potential of the EU algae sector, the communication lists **four overarching aims** accompanied by **23 targeted actions**, based on a preliminary analysis of the algae sector and a stakeholder consultation process (counting 108 respondents)[34]. The aims are the following:

- **Aim 1**: Improving the **governance framework and legislation**.
- **Aim 2**: Improving the **business environment**.
- **Aim 3**: Closing **knowledge, research, technological and innovation gaps**.
- **Aim 4**: Increasing **social awareness and market acceptance** of algae and algae-based products in the EU.

With regards to the **governance framework** (aim 1), some legislation for seaweed cultivation at sea or algae cultivation on-land, such as legislation on food safety or fertiliser products, is at EU-level. However, the majority of relevant legislation is at Member State level, leading to a fragmentation of the regulatory framework. This makes it difficult for companies to navigate the legal landscape and for the industry to develop as a whole. In response to this situation, the communication calls on Member States to simplify their national licensing procedures and governance for algae cultivation. The European Commission argues that a coherent and streamlined governance is needed for the industry to develop and grow, and proposes a series of actions (Table 2). This includes simplified licensing procedures and a monitoring and quality framework. The proposed implementation of "one-stop-shop" systems for aquaculture licences as proposed in the "Strategic guidelines for EU Aquaculture (2021-2030)" is not listed as an action in the EU Algae Initiative.

[34] European Commission, Towards a Strong and Sustainable EU Algae Sector (Commission staff working document)

Table 2: Summary of actions presented as part of aim 1 of the EU Algae Initiative

Improving the governance framework and legislation			
No.	**Description**	**Timescale**	**Responsible body**
1	Development of an **algae farmers' toolkit**	Starting in 2023	Industry, DG MARE
2	Improve **marine space access** for seaweed farming (collaboration with Member States)	Not specified	Member States, DG MARE
3	Standardise testing, quantification and extraction methods for **algae ingredients and contaminants**	Planned to be completed by end of 2026	DG ENER, DG MARE, CEN
4	Development of **algae biofuel** standards and certification	Planned to be completed by end of 2026	DG ENER, DG RTD, CEN
5	Assess application of algae-based material in **fertilising products**	Starting in 2023	DG GROW

Source: EU Algae Initiative

For improving the **business environment** of the EU algae sector (aim 2), the Commission suggests scaling up the industry's collaboration. To achieve this, the Commission will encourage reorientation of fishers' careers towards regenerative ocean farming through pilot projects. The aim is to provide new opportunities for the fishing industry and to contribute to the sustainable development of the blue economy. Additionally, action number 10 proposes the support of small and medium-sized enterprises (SMEs) in the algae sector. The communication suggests that by providing them with the necessary support, the EU can help create a more competitive and sustainable industry. The actions proposed under aim 2 are summarised in Table 3.

Table 3: Summary of actions presented as part of aim 2 of the EU Algae Initiative

Improving the business environment			
No.	**Description**	**Timescale**	**Responsible body**
6	Promote **transfer of technology** from research to market	Starting in 2023	DG MARE, Industry
7	Develop guidance to promote **replacing fish-based feed with algae-based feed**	Complete by end of 2024	Commission, Industry
8	Identify viable nutrients and CO_2 alternatives for **organic microalgae cultivation**; assess **impacts of seaweed aquaculture**	Not specified	Industry, DG AGRI, DG MARE, DG SANTE, EMODnet
9	Support **career transitions** for fishers going into sustainable ocean farming	2023/2024	DG MARE
10	Support for **innovative SMEs** in the algae sector (BlueInvest platform)	Not specified	DG MARE
11	**Facilitate cooperation** by promoting interregional partnerships	Starting in 2023	DG MARE

Source: EU Algae Initiative

To address key knowledge gaps in the algae sector (aim 3), the Commission suggests a **collaborative research initiative**. The primary means to achieve this will be the EU Horizon Europe funding programme, specifically the "Sustainable Blue Economy Partnership" and "EU Mission: Restore Our Ocean and Waters by 2030" dedicated calls. Research and innovation focusing on preserving seaweed biodiversity, understanding contaminants and iodine levels in algae that affect human health, and advancing new methods for cultivating, processing, and producing algae will be essential for achieving the overarching goal. In addition, investigating the contribution of macroalgae to carbon sequestration (blue carbon) is to be completed by the end of 2025. Proposed actions are summarised in Table 4.

