Roadmap Production European Seaweed Industry

The growth potential of European seaweed production, highlighting ambitions, bottlenecks, opportunities, and action plans to drive the sector forward.

Update in collaboration with:

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0.1	First draft	E. Brouwers	28 Nov 2024
0.2	Final draft	K. Peppelman	03 Jul 2025
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Executive Summary

With the rise of global challenges such as climate change and biodiversity loss, the need to transition to a fossil-free and circular/regenerative economy is urgently increasingl. In this world dynamic,seaweed can play a significant role in this transition for Europe. As well as its high growth rates, carbon sequestration properties, low freshwater dependency and mostly not relying on a land already saturated by other human activities, it also possesses valuable components such as proteins and bioactive compounds, which could be utilised in various industries, including food, animal feed, biomaterials, cosmetics and building materials. However, despite its potential, developing large-scale, seaweed-based production systems remains challenging. First, the high costs of production are an obstacle to commercial viability. Technologically, significant variations in seaweed composition, cultivation methods and processing techniques create challenges that must be overcome for the industry to become more predictable in terms of yield and quality.

Although considerable research has been conducted in recent years on seaweed cultivation and its applications and benefits, much of this knowledge remains fragmented or inaccessible to key stakeholders. Consequently, the opportunities within the seaweed industry are not always clearly defined, nor are the steps for achieving large-scale implementation. To realise the potential of seaweed-based production, the European industry must establish clear objectives and create an actionable roadmap.
Critical questions arise: What challenges are seaweed producers facing today? What are the most viable opportunities for seaweed production? How can these opportunities be seized effectively? What level of ambition should the European seaweed industry set for growth? This roadmap aims to begin answering these questions in a structured way, with support from all relevant industry stakeholders.

Today, roadmaps on the seaweed industry are being developed for packaging, biostimulants and a transition to seaweed-based protein. There are also plans to evaluate the food, feed, cosmetics, construction and textiles markets, as well as potentially ecosystem services. This production roadmap completes those market-specific roadmaps by indicating the supply ambition, as opposed to the expected demand. Together, these will provide a comprehensive analysis of the seaweed industry, including promising markets, a vision for 2050, and an overview of the challenges and opportunities. The roadmap will also provide targeted recommendations on how to scale up the seaweed industry.

It is important to recognise that the European seaweed landscape is highly dynamic and subject to change, requiring ongoing adaptability. Accordingly, this roadmap is intended as a living document, designed to evolve in response to emerging developments and changing production and market conditions.

1 Central question and sub questions

1.1 Scope

This roadmap focuses on sustainably cultivated seaweed from Europe whether it's onshore, nearshore or offshore, with the latter two as the potential highest volume producing production locations. Wild-harvested seaweed is included in this roadmap as a significant contributor to Europe's yearly production numbers, but this roadmap will not define any goals or actions specific to wild harvest production of seaweed.

The geographic focus is the European Union plus the United Kingdom and Norway. Although this includes all ocean basins in this geographical region, it is expected that in terms of onshore and nearshore all of these regions may be applicable. For offshore we anticipate the North Sea basin to be the first to scale-up.

2 Ambitions 2050 and key assumptions

2.1 European Seaweed Production Categories

The European seaweed sector encompasses a variety of production methods, each shaped by environmental conditions, technological choices, and socio-economic contexts. The following categories distinguish the principal modes of production currently practiced or under development.

2.1.1 Wild harvest of natural stocks

Wild harvesting refers to the direct collection of naturally occurring seaweed from coastal ecosystems such as rocky shores, intertidal zones, and shallow subtidal areas. Representing the very large majority of all seaweed production in Europe, this practice has a long cultural history in many European regions and continues to provide raw material for food, feed, and industrial applications. Sustainable management is essential to avoid overexploitation and ensure the resilience of natural seaweed beds.

2.1.2 Onshore farms

Onshore production systems involve the cultivation of species in land-based facilities, including tanks, raceways, and ponds supplied with seawater. Such systems allow for greater control over growth conditions (light, nutrients, temperature), reduce exposure to environmental variability, and enable integration with other forms of aquaculture (e.g., fish or shellfish farming in integrated multi-trophic aquaculture, IMTA). However, they are often more capital- and energy-intensive compared to marine-based systems.

2.1.3 Small scale farms

Small-scale farms are typically located in sheltered nearshore environments and operated by individual producers, cooperatives, or community groups. Very often as an expansion of an already existing aquaculture activity (shellfish, passive fishing, etc.),they generally produce lower volumes intended for local or niche markets (e.g., artisanal food products, cosmetics). These farms play an important role in regional development, innovation, and social acceptance of seaweed cultivation, often serving as stepping stones towards larger commercial operations.

2.1.4 Nearshore farms

Nearshore farms are situated in relatively protected marine environments, such as bays, fjords, or coastal inlets. Nearshore Seaweed cultivation usually employs rope, net, or frame systems suspended in the water column. These farms can operate at moderate scales and are often more accessible and cost-efficient than offshore sites, though they may be constrained by competition for space and potential interactions with coastal ecosystems and human activities.

2.1.5 Offshore farms

Offshore seaweed cultivation refers to large-scale farming systems located in open-sea conditions, often at significant distance from the coast. These farms are exposed to higher energy environments with stronger waves, currents, and wind, requiring robust engineering solutions and advanced logistics. Offshore cultivation offers substantial potential for scaling up European seaweed production, particularly through co-location with offshore wind farms, but also presents challenges in terms of cost, safety, and operational complexity.

2.1.6 Sustainable seaweed production

Sustainable seaweed production encompasses practices that balance ecological integrity, economic viability, and social responsibility. It involves minimizing negative impacts on marine ecosystems, supporting biodiversity, contributing to circular economy principles, and ensuring fair distribution of economic benefits across stakeholders. Sustainability in seaweed production is increasingly framed within European policy contexts such as the Green Deal, the Farm to Fork strategy, and marine spatial planning initiatives.

