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Deliverable 2.4

Updated Report on the Blue Bioeconomy Value Chains

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Abstract	Blue Bioeconomy values chains across the BBC partner regions that were first defined and collated in D2.1 are updated, expanded and added to, in this report. First, the Blue Bioeconomy is characterized and presented in terms of its value chains with particular focus on side streams. Secondly, updates across the BBC project regions are presented to give an overview of blue bioeconomy activities and their side streams in practice, including the knowledge gaps and barriers to development.
Keywords	BlueBioClusters, Blue economy, Value Chains, Side streams

1. Introduction

This deliverable is an update to Deliverable 2.1, which presented an initial overview of the blue bioeconomy value chains of the BBC project partners, including examples of companies operating across the value chains. Here, we present an overview of the blue bioeconomy in the EU (sections 1.1 to 1.3), we expand on the side-stream component of the BBC value chains, highlighting their potential (sections 2.1 to 2.3), and provide an update to the activities in the blue bioeconomy from each partner country including the gaps and barriers to expansion (sections 3.1 to 3.9) (an overview is available in Appendix 1).

1.1 The Blue Economy in the EU

The Blue Bioeconomy sits within the larger economic field of the Blue Economy, which generates billions annually in Europe alone (see Table 1). Traditional maritime activities like fisheries, oil and gas extraction and shipping belong to the wider Blue Economy. The EU Blue Economy Report 2024 defines the Blue Economy as economic activities that are:

> (a) marine-based, including those undertaken in the ocean, sea and coastal areas, such as capture fisheries and aquaculture, offshore oil and gas, offshore wind energy, ocean energy, desalination, shipping and maritime transport, and marine and coastal tourism; and
>
> (b) marine-related activities which use products and/or produce products and services for the ocean and marine-based activities; for example, seafood processing, marine biotechnology, shipbuilding and repair, port activities, maritime communication, maritime equipment, maritime insurance and maritime surveillance." (European Commission, 2024)

This definition does not include but mentions related sectors such as national defence, coast guard, environmental protection, education and research, as well as some ecosystem services like carbon sequestration and climate regulation. However, the report acknowledges that in the blue economy, innovations are rapidly developing in the field, for example, in terms of blue biotechnology (European Commission, 2024). Blue Bioeconomy activities like algae farming fall under this category.

The report recognises seven established blue economy sectors, including marine living resources, marine non-living resources, marine renewable energy, port activities, shipbuilding and repair, maritime transport and coastal tourism.

Table 1 indicates that in 2021, the direct Gross Value Added (GVA) of the Blue Economy sectors amounted to €171.1 billion, representing 1.3% of the EU-27 economy. This is a 35% increase from €126.6 billion (1.0% of the EU-27 economy) in 2020. Despite this strong recovery following the pandemic, the 2021 GVA still fell short of the 2019 value of €186.8 billion. The turnover in the EU Blue Economy rose by 21%, from €513.2 billion in 2020 to €623.6 billion in 2021. Employment in Blue Economy sectors grew by 17%, from 3.07 million people in 2020 to 3.59 million in 2021. Fig. 1 shows the developments in the Blue Economy established sectors between 2015 and 2021.

Table 1. EU Blue Economy established sectors, main indicators, 2021 (European Commission, 2024).

Indicator	EU Blue Economy 2021
Turnover	€623.6 billion
Gross value added	€171.1 billion
Gross profit	€76.4 billion
Employment	3.59 million
Net investment in tangible goods	€6.75 billion
Net investment ratio	8.8%
Average annual salary	€26 400