Table 4: Summary of actions presented as part of aim 3 of the EU Algae Initiative

Closing knowledge gaps regarding research, innovation and technology			
No.	**Description**	**Timescale**	**Responsible body**
12	Integrate algae sector knowledge into the **EU aquaculture assistance mechanism**	Complete by end of 2023	Commission
13	Study of the role of seaweed as a **blue carbon source**	Complete by end of 2025	Commission, Member States
14	Assess options for EU-wide approach to **conserving seaweed biodiversity** (centralised databank)	Complete by end of 2025	Commission, Academia
15	Discussions toward the establishment of **maximum levels of contaminants and iodine** in algae	Starting in 2023	Commission, Member States
16	Study **monitoring schemes** of wild seaweed harvesting	Not specified	Commission
17	Support research into **algae processing systems and production methods** for high-value compounds	Not specified	Commission
18	Support development of **improved algae cultivation systems**	Not specified	Commission, Member States
19	Address algae **biofuel specific challenges**	Not specified	Commission
20	Produce overview of **algae-related data** and recommend centralising data sources	Starting in 2023	Commission, Member States

Source: EU Algae Initiative

Aim number 4 is largely centred on **market development** necessary for expanding the algae sector (Table 5). This includes awareness raising actions under the umbrella of the Blue Bioeconomy, as well as targeted communication and analysis of product perceptions by consumers.

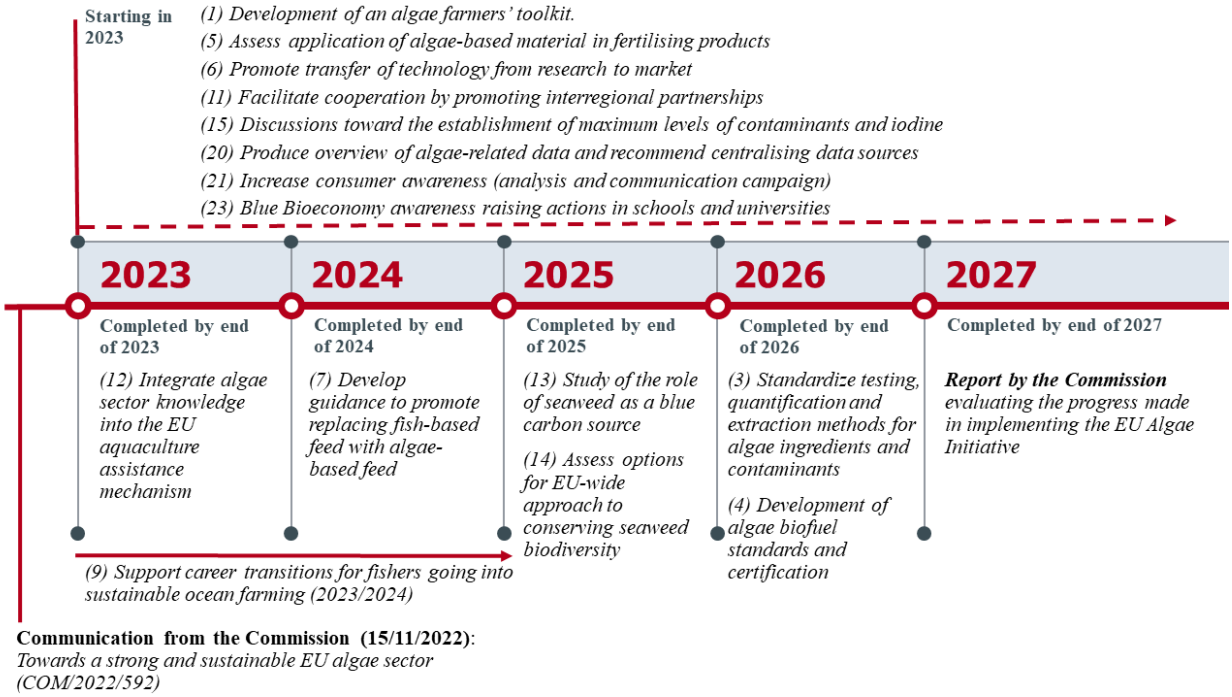
Table 5: Summary of actions presented as part of aim 4 of the EU Algae Initiative