2.2 Benefits of European Cultivated Seaweeds

2.2.1 European Seaweeds

What constitutes European seaweeds, and when do we call it European?

2.2.2 European wild harvest

2.2.3 What are the ongoing dynamics between wild harvested seaweed and cultivated seaweed? What are the main points of comparison? Imported seaweeds and/or derived products

2.3 What are the ongoing dynamics between imported seaweed and derived products in Europe, and cultivated seaweed? State-of-the-art European Seaweed Production

2.3.1 Species

2.3.2 Onshore production technology

2.3.3 Nearshore production technology

2.3.4 Offshore production technology

2.3.5 Preprocessing & conservation

2.3.6 Logistics

2.3.7 Key challenges in seaweed production

2.4 Biological scope of cultivated seaweed production

The ambition of large-scale seaweed production needs constant evaluation, especially in the context of potential environmental constraints. Productivity of seaweed farms is mainly dependent on species (strain), temperature; water quality and nutrient and light availability. Nutrient availability itself is based on a combination of current speeds and their concentrations in the water. Naturally, the optimal environmental conditions are highly species-dependent, therefore the ideal location for seaweed farming varies per species. For example, some seaweed species thrive in low phosphate conditions but require abundant light, while others can tolerate low nitrogen but need more phosphate. Some specific limitations for the different species types in the different European regions are provided in Table 1 below.

Table 1: Suitable area species-specific seaweed cultivation and their limitation factors. For specific SSS (seaweed site suitability) map, see Appendix **Error! Reference source not found.** and **Error! Reference source not found.**. NWES = north-west European shelf, SWES = south-west European shelf, S = salinity, T = Temperature, P = phosphate, N = nitrate, NS = North Sea, IS = Irish Sea, CS = Celtic Sea, BC = British channel. Derived from: Macias et al., 2025

Climate	Species[1]	Location	Suitable area (km2)	Marine Region	Main limitations
Cold	Brown	Baltic	0	Coastal	S
				Open Sea	S
		NWES	880.000	Coastal	T, P
				Open Sea	NS, IS, CS, BC: N

[1] For more information on which specific species are categorized cold or intermediate, see Error! Reference source not found.

Climate	Species[1]	Location	Suitable area (km2)	Marine Region	Main limitations
					N-W NWES: Waves
		SWES	200.000	Coastal	South coast: T Northern coast: N
				Open Sea	N
Intermediate	Green, Red	Baltic Sea	50.000	Coastal	T
				Open Sea	T
		NWES	970.000	Coastal	IS, BC: S, T NS: T
				Open Sea	IS, BC: S NS: T N-W NWES: Waves
		SWES	430.000	Coastal	S, P, or N
				Open Sea	N

Some additional limitations from other regions mentioned are:

- The Mediterranean and the black sea are less suitable for large-scale seaweed cultivation, mostly due to temperature and nutrient limitations (Phosphate around the coast and Nitrate In the open sea) (Friedland et al., 2021; Huertas et al., 2012; Macias et al., 2025; Miladinova et al., 2020; Tanaka et al., 2011)
- The Baltic Sea has some potential but low salinity, limited hard substrata for seaweed attachment, and highly eutrophicated areas limit growth and suitability, making it less suitable compared to the North Sea or Atlantic. (Macias et al., 2025)

2.4.1 Site selection

Determining optimal regions for seaweed cultivation requires advanced tools and reliable data, yet this remains a significant challenge. Modelling tools, such as those utilized by Macias et al., 2025, use biophysical analyses to assess the suitability of marine regions. These tools are critical for identifying future cultivation areas, especially in Europe, where such assessments are underexplored. Until recently, the suitability of EU marine regions for seaweed farming was poorly understood, primarily due to a lack of consistent and comprehensive data.

While remote sensing can provide valuable information, such as sea surface temperature and significant wave height, many other key parameters such as nutrient levels, current velocities, and light availability, are measured sporadically in both time and space. This data scarcity presents a significant barrier to accurately modelling regional suitability, especially for smaller, dynamic seas like the Mediterranean or the North Sea. Validation of these models is further complicated by the absence of robust monitoring data, making it difficult to test the reliability of hydrodynamic and biogeochemical calculations (Macias et al., 2025).

Adding to the complexity, species-specific suitability models remain underdeveloped. Limited research on European seaweed species means there is insufficient knowledge about their precise growth requirements and optimal cultivation conditions. For seaweed farmers, this is a crucial gap, as ensuring a consistent supply of high-quality seaweed depends on understanding which species thrive in specific locations and under varying environmental conditions. Without this information, production is subject to variability, which hampers both product quality and market trust (Research and innovation; Oxford Academic).

2.4.2 Biological risks

Biological risks are another key obstacle. Seasonal differences, environmental conditions, and fouling (the accumulation of unwanted organisms on seaweed or infrastructure) can impact seaweed quality and consistency. Fouling reduces seaweed yield and degrades the final product's quality, making it less appealing for market use. Diseases further threaten seaweed health, and research into their mitigation is still in its infancy.

Variability in growing conditions, combined with genetic and strain-specific differences among seaweed, adds another layer of complexity. This inconsistency can lead to fluctuations in product quality, hampering the scalability of seaweed farming and reducing market confidence (Ciravegna et al., 2023). Research and innovation are crucial to addressing these challenges, but significant knowledge gaps persist, particularly in understanding how environmental factors affect different seaweed strains.

2.4.3 Offshore farms

Expanding seaweed farming into offshore environments introduces its own set of challenges. Offshore farms are exposed to harsh and unpredictable environmental conditions, including wave action, storms, and strong currents. These forces can damage cultivation infrastructure and delay scheduled farming operations, impacting both productivity and profitability. The infrastructure itself must be resilient to withstand these conditions, but designing and implementing such systems adds to the cost and complexity of offshore farming.