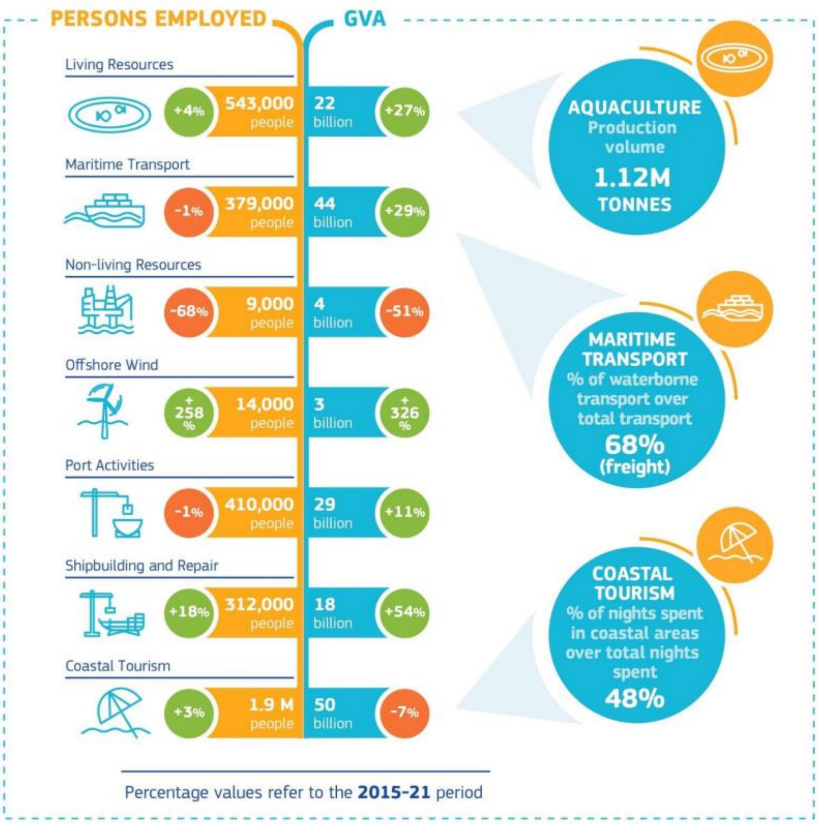


Fig. 1. The EU Blue Economy established sectors 2021 (European Commission, 2024).

1.2 Blue Biotechnology in the EU

The blue bioeconomy, as described in the EU Blue Economy Report, is referred to as blue biotechnology and offers significant potential to address global challenges in human health, food security, energy sustainability, and environmental protection. By utilising marine biodiversity, technological innovation, and collaboration, it could deliver economic and societal benefits while sustainably using marine ecosystems. Key applications include:

- **Development of novel therapeutics:** Marine organisms produce bioactive compounds with potential applications in pharmaceuticals, including antimicrobial, anticancer, and anti-inflammatory agents.
- **Nutraceuticals and functional foods:** Marine-derived ingredients, rich in omega-3 fatty acids, antioxidants, and vitamins, can be used in health-focused foods and dietary supplements.
- **Bioenergy and bioremediation:** Marine microorganisms and algae can be harnessed for biofuel production (biodiesel, bioethanol) and to clean up marine pollution, supporting sustainable energy and environmental conservation.
- **Bioprospecting and biodiversity conservation:** Exploring marine biodiversity can uncover new species and genetic resources with commercial value, promoting conservation and sustainable resource use.

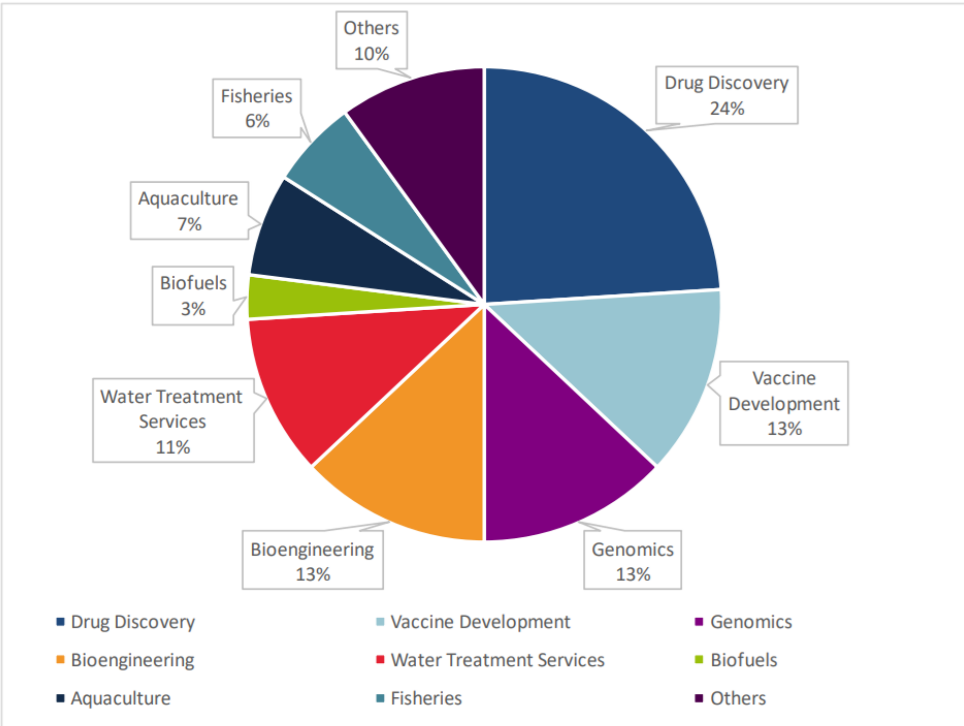


Fig. 2. Blue biotechnology market value by application, 2021 (European Commission, 2024).