Increasing social awareness and market acceptance of algae and algae-based products			
No.	**Description**	**Timescale**	**Responsible body**
21	Increase **consumer awareness** (analysis and communication campaign)	Starting in 2023	Commission
22	Improve **sustainability profile of algae-based products** (the EU sustainable food labelling framework)	Not specified	DG MARE, Member States
23	Blue Bioeconomy **awareness raising actions** in schools and universities	Starting in 2023	Member States, Commission, EU4Ocean

Source: EU Algae Initiative

Figure 24 gives an overview of the perspective deliverables along with the timeframes foreseen as listed by the Commission's communication. There are **eight actions** without specified timescales. Another eight actions are proposed to commence this year but do not have a specific conclusion date. The **training of fishers** for transitioning to seaweed farming is expected to occur in 2023 and 2024 via pilot projects. The addition of EU algae sector knowledge into the **Aquaculture Assistance Mechanism** is to be concluded by the end of 2023. By the end of the following year, the Commission aims to have developed guidance for **replacing fish-based feed with algae-based feed**. Relevant **knowledge gaps**, such as the inclusion of **macroalgae as a blue carbon source** and the EU-wide options for **conserving seaweed biodiversity**, are expected to be closed toward the end of 2025. **Standardization recommendations** for testing, quantification and extraction methods for algae ingredients and contaminants, as well as the development of **algae biofuel** standards and certification, will be published at the end of 2026. By the end of 2027, the Commission will publish a **report evaluating the progress made** in implementing the initiative.

Figure 24: Timescale of proposed actions with given timeframes as set out in the EU Algae Initiative



Source: Own elaboration with information from EU Algae Initiative

5. CONCLUSIONS

While being an "emerging sector of the Blue Bioeconomy"[35], the EU algae sector is still in its infancy. Compared to global production levels, the 287 386 tonnes of algae (99.88% of which is macroalgae) produced in Europe in 2019 accounted for less than 1% of global production. However, as identified in applicable literature, the sector has a high potential of contributing to addressing a range of key challenges, such as **food security, climate change mitigation** and **ocean regeneration**[36]. In addition, the variety of applications of algae products ranging from biofuels, over pharmaceuticals, to food products represent an opportunity for expanding the **blue economy**[37].

As indicated by a series of **23 targeted actions** set out by the European Commission in its **EU Algae Initiative**, increasing micro- and macroalgae production will require a **collective effort** (industry, Member States, EU, scientific community, etc.) for removing barriers, particularly associated with high production costs, administrative barriers and the need for scientific and technological advancements. The **EU Algae Initiative** paves the way for unlocking the potential of this sector through the implementation of **23 targeted actions,** addressing governance framework, business, R&I and market development. The implementation period of these actions is set **between 2023 and 2027**. By the end of 2027, a progress report regarding the implementation of the proposed actions will be published.

[35] Frontiers in Marine Science, Current Status of the Algae Production Industry in Europe: An Emerging Sector of the Blue Bioeconomy;
European Commission, Roadmap for the Blue Bioeconomy

[36] Frontiers in Energy Research, Current status and outlook in the application of microalgae in biodiesel production and environmental protection;
Journal of Biodiversity, Energy and Food Security from Macroalgae;
Nature Geoscience, Substantial role of macroalgae in marine carbon sequestration

[37] AZO Cleantech, Environmental Applications of Algae;
World Scientific, Macroalgal Biorefineries for the Blue Economy;
Journal of Environmental Management, Empowering blue economy: From underrated ecosystem to sustainable industry