In addition, the short- and long-term environmental effects on and of this large-scale offshore seaweed cultivation remain poorly understood. Research to date has primarily focused on medium-scale farms, such as those on the Faroe Islands (Groenendijk et al., 2016), leaving critical questions about ecosystem impacts unanswered. For example, large-scale cultivation may influence local biodiversity, nutrient cycling, and carbon sequestration, but these effects have yet to be thoroughly studied or documented.

2.4.4 Hatcheries

Currently, there are both centralized hatcheries as well as individual hatcheries on-site of seaweed farms, opinions on whether to centralize/combine hatcheries or if farmers should produce their own seed are varying. Individual hatcheries per farm might be easier from a logistical and financial point of view, but control on breeding lines and standardized breeding procedures would be more difficult to maintain, which are essential steps in upscaling seaweed production. Important to note is that close collaboration between hatcheries and farms is essential, where breeding experts work together with farming experts to create strong, high-quality seaweed seed native to the cultivation areas. This avoids any mismatch in supply and demand of seed during farm seeding time to occur. Moreover, the seed currently used for seaweed farming is applicable for sea-based seaweed cultivation, however, knowledge on the effectiveness of these seedlings for large-scale and offshore farming is limited. For future up-scaling it is essential to get actual data on the effectiveness of current seaweed breeding lines on large-scale offshore seaweed cultivation.

Research by Cohen et al., 2025 on specific breeding of *S. latissima*. highlights that technological improvements could lower biomass production costs and increase the economic interest of seaweed aquaculture, one of these technological improvements being selective breeding (Goecke et al. 2020; Huang et al. 2023). With this, selecting breeding lines for higher yields improved (a)biotic stressor resistance, and/or increased biomass quality.

This study specifically confirmed that *S. latissima* populations worldwide are interfertile and can successfully hybridize across different geographical regions and that these genetically diverse "hybrids" could potentially contribute considerably to future seaweed breeding programmes. Hybrid performance is linked to genetic differentiation rather than physical distance and hybrids show varied responses to environmental conditions, emphasising the need for location-specific trials. Including global genetic resources could potentially enhance breeding, improving yield and quality (Cohen et al., 2025).

It is of interest to explore these findings further, also researching different commercially interesting seaweed species in the future. Now, even though this study provides an interesting opportunity for future up-scaling of seaweed production, managing these breeding lines must be done with care and environmental effects should be monitored closely, to prevent unintended ecological consequences.

2.5 Ecosystemic scope

From an ecosystem perspective, the upscaling potential of seaweed production must be approached cautiously, prioritizing **nature-inclusive methods and the carrying capacity of the European seas** rather than simply maximizing output. The goal should be to integrate seaweed into the European food system and to promote a circular economy (Van Den Burg et al., 2021).

2.5.1 2.5.1. Balance quantity with quality

The emphasis needs to be on producing the "right amount" of seaweed, aligned with the capacity of European marine ecosystems. A large-scale, purely quantitative approach could obscure important considerations about optimal integration of seaweed into the food system and its role in a circular economy.

- 2.5.2. Ecosystem Services and Benefits:
  - One of cultivated seaweed's main selling points is its large potential for environmental restoration and sustainability in production. Those qualities include:**Nutrient Removal:** Seaweed cultivation can help mitigate eutrophication by removing excess nutrients, especially in areas near fish farms (Bhuyan, 2023; Visch et al., 2020).**Habitat Provision:** Seaweed farms can act as habitats, potentially increasing local biodiversity, although the long-term effects of this require further research (Duarte et al., 2023; Visch et al., 2020). They can provide shelter, feeding, and nursery areas for various species (Visch et al., 2020).
  - **Carbon Sequestration:** Seaweed cultivation has the potential to act as a carbon sink, capturing atmospheric carbon (Duarte et al., 2023; Fricke et al., 2024; Van Den Burg et al., 2021). However, there are still questions about the feasibility of achieving significant carbon reduction at a large scale (Fricke et al., 2024).
  - **Water Quality Improvement:** Seaweed farms can improve water quality by removing excess nitrogen from coastal waters, which helps to prevent the formation of "dead zones" (Waters et al., 2023).

2.5.2 2.5.3. Potential Negative Impacts:

As with all production systems, caution must be exercised when growing seaweed in offshore waters:

- **Light Reduction:** Seaweed farms can reduce light availability for other organisms, potentially impacting autotrophic life forms (Bhuyan, 2023; Van Den Burg et al., 2020). Light attenuation of about 40% at 5m depth has been noted (Visch et al., 2020). Therefore, it is crucial to consider if farming methods interfere with environments that contain autotrophic organisms (Bhuyan, 2023).
- **Sedimentation:** Increased sedimentation due to seaweed fall-off is possible, though water flow may mitigate this (Bhuyan, 2023; Van Den Burg et al., 2020).
- **Genetic Impacts:** There's a risk of decreased genetic diversity in wild seaweed populations and potential gene flow from cultivated to wild species. The use of

native species in cultivation can help to reduce the threat of genetic extinction in wild populations (Bhuyan, 2023; Visch et al., 2020; Van Den Burg et al., 2021).

- **Disease:** Intensive farming may lead to disease outbreaks (Van Den Burg et al., 2021).
- **Invasive Species:** There's a risk of introducing non-native or nuisance species (Bhuyan, 2023).
- **Changes to Hydrodynamics**: Seaweed farms can alter water flow patterns by absorbing kinetic energy (Bhuyan, 2023).
- **Ecosystem Change:** Large-scale seaweed farming can change local ecosystems, potentially impacting primary production and altering the food web (Bhuyan, 2023; Van Den Burg et al., 2020).

2.5.3 2.5.4. Technological and Management Approaches:

To optimize ecosystem benefits, a polyculture approach, which combines different types of seaweeds and other aquatic organisms, may be more beneficial than monoculture. Integrated multi-trophic aquaculture with filter-feeders or alongside finfish production systems have shown increased growth rates and can be used to recycle waste from fed aquaculture (Fricke et al., 2024). However, the technical expertise and financial requirements needed to set up such systems may be a constraint to their installation.