Blue biotechnology promises considerable growth potential in Europe and worldwide, driven by increasing demand for sustainable resources, technological progress, and economic benefits for coastal communities. Measuring its economic value is challenging, though, as it is a new and rapidly developing field. Estimates on the global market value range from €2.5 to €3.9 billion. Within the EU, the market value is estimated at €868 million in 2021 and projected to reach €1.78 billion by 2032, with Germany and France making up just over half of that market value (see Fig. 3).

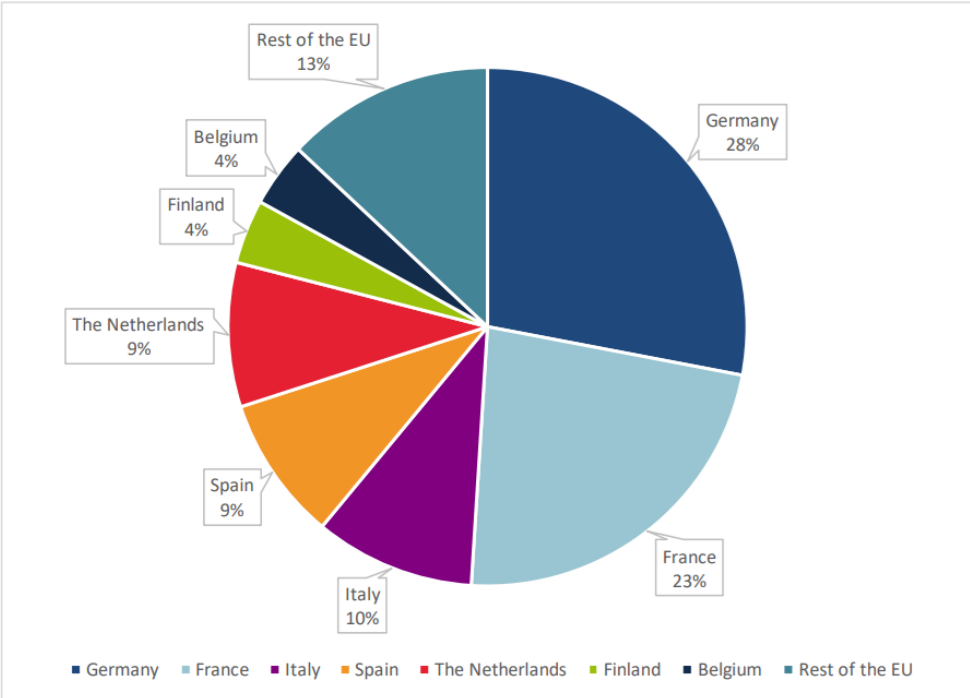


Fig. 3. Market value of the Blue Biotechnology by EU Member states, 2021 (European Commission, 2024).

As a fast-growing sector, blue biotechnology is gaining interest from venture capital. Private funding in blue biotechnology reached €184 million in 2023. Around 95% of these investments were directed toward startups specializing in seaweed and algae, with diverse applications such as pharmaceuticals, food, feed additives to reduce methane emissions in cows, biomaterials, and biofuels (see Fig. 4)

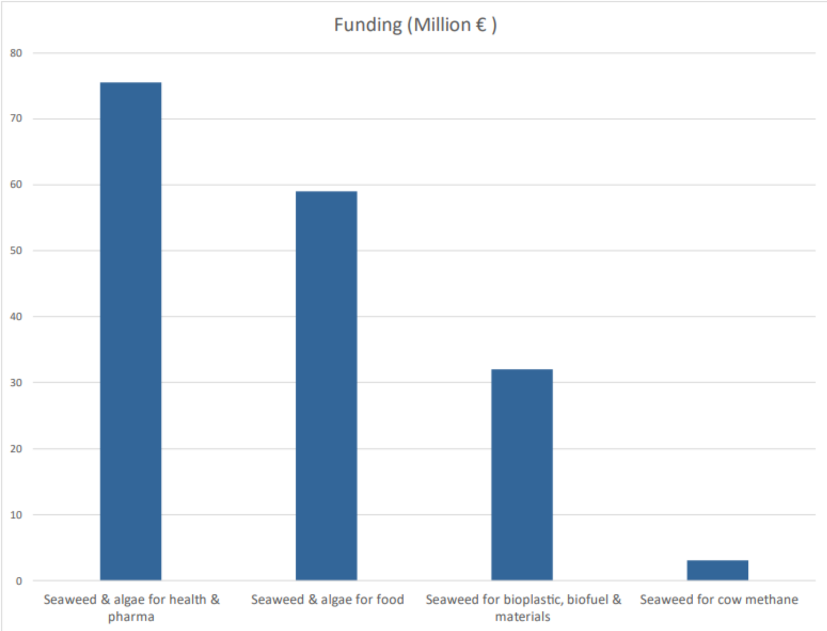


Fig. 4. Blue Biotechnology funding by product category (European Commission, 2024).