REFERENCES

- Araújo, R., Vázquez Calderón, F., Sánchez López, J., Azevedo, I.C., Bruhn, A., Fluch, S., Garcia Tasende, M., Ghaderiardakani, F., Ilmjärv, T., Laurans, M. and Mac Monagail, M., 2021. Current status of the algae production industry in Europe: an emerging sector of the blue bioeconomy. *Frontiers in Marine Science*, *7*, p.626389.
- Benner, P., Meier, L., Pfeffer, A., Krüger, K., Oropeza Vargas, J.E. and Weuster-Botz, D., 2022. Lab-scale photobioreactor systems: Principles, applications, and scalability. *Bioprocess and Biosystems Engineering*, *45*(5), pp.791-813.
- Bermejo, R., Buschmann, A., Capuzzo, E., Cottier-Cook, E., Fricke, A.., Hernández, I., Laurie Carol Hofmann, L. C., Pereira, R. and S. van den Burg, 2022. State of knowledge regarding the potential of macroalgae cultivation in providing climate-related and other ecosystem services. Report prepared by an Eklipse Working Group.
- Bloomberg, 2021. Plant-based Foods Market to Hit $162 Billion in Next Decade, Projects Bloomberg Intelligence. Available at: https://www.bloomberg.com/company/press /plant-based-foods-market-to-hit-162-billion-in-next-decade-projects-bloomberg-intelligence/ .
- Burrows, M., Fox, C., Moore, P., Smale, D., Greenhill, L. and Martino, S., 2018. Wild seaweed harvesting as a diversification opportunity for fishermen.
- Cai, J., Lovatelli, A., Aguilar-Manjarrez, J., Cornish, L., Dabbadie, L., Desrochers, A., Diffey, S., Garrido Gamarro, E., Geehan, J., Hurtado, A. and Lucente, D., 2021. Seaweeds and microalgae: an overview for unlocking their potential in global aquaculture development. *FAO Fisheries and Aquaculture Circular*, (1229).
- Chopin, T., Buschmann, A.H., Halling, C., Troell, M., Kautsky, N., Neori, A., Kraemer, G.P., Zertuche-González, J.A., Yarish, C. and Neefus, C., 2001. Integrating seaweeds into marine aquaculture systems: a key toward sustainability. *Journal of phycology*, *37*(6), pp.975-986.
- Coleman, S., Gelais, A.T.S., Fredriksson, D.W., Dewhurst, T. and Brady, D.C., 2022. Identifying scaling pathways and research priorities for kelp aquaculture nurseries using a techno-economic modeling approach. *Frontiers in Marine Science*, *9*, p.894461.
- de Vree, J.H., 2016. Outdoor production of microalgae. Thesis. *Wageningen University*.
- European Commission, 2017. Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, *Food from the oceans : how can more food and biomass be obtained from the oceans in a way that does not deprive future generations of their benefits?*, Publications Office, https://data.europa.eu/doi/10.2777/66235.
- European Commission, 2020. Directorate-General for Research and Innovation, *Regenerating our ocean and waters by 2030 : Interim report of the mission board healthy oceans, seas, coastal and inland waters*, Publications Office, 2020, https://data.europa.eu/doi/10.2777/885438.
- European Commission, 2020. Executive Agency for Small and Medium-sized Enterprises, Sijtsma, L., Guznajeva, T., Le Gallou, M., et al., *Blue Bioeconomy Forum: roadmap for the blue bioeconomy*, Publications Office, https://data.europa.eu/ doi/ 10.2826/605949.
- European Commission, 2021a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a new approach for a sustainable blue economy in the EU. Transforming the

EU's Blue Economy for a Sustainable Future. *Official Journal of the European Union*. COM/2021/240 final.