2.5.4 2.5.5. Site Selection

Careful site selection is crucial to minimize competition for space and resources, which can be a major constraint for seaweed aquaculture in Europe. Collaboration with existing users of marine space, such as wind farms, should continuously be explored as they may offer large-scale farming opportunities as well as cheaper operation procedures when collaborating with neighbouring industries (boat sharing, permits...) (Fricke et al., 2024).

2.5.5 2.5.6. Monitoringand harvesting regimes

Continuous monitoring of environmental impacts is essential for responding to potential threats (Fricke et al., 2024; Bhuyan, 2023). Adjusting the timing of the harvest may resolve some issues related to the reproduction of species that use seaweed farms as habitat or shelter (Visch et al., 2020).

2.5.6 2.5.7. Seed Banks

The creation of national seed banks can help ensure high standards of seed stock health and breeding methods (Bhuyan, 2023).

2.5.7 2.5.8. Focus on Circularity, and avoid a “Linear” approach

Seaweed should not be viewed as a new product added to the market but rather become an integral part of the European food system, utilized for human consumption, animal feed, and to enhance production processes (Van Den Burg et al., 2021).
Furthermore, upscaling does not only imply solely intensifying current practices. Focus on innovation, by-product utilization, and social and economic benefits to align the market can be a development strategy to upscale seaweed use in Europe, and hence allow for growth in production to develop (Van Den Burg et al., 2021).

2.5.8 2.5.9 Knowledge Gaps:

There is a need for more research on:

- Long-term effects of habitat provision by seaweed farms (Visch et al., 2020).
- The dynamics of carbon and nutrient cycling in seaweed aquaculture (Van Den Burg et al., 2021).
- The impact of scale on the provision of ecosystem services (Fricke et al., 2024).
- The overall carbon footprint of large-scale seaweed farms (Fricke et al., 2024).
- The environmental impacts of processing seaweed (Van Den Burg et al., 2021).
- The quantification of ecosystem services provided by seaweed farming (Fricke et al., 2024).

In conclusion, the upscaling potential for seaweed production from an ecosystem perspective requires a focus on **sustainable and integrated practices**. It calls for a balanced approach that maximizes the benefits of seaweed cultivation, such as nutrient removal and habitat provision, while carefully mitigating potential risks such as light reduction and genetic impacts. Prioritizing research, monitoring, and adaptive management strategies is vital for ensuring that seaweed aquaculture contributes positively to marine ecosystems while also meeting the demands of the European food system. A **regional approach** that acknowledges the variability of local conditions is also necessary (Fricke et al., 2024).

An ecological risk of large-scale seaweed cultivation is that foreign, genetically different seaweed breeding lines might be introducing foreign genetic material into the environment, with this affecting wild seaweed populations. An opportunity to mitigate this risk of introducing foreign genetic material into the environment is to produce sporeless sporophytes (Vissers et al., 2024).

3 Regulatory and Market Context

3.1 Regulatory context

The EU Algae Initiative ambition is to position algae as a cornerstone of Europe's sustainable Blue Economy by addressing regulatory, economic, scientific, and societal barriers to growth. By implementing strategic priorities, the EU aims to establish a thriving, resilient, and sustainable algae industry, contributing to food security, climate resilience, and the broader objectives of the EU Green Deal and Blue Economy Strategy. Moreover, it aims to improve the business environment of the EU algae sector, fostering growth, innovation, and collaboration within the industry (Kuech et al., 2023).

There are several initiatives and consortiums with and from the European Union aimed at stimulating growth towards a strong and sustainable EU algae sector (for a complete list, go to section 8.2). Aiming to improve governance framework and legislation by simplifying Horizon Europe is financing R&D on improving seaweed cultivation, harvesting, and processing together with raising awareness on seaweed application and implementation[2].

3.2 Market context

The sector faces high production costs due to manual labour dependency, expensive offshore technologies, and a limited scale of production preventing economies of scale (Macias, 2025; Groenendijk et al., 2016; van den Burg et al., 2016; Bak, 2018; STECF, 2023).

Key among these challenges is the high production costs associated with aquaculture itself. Offshore cultivation technologies are expensive, and the sector still relies heavily on manual labour, resulting In high operational costs adding onto the investments made for farm set-up, such as seed lines and cultivation Installations (Macias, 2025; Groenendijk et al., 2016; van den Burg et al., 2016; Bak, 2018; STECF, 2023). The economic strain is not limited to direct production costs but also indirect costs such as processing and transport costs that add to it. Processing the seaweed, especially the drying step, is one of the most expensive steps in the process (Ciravegna et al., 2023).
Cultivating seaweed further offshore adds to the costs even more since it increases transportation distance and thus costs and the risk of system damage is higher because of the strong forces of the water (maintenance costs) (Kapetsky et al., 2013; Lehahn et al., 2016). Nearshore is therefore analysed as the more likely option for sea-cultivating seaweed, as logistically it's easier to manage. These areas, on the other hand, already experience high human pressure. This is only increasing, highlighting the relevance of further offshore seaweed cultivation to reach the ambitions to scale up European seaweed production levels (Gentry et al., 2017; Kapetsky et al., 2013; Lehahn et al., 2016; Ross et al., 2024; Van Den Burg et al., 2020, 2021; Van Oort et al., 2023).
Even with advancements in large-scale seaweed farming, current production expenses are estimated to be as much as six times higher than the revenue they can potentially generate (Groenendijk et al., 2016; Van Den Burg et al., 2016), which is not a good business model.

[2] https://projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/butter-baths-seaweeds-potential-being-tapped-europe

These financial hurdles raise concern for European seaweed producers to achieve economies of scale without any financial aid, where solely based on prices, it will be hard for them to compete with other sectors.