1.3 Value Chains in the Blue Bioeconomy

Value chains in the blue bioeconomy refer to the series of interconnected activities and actors involved in developing, producing, and distributing products and services derived from marine resources. These value chains encompass the entire lifecycle of marine-based products, from resource extraction or cultivation to end-user consumption and disposal. However, the value chains are complex and difficult to describe, as they often interlink, and what could be described as the main value chain could be a side stream in another context. This makes the overall valorization of those value chains and side streams challenging. In the BlueBioClusters project, we focused on six categories of biomass utilized by blue biotechnology sectors; Fish, Bivalves, Microalgae, Macroalgae, Crustaceans, and Marine Bacteria. Information on the value chains for each BBC project partner, updated from D2.1, can be found in Appendix 1 and includes the value chain by country, biomass, cultivated/ wild harvest, pre-processing and processing techniques, extraction techniques, end product and side products/ other information.

2. Side Streams: Potential for Valorization

Side streams utilise secondary yield or secondary products, such as heads, skins, bones, guts, shells, stems/ holdfasts, that are often not considered as part of the primary product from blue bioeconomy species. Research and development in blue bioeconomy sectors show the increasing usability and value of blue biomass byproducts (European Commission, 2019). Below, we provide an overview of side-stream innovation across fish, micro- and macroalgae, and shellfish processing.

2.1 Side streams in fish processing

The commercial capture fisheries sector generates substantial waste from discards/ bycatch and by-products during pre-processing, processing, and preservation (World Economic Forum, 2024). These materials are often discarded or underutilized, but they present significant opportunities for sustainable valorization in the form of side streams. By efficiently recovering valuable components from by-products, we can reduce waste and unlock their potential for various applications, enhancing both economic and environmental outcomes. Below is a general overview of the side stream possibilities in fish processing, and Section 3 provides examples from BBC project regions of how these side streams are developing.

The side streams generated during fish processing include heads, fins, tails, bones, skin, viscera (internal organs), dark muscle, and blood. These by-products are rich in valuable nutrients, such as proteins, collagen, essential fatty acids, omega-3 fatty acids, and minerals. For instance, fish heads, bones, and skin are particularly rich in collagen and essential fatty acids, while the viscera are nutrient-dense, containing proteins, fats, and essential minerals. Dark muscle, on the other hand, is high in fat and omega-3 fatty acids, which are of significant value for health-related products. Other components, such as fins, tails, and blood, carry nutritional value that can be further utilized across different value chains. There are innovations gaining momentum in this area, such as the Iceland Ocean Cluster 100% Fish movement. 100% Fish shows the potential economic value that can be created out of utilization of by-products, and the replicability of this type of model.

Protein recovery is one of the ways in which side streams can be valorized. A process called enzymatic hydrolysis, for example, can break down proteins in these side streams, producing high-quality protein hydrolysates that are suitable for both human and animal consumption. These hydrolysates contain essential amino acids and bioactive peptides, which may offer health benefits. Additionally, the fatty acids present in dark muscle can be extracted for use in supplements or as fish oil for animal feed. Another significant opportunity lies in the recovery of collagen and gelatin from fish skin and bones, which are valuable in industries like food, cosmetics, and pharmaceuticals. Fishmeal and silage production also provide sustainable sources of protein for animal feed, contributing to a circular economy by reducing waste and maximizing the value of marine resources.

Various technologies are being used or developed for the extraction of these components. Enzymatic hydrolysis is a commonly used method to break down proteins, enhancing the recovery of bioactive peptides and amino acids. Chemical processing techniques, such as acid or alkaline hydrolysis, also help to extract proteins and oils, while fermentation processes utilize microorganisms to convert fish side streams into products like silage or bioactive compounds.

The products derived from valorizing fish processing side streams can be used in a wide range of applications. For instance, nutrient-rich proteins and oils can be incorporated into food products, dietary supplements, or nutraceuticals. Fishmeal, hydrolysates, and silage are increasingly used as sustainable ingredients in animal feed for both livestock and aquaculture. Collagen and gelatin, extracted from fish skin and bones, are also in demand for their use in cosmetics, skincare, and medical applications, such as wound healing. The marine collagen market is currently worth $1.0 billion and is projected to reach $1.6 billion by 2023.

The environmental and economic benefits of valorizing fish side streams are substantial. By reducing waste through the extraction and use of valuable components, the environmental impact of fish processing can be decreased. Making use of side streams also makes the blue economy more sustainable by implementing more circular models as well as increasing the economic value of fish processing (Sasidharan et al., 2023).