- European Commission, 2021b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030. *Official Journal of the European Union*. COM(2021) 236.
- European Commission, 2021c. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Sustainable Carbon Cycles. *Official Journal of the European Union*. COM(2021) 800.
- European Commission, 2022. Joint Research Centre, Vazquez Calderon, F., Sanchez Lopez, J., *An overview of the algae industry in Europe : producers, production systems, species, biomass uses, other steps in the value chain and socio-economic data*, Publications Office of the European Union, https://data.europa.eu/doi/10.2760/813113.
- European Commission, 2022a. Commission Staff Working Document Blue Bioeconomy – Towards a strong and sustainable EU algae sector accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Towards a Strong and Sustainable EU Algae Sector. *Official Journal of the European Union*. SWD(2022) 361.
- European Commission, 2022b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Towards a Strong and Sustainable EU Algae Sector. *Official Journal of the European Union*. COM(2022) 592.
- European Commission, 2023a. Communication from the Commission to the European Parliament and the Council. The common fisheries policy today and tomorrow: a Fisheries and Oceans Pact towards sustainable, science-based, innovative and inclusive fisheries management. *Official Journal of the European Union*. COM(2023) 103.
- European Commission, 2023b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. On the Energy Transition of the EU Fisheries and Aquaculture sector. *Official Journal of the European Union*. COM(2023) 100.
- European Market Observatory for fisheries and aquaculture (EUMOFA), 2023. *Blue Bioeconomy Report*.
- FAO, 2016. The state of world fisheries and Aquaculture—2016 (SOFIA).
- FAO, 2021. Global seaweeds and microalgae production, 1950–2019, 2021. *FAO*. Available at: https://www.fao.org/3/cb4579en/cb4579en.pdf (Accessed: February 2023).
- Filippini, M., Baldisserotto, A., Menotta, S., Fedrizzi, G., Rubini, S., Gigliotti, D., Valpiani, G., Buzzi, R., Manfredini, S. and Vertuani, S., 2021. Heavy metals and potential risks in edible seaweed on the market in Italy. *Chemosphere*, *263*, p.127983.
- Greene, C.H., Scott-Buechler, C.M., Hausner, A.L., Johnson, Z.I., Lei, X.G. and Huntley, M.E., 2022. Transforming the Future of Marine Aquaculture. *Oceanography*, *35*(2), pp.26-34.

- Hermans, S., 2023. *2023* Seaweed State of the Industry, Seaweed State of the Industry. *Phyconomy*. Available at: https://phyconomy.net/articles/2022-seaweed-review/#more-1935 (Accessed: February 2023).
- IEA, 2017. State of Technology Review –Algae Bioenergy. *IEA Bioenergy*. Available at: https://www.ieabioenergy.com/blog/publications/state-of-technology-review-algae-bioenergy/ (Accessed: February 2023).
- Koyande, A.K., Chew, K.W., Rambabu, K., Tao, Y., Chu, D.T. and Show, P.L., 2019. Microalgae: A potential alternative to health supplementation for humans. *Food Science and Human Wellness*, *8*(1), pp.16-24.
- Krause-Jensen, D., Lavery, P., Serrano, O., Marbà, N., Masque, P. and Duarte, C.M., 2018. Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. *Biology letters*, *14*(6), p.20180236.
- Kumar, V. and Jain, S.M., 2014. Plants and algae species: Promising renewable energy production source. *Emirates Journal of Food and Agriculture*, pp.679-692.
- Langford, A., Zhang, J., Waldron, S., Julianto, B., Siradjuddin, I., Neish, I. and Nuryartono, N., 2022. Price analysis of the Indonesian carrageenan seaweed industry. *Aquaculture*, *550*, p.737828.
- Mac Monagail, M., Cornish, L., Morrison, L., Araújo, R. and Critchley, A.T., 2017. Sustainable harvesting of wild seaweed resources. *European Journal of Phycology*, *52*(4), pp.371-390.
- Marinho, G.S., Holdt, S.L., Birkeland, M.J. and Angelidaki, I., 2015. Commercial cultivation and bioremediation potential of sugar kelp, Saccharina latissima, in Danish waters. *Journal of applied phycology*, *27*, pp.1963-1973.
- Mathimani, T., Baldinelli, A., Rajendran, K., Prabakar, D., Matheswaran, M., van Leeuwen, R.P. and Pugazhendhi, A., 2019. Review on cultivation and thermochemical conversion of microalgae to fuels and chemicals: process evaluation and knowledge gaps. *Journal of cleaner production*, *208*, pp.1053-1064.
- Meng, W., Mu, T. and Marco, G.V., 2022. Seaweeds and microalgal biomass: The future of food and nutraceuticals. In *Future Foods* (pp. 183-201). Academic Press.
- Mobin, S. and Alam, F., 2017. Some promising microalgal species for commercial applications: a review. *Energy Procedia*, *110*, pp.510-517.
- Mouritsen, O.G., Rhatigan, P., Cornish, M.L., Critchley, A.T. and Pérez-Lloréns, J.L., 2021. Saved by seaweeds: phyconomic contributions in times of crises. *Journal of Applied Phycology*, *33*(1), pp.443-458.
- Mutanda, T., Naidoo, D., Bwapwa, J.K. and Anandraj, A., 2020. Biotechnological applications of microalgal oleaginous compounds: current trends on microalgal bioprocessing of products. *Frontiers in Energy Research*, *8*, p.598803.
- National Food Institute, Technical University of Denmark, Denmark, Sá Monteiro, M., Sloth, J., Holdt, S. and Hansen, M., 2019. Analysis and risk assessment of seaweed. *EFSA Journal*, *17*, p.e170915.