3.2.1 Production costs

Production cost of cultivated seaweed is currently exceptionally high. It is difficult to state the exact production costs as this highly depends on the system used, the labour costs in the country, and parameters used for calculation, this combined with inconsistent data and lack of standardized data collection creates difficulties in comparing costs. Van Den Burg et al., 2016 evaluated production cost prices around €1850 per tonne DM, whereas a different source evaluated it to be between €500-€1000 per tonnes of seaweed produced (EUMOFA, 2023). A report by Ciravegna et al., 2023) created an overview to try and compare production costs (Table 2), but here again becomes apparent that there is no real standardization in parameters used for calculating production costs which makes it difficult to compare research data. It is apparent however that costs for small-scale seaweed farming is exceptionally high. There are concerns about the economic feasibility of large-scale seaweed farming , however looking at estimated made on production costs for large-scale offshore seaweed farming in Europe, these costs actually turn out lower than small-scale farms, where the average costs are estimated to be around €3,050 per km per year (Ciravegna et al., 2023; Van Den Burg et al., 2016) Moreover, from international experiences, it is shown that it can be feasible with some needed alterations and action points (Ciravegna et al., 2023). The ambition is to decrease the production costs to €100 per tonnes when scaling up (EUMOFA, 2023). Personal contact through an interview with a production partner confirmed this ambition, mentioning ambitions to decrease production costs to €0.1-0.2 per kg (€100-200 per tonnes) seaweed.

Current biomass is going to products with lower values, such as biostimulants and fertiliser. Refining the extraction of high-value products from farmed seaweed can unlock more application potential and product lines and increase the market value. To do this, an understanding of the composition of the European cultivated seaweed, products, and its product ingredients through R&D Initiatives and projects is needed (Robb & Thorne, 2023).

Table 2: Overview of production costs for small scale seaweed farming in Europe, taken from: Ciravegna et al., 2023

Small scale						
	Variable/units	Denmark	Ireland		Sweden	Faroe islands
		6 tests sites, 3 Farms	Project	Farm	Farm	Farm
Production	Species	*Saccharina latissima*	*Laminaria digitata*	*Alaria esculenta*	*Saccharina latissima*	*Saccharina latissima*
	Life Span	10 years	3 years	20 years	10 years	8 years
	Yield		7.25t/km/yr (dw=15%)	12t/km/yr (dw=10%)	8t/km/yr	6t/km/yr
		7.65 t/ha/yr		48.4 t/ha/yr		35t/ha/yr
Total OpEx			**151,159 €/14.4km/yr**	**10,813 €/1.210km/yr ***	**43,600 €/ha/yr**	**12,609 €/ha/yr***
Long- term cost >5 y (CapEx)	Total		**130,128 €/14.4km/3yr**	**100,140 €/1.210km/20yr ***	**67,810 €/ha/10yr**	
	broken down to year and ha or km		**3,012 €/km/yr**	**4,138 €/km/yr**	**3,391 €/ha/yr***	**15,784 €/ha/yr****
Total costs	**Individual unit**	**116,000 €/ha/10yr***	**580,945 €/total/ 3yr *****	**15,820 €/6ha/yr ****	**46 988 €/ha/yr****	**28,394 €/ha/yr**
	€/kms/yrs	**116,000 €/1.1km/10yr *****	**580,945 €/14.4 km/3yr**	**15,820 €/1.210 km/yr**	**46,988 €/2.34 km/yr**	**28,394 €/2.5 km/yr**
	€/km/ yrs	**105,455 €/km/10yr**	**40,343 €/km/3yr**			
	€/km/yr	**10,546 €/km/yr**	**13,449 €/km/yr**	**13,074 €/km/yr**	**20,081 €/km/yr**	**11,357 €/km/yr**
Source		Zhang et al. (2020)	Watson and Dring (2011)	Collins et al. (2022)	Hasselström et al. (2020) **	Bak et al. (2020)***

ww = wet weight, fw = fresh weight, dw=dry weight. Fw and ww represent the same, but we respected the definition the authors of the papers chose.
All * are found in Appendix 3.

3.2.2 Market conditions

The market value of seaweed is highly dependent on factors such as species type, processing methods, and the quality of the seaweed or its derived products. For example, the at-harvest price of British wet kelp typically ranges between **€3.0 and €3.5 per kilogram** (wet weight). This means that for a farmer, each 100-meter longline of kelp would be worth approximately **€2,900 to €4,100** (EUMOFA, 2023).

In contrast, market prices for seaweed are significantly higher than at-harvest prices. Fresh or frozen seaweeds, such as dulse (*Palmaria palmata*), kelp (*Saccharina latissima*), sea lettuce (*Ulva*), and sea spaghetti (*Himanthalia elongata*), are usually sold at market prices ranging from **€25 to €35 per kilogram**. Similarly, species like *Alaria esculenta* are priced at **€30 to €40 per kilogram** in retail markets (Ciravegna et al., 2023). Dried seaweed market value is generally high, > **€100 per kilogram**, however, these require additional processing steps that add to the production costs. A few commercially sold seaweeds, as dried products, and their market values are shown in Table 1.

Table 1: An overview of produced seaweed species and their market values after drying occurred (Araújo et al., 2021).

Seaweed species	Market Value
Porphyra spp. (nori)	Flakes: €179 per kg Sheets: €383 per kg
Codium spp.	€155 per kg

Seaweed species	Market Value
Gracilaria sp.	€155 per kg
P. palmata	€114 per kg
U. pinnatifida	€108 per kg
Laminaria spp.; *S. latissima*	€88 per kg
H. elongata	€86 per kg
C. crispus	€72 per kg
Fucus spp.	€25 per kg

Alginates and agar are also products derived from seaweed (mostly *S. lattisima*), the value of these depends a lot on the quality, however, sodium alginate used for average quality application can sell at around 3000 euros a ton (Groenendijk et al., 2016).

Inconsistencies in market evaluations and the lack of standardized parameters—such as whether seaweed is processed or unprocessed and the specific product being measured—make it difficult to compare market values. The final value of seaweed is highly dependent on the extent of processing, which is often unclear in market assessments.