2.2 Side streams in micro- and macroalgae processing

Side streams can also be used for adding value to waste products in algae processing and cultivation. Algae are highly efficient at photosynthesis and can grow rapidly in inexpensive environments, including effluents from aquaculture and seafood processing. These algae not only degrade organic waste like unused food and excretory products but also remove pollutants such as CO2, ammonia (NH3), and hydrogen sulfide (H2S), which can help address environmental pollution. This section presents a general description of side streams in micro- and macroalgae processing, with examples from the BBC partner regions in Section 3.

One of the products derived from an algae-based biorefinery approach is Single-Cell Protein (SCP), which is a biomass rich in proteins, vitamins, lipids, and other beneficial nutrients. SCP is produced by microorganisms, including algae, and offers advantages over conventional protein sources, such as the short generation times and the ability to use inexpensive growth media. Algae grown in seafood processing effluents can yield SCP with protein content ranging from 40% to 60%, along with lipids and minerals, making it valuable for animal feed, human nutrition, and biofuel production (Venugopal, 2022; see Fig. 5).

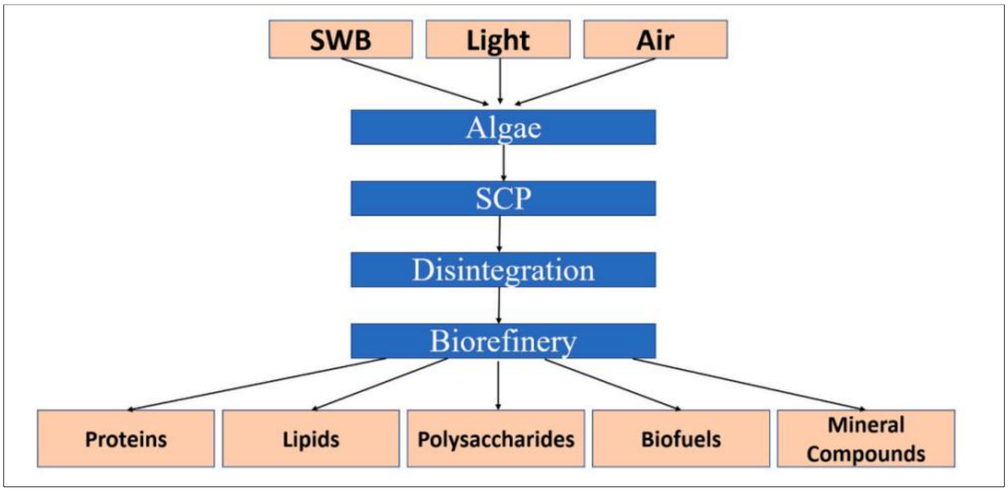


Fig. 5. Value-added products from SWB (seafood waste biomass), algae-based biorefinery (Venugopal, 2022)

Microalgae, like *Haematococcus pluvialis*, cultivated in fish processing water can produce SCP rich in pigments, such as astaxanthin, which are valuable in the nutraceutical and food industries.

The wastewater from seafood processing can be utilized as a growth medium for algae, leading to efficient biomass production. It has been estimated that large volumes of seafood industry effluents could be used to produce significant amounts of SCP, making algae cultivation a viable solution for waste management and resource recovery.

After the algae are harvested, valuable compounds like proteins, lipids, and pigments can be extracted using various methods, such as enzyme-assisted extraction, supercritical fluid extraction, and microwave-assisted methods. Membrane filtration techniques also provide options for separating and purifying bioactive compounds, which can be used in nutraceuticals, biofuels, or other chemicals.

The algae-based biorefinery approach helps maximize the use of seafood waste by transforming it into multiple value-added products, including proteins, biofuels, biofertilizers, and high-value chemicals. The concept of a biorefinery process is similar to petroleum refineries, where waste biomass is converted into valuable products through a series of processes. Algae-based biorefineries are gaining attention because of their versatility and ability to produce a wide range of products from the same raw material.

2.3 Side-streams in shellfish production

The biorefinery approach is also applied to generate side streams from shellfish production. For example, chitin (a biopolymer) can be recovered from crustacean shells and transformed into chitosan and other products, while proteins and lipids can be extracted for use in various industries. Furthermore, enzyme-assisted bioconversions play a key role in extracting useful components from seafood waste. For example, enzymes can help break down chitin from shellfish or extract proteins from fish waste. Other green technologies, such as isoelectric solubilization precipitation (ISP), can be used to recover proteins from seafood discards (Venugopal, 2022). An example of a full product approach is the 100% Shrimp project, a collaboration between Royal Greenland, Primex, and Iceland Ocean Cluster which aims to close supply chain gaps for chitosan production, and develop a blueprint for other seafood companies.