- *North Sea Farm Foundation, 2019. D4.1.1* Study on existing market for algal food applications, 2019. Available at: https://ilvo.vlaanderen.be/uploads/images/Valgorize/Valgorize-D4.1.1A_Study-on-the-existing-market-for-seaweed-food-applications-1.pdf (Accessed: February 2023).
- Onen Cinar, S., Chong, Z.K., Kucuker, M.A., Wieczorek, N., Cengiz, U. and Kuchta, K., 2020. Bioplastic production from microalgae: a review. *International journal of environmental research and public health*, *17*(11), p.3842.
- Porse, H. and Rudolph, B., 2017. The seaweed hydrocolloid industry: 2016 updates, requirements, and outlook. *Journal of applied phycology*, *29*(5), pp. 2187-2200.
- Roohinejad, S., Koubaa, M., Barba, F.J., Saljoughian, S., Amid, M. and Greiner, R., 2017. Application of seaweeds to develop new food products with enhanced shelf-life, quality and health-related beneficial properties. *Food Research International*, *99*, pp.1066-1083.
- Roohinejad, S., Koubaa, M., Barba, F.J., Saljoughian, S., Amid, M. and Greiner, R., 2017. Application of seaweeds to develop new food products with enhanced shelf-life, quality and health-related beneficial properties. *Food Research International*, *99*, pp.1066-1083.
- Searchinger, T., Waite, R., Hanson, C., Ranganathan, J., Dumas, P. and Matthews, E., 2019. World resources report: Creating a sustainable food future. *World Resources Institute*.
- Sivaramakrishnan, R., Suresh, S., Kanwal, S., Ramadoss, G., Ramprakash, B. and Incharoensakdi, A., 2022. Microalgal biorefinery concepts' developments for biofuel and bioproducts: Current perspective and bottlenecks. *International Journal of Molecular Sciences*, *23*(5), p.2623.
- Sutherland, D.L. and Ralph, P.J., 2019. Microalgal bioremediation of emerging contaminants-Opportunities and challenges. *Water research*, *164*, p.114921.
- The Nature Conservancy, 2021. Global Principles of Restorative Aquaculture.
- Usher, P.K., Ross, A.B., Camargo-Valero, M.A., Tomlin, A.S. and Gale, W.F., 2014. An overview of the potential environmental impacts of large-scale microalgae cultivation. *Biofuels*, *5*(3), pp.331-349.
- Vigani, M., Parisi, C., Rodríguez-Cerezo, E., Barbosa, M.J., Sijtsma, L., Ploeg, M. and Enzing, C., 2015. Food and feed products from micro-algae: Market opportunities and challenges for the EU. *Trends in Food Science & Technology*, *42*(1), pp.81-92.
- Waycott, B., 2020. Making algae can get expensive. Innovations aim to bring costs down. *Global Seafood Alliance*. Available at: https://www.globalseafood.org/advocate/making-algae-can-get-expensive-innovations-aim-to-bring-costs-down/ (Accessed: February 2023).
- Zhang, X., Rong, J., Chen, H., He, C. and Wang, Q., 2014. Current status and outlook in the application of microalgae in biodiesel production and environmental protection. *Frontiers in Energy Research*, *2*, p.32.

This study examines the EU Algae Initiative communication by the European Commission and gives an overview of the European algae sector in terms of production, applications, opportunities and barriers. The 23 targeted actions proposed by the European Commission have been set out with the goal of unlocking the vast potential of algae for the EU's Blue Bioeconomy, addressing key challenges, such as food security and climate change mitigation. For successfully developing the sector, a set of barriers will need to be overcome. This requires a collective effort by policymakers, at Member State and EU level, as well as industry stakeholders, scientific community, administration and others.

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