3.2.3 Investment

Blue economy solutions remain significantly underfunded compared to land-based food and agriculture initiatives. Notably, UN Sustainable Development Goal 14,Life Below Water, is the least funded of all SDGs, even though four of the SDG 2020 targets fell under its scope (Sachs et al., 2024). The demand for regenerative and well-managed alternative food sources has never been more critical. The need for alternative food sources that are regenerative and well-managed has, therefore, never been more necessary. The EU's Fark to Fork strategy even mentions the need for ”well-targeted support for the algae industry, as algae should become an important source for a sustainable food system and global food security” (EUMOFA, 2023). Funding the seaweed industry will help tackle the current limitations in upscaling. The focus should be on R&D initiatives that mitigate risks for farmers (both in starting up and scaling-up), improve biorefinery processes, map out potential cultivation areas through modelling, automate cultivation methods, and fill the current knowledge gaps on European seaweed species (traits, both genetics as well as preferred environmental conditions, their application opportunities, etc.). A list of such initiatives that currently focus on accelerating seaweed production growth is provided in 8.2. Building on these and adding new funded projects tackling the whole value chain, from pilot farms and in-field data for seaweed farming to processing to market application is essential for upscaling the industry. In the long term, a business case without subsidies is essential, but to get there, investments are needed through:

- Government subsidies.
- Financial support mechanisms to encourage co-use with i.e. wind farms (Groenendijk et al., 2016).
    - Safety assessments and operating practices should be established to set up insurance for the businesses that use the platforms.
    - There are high costs involved in collaborating with wind farms.
- EU funding (EUMOFA, 2023).
    - Generate reliable data (biorefinery, seaweed cultivation, and harvesting at scale) for Life Cycle Assessments and econometric analysis to validate investment decisions.

    - Open-access pilot sites
- Environmental Finance (EUMOFA, 2023; Feehan, 2023; Waters et al., 2023).
    - Explore the potential for carbon credits and markets (or other mitigating opportunities) for extra revenue.
    - Monetize environmental services provision.

3.2.4 Production subsidies

To kick-start seaweed production and make it more attractive, production subsidies can play a crucial role (figure 1). Subsidies can help bridge the price gap between cultivated seaweed and wild-caught seaweed, the latter being significantly cheaper and currently dominating the sector. This method of reducing costs until economies of scale have been established has been done before with sectors such as the wind energy sector. An example calculation of how to implement this is executed below in Table 2.

Table 2: Example Calculation: Required Seaweed Production Subsidy to Bridge the Cost Gap Between Wild Harvesting and Cultivation (2024–2050) – Source: internal communication from the European Seaweed Association.

Begin	End	Price wild -harvest [ct/kg-w	Price cultivated [ct/kg-w	Volume [t-wet/yr]	Cost per year	Cost over lifetime of 40yrs
2024	2030	15	100	5.000	€ 4.250.000	€ 170.000.000
2030	2035	20	70	30.000	€ 15.000.000	€ 600.000.000
2035	2040	22	50	150.000	€ 42.000.000	€ 1.680.000.000
2040	2045	24	40	600.000	€ 96.000.000	€ 3.840.000.000
2045	2050	26	30	1.800.000	€ 72.000.000	€ 2.880.000.000
				2.585.000		€ 9.170.000.000

4 Strategic scaling framework - Capability, Infrastructure and Investment milestones

4.1 Capabilities

The European seaweed sector requires a comprehensive capacity building agenda to accelerate growth, strengthen knowledge transfer, and foster innovation across society. This agenda engages three main target groups: professionals, the education sector, and governments. Together, these actions form a capacity building agenda that bridges professionals, education, and governments. By combining training, outreach, and policy support, the European seaweed sector can build the knowledge base, talent pipeline, and social acceptance needed to unlock its full potential within a sustainable blue economy.

4.1.1 Informing and educating the market on the potential of seaweed

Many market stakeholders have no idea of the potential of seaweed in terms of applications and their associated benefits. This differs per market and per application so it should be addressed in the specific market roadmaps. Anyone in those markets promoting seaweed-based solutions, should be sufficiently informed to clarify the benefits of seaweed in that specific application in terms of climate impact (e.g. CO_2), pollution impact (e.g. plastic, pesticides), resource efficiency (e.g. less water needed in agriculture, recyclability). Furthermore, it is recommended to clarify the general benefits of seaweed to the general public. These are effectively the end-users of any product so their perception will be important for market stakeholders. Promotion to the general public could be setup in the form of awareness campaigns.

4.1.2 Informing product developers & manufacturers

These stakeholders should be informed on the practical applications of various seaweed-based ingredients. More specifically to their profession, should be informed about the technical capabilities of the ingredients as can be supplied by the seaweed industry. Furthermore, the (future) capabilities of the supply chain should become available to enable them to assess when and in what quantities seaweed-based ingredients become relevant to them. Again this should be included in the respective downstream industry roadmaps. Nevertheless, information websites, social media campaigns and visibility at industry events are important ways to spread this awareness under this group of stakeholders.

4.1.3 Seaweed producers & processors

Seaweed breeding: informing seaweed farmers what species are available for their conditions as well as market potential

Seaweed production & conservation: informing producers with an overview of state-of-the-art production methods as well as pre-processing and conservation methods to be able to supply to various processors/market applications

Seaweed processing & sidestream valorisation: informing seaweed processors of the potential users of side streams and their requirements w.r.t. traceability, datasheets, specific application requirements for each side stream.

4.1.4 Students

Integrating seaweed into education ensures that future generations of researchers, engineers, and entrepreneurs are equipped to advance the sector. Existing curricula can be enriched with seaweed-based case studies and applications (for instance, natural polymers in materials engineering, seaweed-derived ingredients in nutrition, or aquatic flora in biology). More ambitious initiatives include the creation of dedicated courses, MOOCs, and even entire degree programmes in seaweed cultivation and the broader blue bioeconomy.