3. Blue Bioeconomy Value Chains: Updates from the BBC Regions

Throughout the project, several key themes have emerged that connect the stories of blue bioeconomy value chains across the BBC region. While the development of blue bioeconomy activities is at different stages in each country and region, many start-ups, small businesses and other organisations are forming business clusters, knowledge exchange platforms, hosting discussions, bootcamp events or incubators to share knowledge, expand skills and support the development of the blue bioeconomy sectors. This trend seems to be a response to the many barriers that blue bioeconomy businesses encounter in their operations. For example, practitioners often find themselves hindered by local legislation, either around licensing, i.e. for seaweed farming or regarding product development, as well as difficulties attracting investors and establishing markets for their products, despite active research and innovation activities in nearly all regions.

The following section highlights the status quo and recent developments as well as identifies gaps in the blue bioeconomy value chains and related operations across the BBC Regions.

3.1 Belgium

Belgium has seen the development of its first mussel farm, Zeebeorderij Westdiep, owned by Colruyt Group in the North Sea over the course of the BBC project, with its first harvest in the summer of 2023. While the farm is still evolving, its current production remains low and faces logistical challenges, such as securing the right vessels and specialized crew. However, it could pave the way for more offshore cultivation in the future, despite the significant challenge of competing interests in the Belgian North Sea, such as shipping, military activities, and fishing. As production scales up, the potential for utilizing its side streams—such as shells and byssus—will increase. However, production levels are currently too low to establish a robust supply chain for these byproducts, as is the case for most mussel producing nations.

On land, aquaculture production remains limited in volume. However, there is growing activity in the microalgae sector, particularly on agricultural farms. Microalgae are emerging as a more environmentally friendly food source and a precursor of valuable bio-compounds for health applications. Nevertheless, challenges persist, including legislative barriers to side-stream usage, which restrict market access for human consumption and novel food applications.

There are few fish and shrimp farms operating in closed systems, and they remain relatively small in scale. The recent closure of Belgium's largest RAS (Recirculating Aquaculture System) fish producer (100 tons) has highlighted the economic challenges of fish farming. However, farmers and technology suppliers are actively seeking and developing solutions to scale up land-based aquaculture. Additionally, efforts should be made to raise consumer awareness to ensure a fair market price for sustainably farmed fish.

The Blue Cluster aims to support the blue bio sector by assisting with innovation projects. These initiatives should facilitate more profitable aquaculture and fisheries production, promote the integration of blue bio production within the sector and with other industries, encourage investments in bioprospecting tools, and enhance financial rewards for the ecosystem services provided through blue bio production.

3.2 Estonia

In recent years, the blue bioeconomy has gained increasing attention in Estonia, particularly in coastal regions and specifically on the island of Saaremaa. This growing interest has been driven in part by EU funding and various projects aimed at fostering sustainable marine-based economic activities. Several awareness-raising events have been organized to engage a wider audience, including minority communities. Examples include the Blue Economy Seminar held in Saaremaa in February 2023 and the Blue Bioeconomy and Innovation workshop in November 2024. The adoption of a Communities of Practice approach in Saaremaa has helped unify local stakeholders, encouraging collaboration in the sector. The D6.4 Blue Bioeconomy Action Plan report provides a detailed analysis of regional initiatives and future strategies, with a focus on Saaremaa.

The Agriculture and Fisheries Development Plan 2030 (Government of Estonia, 2021) outlines Estonia's nationwide approach to fostering sustainable fisheries and aquaculture. Estonia possesses favorable conditions for fishery and aquaculture production, including available fish stocks, water resources, and land. However, the development of offshore aquaculture is hindered by unfavorable climatic conditions, the ecological status of the Baltic Sea, and a complex and time-consuming permitting process for marine infrastructure. Despite these challenges, sustainable marine aquaculture is seen as a crucial regional development measure that can help create and maintain jobs in rural areas while attracting investment beyond major urban centers.

Estonia aims to expand offshore aquaculture, with a strategic goal of increasing offshore fish farming production to 10,000 tons annually over the next five years. The guiding principle is that fish fry should primarily be cultivated in land-based aquaculture facilities before being introduced to marine environments.

Estonia currently has one marine-based fish farm combined with shellfish farming, located in Tagalaht Bay (Saaremaa). The mussel farm, established in 2019, has so far been used only for scientific research purposes.

Additionally, Estonia has one industrial seaweed processing company, AS Est-Agar, which has been harvesting red seaweed (Furcellaria lumbricalis) in Kassari Bay since 1966 (AS Est-Agar, n.d.). The company specializes in producing furcellaran, a valuable hydrocolloid. Seaweesh, a subsidiary of Est-Agar, was founded to develop innovative solutions using residual red seaweed biomass, aiming to create sustainable alternatives to petroleum-based plastic packaging.