Beyond formal education, summer schools and camps offer young people early exposure to seaweed and aquaculture, normalizing the sector as a relevant and attractive career path. Students, particularly those from coastal communities, can also be actively involved in collaborative research projects, giving them a stake in the development of solutions for resilient marine ecosystems.

4.1.5 Governments and Communities

Local and regional governments play a vital role in enabling capacity building through policy support and visibility. Roadmaps such as these go a long way in informing policy makers on all levels. Furthermore, specific events such as work visits to seaweed industry members prove to be very useful to informing them. If these are properly coordinated with information from the roadmaps and with policy makers on regional and national level and the respective industry players in that region, it can form a powerful method.

4.2 Infrastructure

4.3 Investment milestones

5 Roadmap Milestones 2050

Here should the outcomes of the Deltares modelling be included – check Lauriane for update

6 Do’s and Don’ts

6.1 Do’s:

- Valorize all elements of your seaweed by finding markets for your sidestreams. (e.g. in biomaterials, feed or biochar)
- Cater your production (yield, composition, processing) to your target market, through partnerships and market research.
- Co-operative business model for smaller farms -sharing a centralised processing facility that adds value and allows for sale of larger volumes.
- Co-Use with Other Sectors:
  - Collaborate with other aquaculture industries through co-use of infrastructure (nets, boats etc.) or Integrated Multi-Trophic Aquaculture (IMTA).
  - Establish synergies with other offshore industries (i.e. wind farms, fisheries) to reduce costs through shared infrastructure, transport, and knowledge.
- Use integrated modelling tools to determine areas with a high potential for seaweed farming.
- Automate seeding and harvesting through direct seeding to decrease costs.
- Concentrate on a single market rather than multiple.
- Explore marketability of specific species.
- Integrate vertically through acquisitions or joint ventures.
- Find your Unique Selling Points (USP’s)

6.2 Don't:

- Focus on producing seaweed without securing buyers – find market commitment
- Try to re-invent the wheel – communicate with each other about what works and what has been done.
- Follow a linear development approach – find the role of seaweed in the circular economy context.

7 Recommendations

This report and enclosed roadmap is intended as a living document. Therefore, we include recommendations for next steps to further develop this roadmap and its feasibility through time.

The following is recommended:

- Continue to innovate and explore new cultivation methods in different locations across Europe (off- and nearshore)
- Harvesting methods must fit the end-use: manual harvests suit small-scale or high-value uses, while mechanical systems increase throughput but require adaptation for delicate Ulva thalli (NSF: yes, for Ulvans but this very likely will apply to onshore production methods in general) [3].

[3] Roadmap database item 6

8 Annexes

8.1 Modelling Tools of Interest

- *EMODnet Human Activities portal (https://e modnet.ec.europa.eu/en/human-activities)*

Locates existing seaweed cultivation sites

- *Blue2MF*

Integrated biophysical modelling tool using environmental data. Explores management and policy consequences on marine ecosystems.

- *Copernicus Marine Environmental Service Model*

Provides open and free marine data and services for enabling Implementation of marine policy, support Innovation and blue growth.
In-situ data and forecasts on physical and biogeochemical ocean parameters
http://marine.copernicus.eu/

- *WOMAPP (world offshore macro algae production potential)*

Set of r-scripts to estimate global offshore seaweed production potential
van Oort, P. A. J., Verhagen, A., & van der Werf, A. K. (2023). World Offshore Macro Algae Production Potential (WOMAPP) code. Software, Wageningen University & Research. https://doi.org/10.5281/zenodo.7598569

8.2 Initiatives that strengthen the seaweed sector:

1. *Farm to Fork*
Policy level: part of the European New Green Deal to accelerate the transition to more sustainable, healthy, and fair food system. (European Commission, 2012).
2. GENIALG & SeaMark
Research project providing Input for sustainable production and harvesting of (macro)algae In Europe.
3. NETALGAE
4. INTERREG?
5. OCEANIUM
6. CIRCALGAE
7. KELP-EU
8. GenialG
9. AquaVitae
10. AlgaePro Banos
11. ASPIRE