Another company, Vetik, is advancing the use of seaweed-based biostimulants in agriculture, contributing to more sustainable and eco-friendly farming practices (Vetik OÜ, n.d).

The Ministry of Climate of Estonia (2023) commissioned the Business Plan Analysis of Mussel and Seaweed Farming to assess the economic feasibility of mussel and seaweed cultivation in Estonia. The report identifies two main sectors within the country's marine aquaculture industry:

1) Marine-based activities, including the cultivation of seaweed and mussels.

2) Land-based processing, which involves refining raw materials into higher-value products.

The predominant business model in Estonia’s aquaculture sector—whether for shellfish, seaweed, or fish farming—is Business-to-Business (B2B). In this model, companies engage in aquaculture operations and, when necessary, conduct initial processing (such as cleaning, drying, and chopping). These processed raw materials are then sold wholesale to other businesses that further refine them into intermediate or final products for commercial sale. Estonia’s blue bioeconomy sector continues to evolve, with growing investments in marine-based resources, innovative bioproducts, and sustainable aquaculture practices aimed at strengthening the country’s position in the circular economy.

3.3 France

In France, blue bioeconomy activities have a major economic impact on coastal areas. The production of shellfish, fish and other protein sources in inland and coastal waters is an age-old activity, notably in the regions of Brittany and Pays de Loire on the Atlantic coastline. The development of the value chains in the sector provides employment locally as well as significant technological development. With its coastline, its diversity of fish stocks, its producers, its processors, its scientific community and the various economic sectors that make use of seaweed in all its forms, France is now one of the great seaweed nations of the 21st century. It is the leading producer of algae in the European Union. In addition to production, France is also an area of development, with dynamic players in all areas of seaweed potential (food, agriculture, industry, environment, etc.).

Fishing, aquaculture, and biotechnology sectors aim to use marine resources in a way that meets growing food demands while also contributing to the diversification of raw materials. This diversification benefits various industries, such as cosmetics, healthcare, and materials production, by expanding the range of marine-based resources used across these sectors. Strategically, players in the field of marine biological resources are increasingly committed to meeting environmental challenges while preserving their economic profitability. Many focus on limiting their environmental impact and reducing operating costs, especially for fuel, as well as developing efficient cultivation processes.

The French West regions have major strengths in these areas across the entire value chain, including: research skills in the chemistry and biology of marine organisms, marine organisms physiology, analytical skills (biochemistry of poly-oligo-saccharides), platforms and companies for screening and assessing the activity of active molecules the activities of active molecules, manufacturers with the potential to use these molecules in food. In Brittany and Pays de la Loire regions, some of the innovations are focused on: Biorefining of microalgae and cyanobacteria, Red algae and the treatment of haematological diseases, research into the bioactive metabolites of micromycetes.

Pôle Mer Bretagne Atlantique, a competitiveness cluster for the blue economy, brings together over 450 members, including start-ups, SMEs and mid-size companies, as well as large corporations, R&D companies, research consultancies and professional organisations. Activities engage with the full range of marine and freshwater production, including fish farming, macro- and microalgae cultivation, with a focus on sustainable development and innovation.

Sustainable fishing practices in France encompass all activities related to the exploitation of fishery resources and the entire production process, from commercial fishing (on foot, small-scale, deep-sea, and industrial) to the processing of catches (whole products, fresh, and processed foods). These fishing activities can also interact with recreational fisheries and with other users of the marine environment. Sustainable aquaculture in France includes fish farming, shellfish farming, algal farming (macro- and micro-algae) and integrated multi-trophic aquaculture, both offshore and onshore.

Regarding the development of blue biotechnology, the Blue Invest report states that among the EU countries, France stands out as leading this sector, commanding a significant share of 31.4% of the EU deals. France possesses the world's second-largest maritime territory – its coastline spans nearly 20,000 kilometers including overseas territories – and has a large ocean resource for developing marine technologies, as well as a business environment that is strongly supportive of start-ups via a well-established network of seed and early fund managers.

In the development of value chains in blue bioeconomy, French actors are focused on key innovation trends, such as, inland sustainable aquaculture, in which they aim at establishing new technical abilities, social acceptability, recirculation systems, aquaponic/hydroponic systems, life cycle assessments, waste and discharge management. There is also offshore sustainable aquaculture, harvesting techniques, growth and predation control systems, colocation with offshore renewables, and the development of biobased gears. Multi-trophic aquaculture and diversification is another main development area, including, LCA assessment, zero waste and circularity, long term stability, quality certifications and resilience.