8.3 Interview data

8.4 Mapped out suitable areas for seaweed cultivation

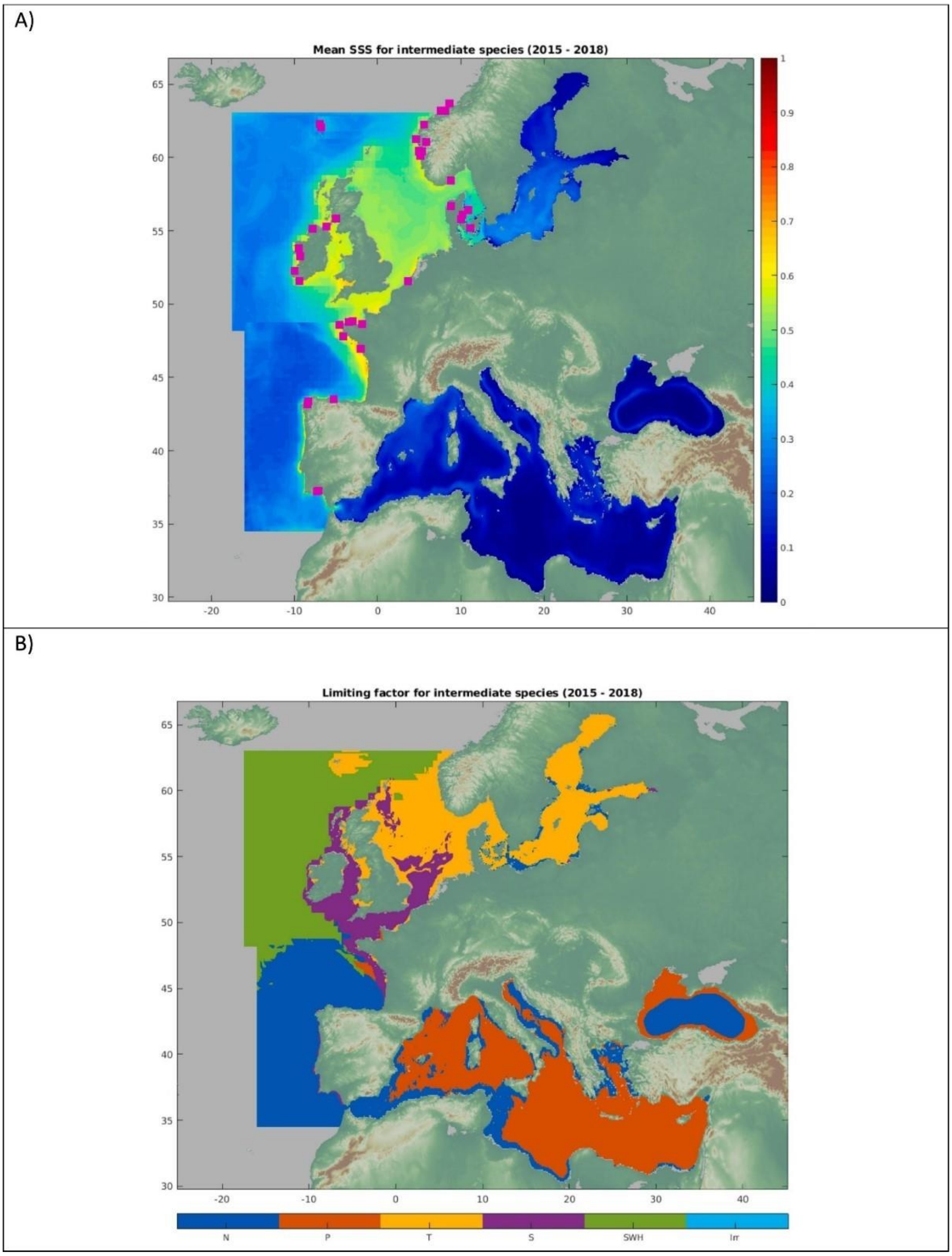
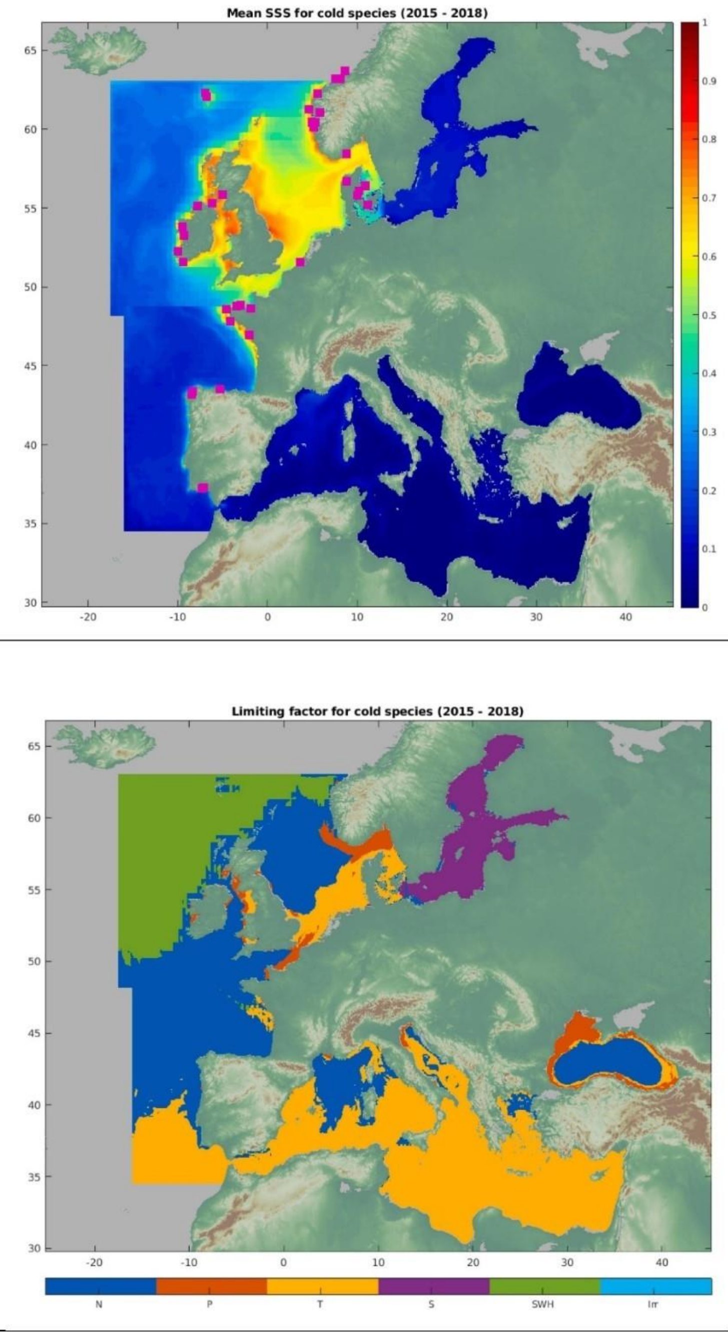


Figure A1: Mean Seaweed Site Suitability for intermediate seaweed species in the EU marine regions. Known seaweed cultivation sites are marked in Figure A above. B shows the main limitation for the intermediate species, where N = nitrate, P = phosphate, T = Temperature, S = salinity, SWH = significant wave height, and irr = irradiance, taken from: (Macias et al., 2025)

A)



B)

Figure A2: Mean Seaweed Site Suitability for cold seaweed species in the EU marine regions. Known seaweed cultivation sites are marked in Figure A above. B shows the main limitation for the cold species, where N = nitrate, P = phosphate, T = Temperature, S = salinity, SWH = significant wave height, and Irr. = irradiance, taken from: (Macias et al., 2025)