3.4 Iceland

Iceland does not have a formal blue bioeconomy strategy, yet numerous projects, start-ups, and initiatives contribute to a dynamic and rapidly evolving marine bioeconomy with innovations and successes in side stream development both in fish as well as seaweed processing. Apart from the startups and SMEs that make up the bulk of blue bioeconomy companies here, there are also several large blue bioeconomy businesses, e.g. Marel, Brím, Hampiðjan, that were founded in Iceland but operate all over the world.

Iceland is spearheading the development of whitefish side streams with the Iceland Ocean Cluster (IOC) reporting that 90% of the cod landed in the country is fully utilized. In comparison, international estimates suggest that up to 43% of captured fish and shellfish resources globally are discarded or wasted. In 2012, seven fishing and ocean-related companies founded 'Codland' with the objective of maximizing the value of all parts of cod. Within ten years, the initiative has turned fish waste into valuable products including marine collagen, mineral supplements, and fish oil. The now global 100% Fish movement similarly aims to utilize every part of fish caught or raised across the value chains. The IOC is adapting the lessons learned from the success of cod and is applying them across various seafood sectors, including salmon—an important and rapidly growing blue bio value chain in Iceland with both sea cage and land-based production. Another example of valorizing side streams has been developed by Kerecis, a company using fish skins for medical skin grafts and surgical products for human and animal tissue regeneration of wounds. This model is now being adopted globally.

A new and developing area of investigation and learning is the emergence of AI technologies. Their applications was discussed in the technology seminars as enabling actors in information, prediction, decision making and supporting the blue bioeconomy.

Beyond fish processing, seaweed and algae processing and farming are a growing focus of blue bioeconomy activities in Iceland. Most actors in this sector are smaller businesses in the early stages of development. The Iceland Ocean Cluster (IOC) conducted a bootcamp event with Swedish partners around the question of how those value chains can be further developed to strengthen this emerging industry. To date, there are significant gaps in legal frameworks for establishing seaweed farms. Icelandic law only covers the wild harvesting of seaweeds, so there is no legal process to farm at sea which presents a significant barrier for the sector. Microalgae farming has been launched in Iceland, for example, the Blue Lagoon produces them as ingredients for cosmetics. Another company, Vaxa Technologies is producing high-end spirulina using run-off heat from a geothermal power plant, ON. However, the cost of production is currently too high to make these ventures economically feasible, despite considerable demand from industries producing livestock feed.

3.5 Lithuania

Overall. Lithuania’s bioeconomy sector is expanding, focusing on the sustainable use of biological resources across various industries. Within this broader bioeconomy, the blue bioeconomy is in its early stages but a rapidly growing sub-sector, primarily concentrated in the Klaipėda Region, with significant academic involvement. It focuses on marine and freshwater resources, including the use of microorganisms, algae, shrimp and fish biomass for food, feed, pharmaceuticals, cosmetics, packaging and other applications.

In 2021, Lithuania’s blue economy employed about 26,600 people and generated €782 million in Gross Value Added (GVA) (European Commission, 2021), with shipbuilding and living marine resources being the largest sectors. Although it contributes just 0.1% to turnover and GDP, the blue bioeconomy has seen significant growth in labor productivity, turnover, and exports. The rising demand for fish and aquatic products is boosting the potential for aquaculture, which is expected to grow by 34.2% by 2025, helping to manage fish quality and increase valuable fish species in ponds and closed systems.

The Marine Research Institute at Klaipėda University plays a crucial role in this development, driving innovation and providing scientific knowledge and infrastructure for blue bioeconomy initiatives. Another initiative, the Lithuanian Bioeconomy HUB, was launched in 2024 by Vytautas Magnus University and aims to foster collaboration across ministries, industry, and academia to enhance the country's competitiveness in the bioeconomy sector (BIOEAST, 2024). However, challenges remain, including gaps in investment and policy alignment. Further efforts are necessary to develop robust market mechanisms and consistent private and public investments for the blue bioeconomy.

3.6 Norway

The Norwegian blue bioeconomy, particularly within the white fish sector and its associated side streams, has seen notable advancements over the BBC project lifetime aimed at enhancing sustainability and resource efficiency.

The seafood sector in Norway represents an important sector for value creation both for inland activities and for Norwegian export. A total of 2.8 million tonnes of Norwegian seafood worth NOK 175.4 billion was exported in 2024. This corresponds to 38 million meals every single day - all year round. 2024 was characterized by quota cuts for cod, significant production challenges for salmon, geopolitical fluctuations and economic turmoil in the global market.

Norway exported more than 60 different species to over 150 countries around the world, and the most important species in value are salmon, cod, mackerel, trout and herring (Norwegian Seafood Council, 2025) In times where full utilization is high on the sustainability agenda combined with lower quotas and higher cost level in fisheries in general – utilization of residuals has gained traction and attention (see Fig. 6).

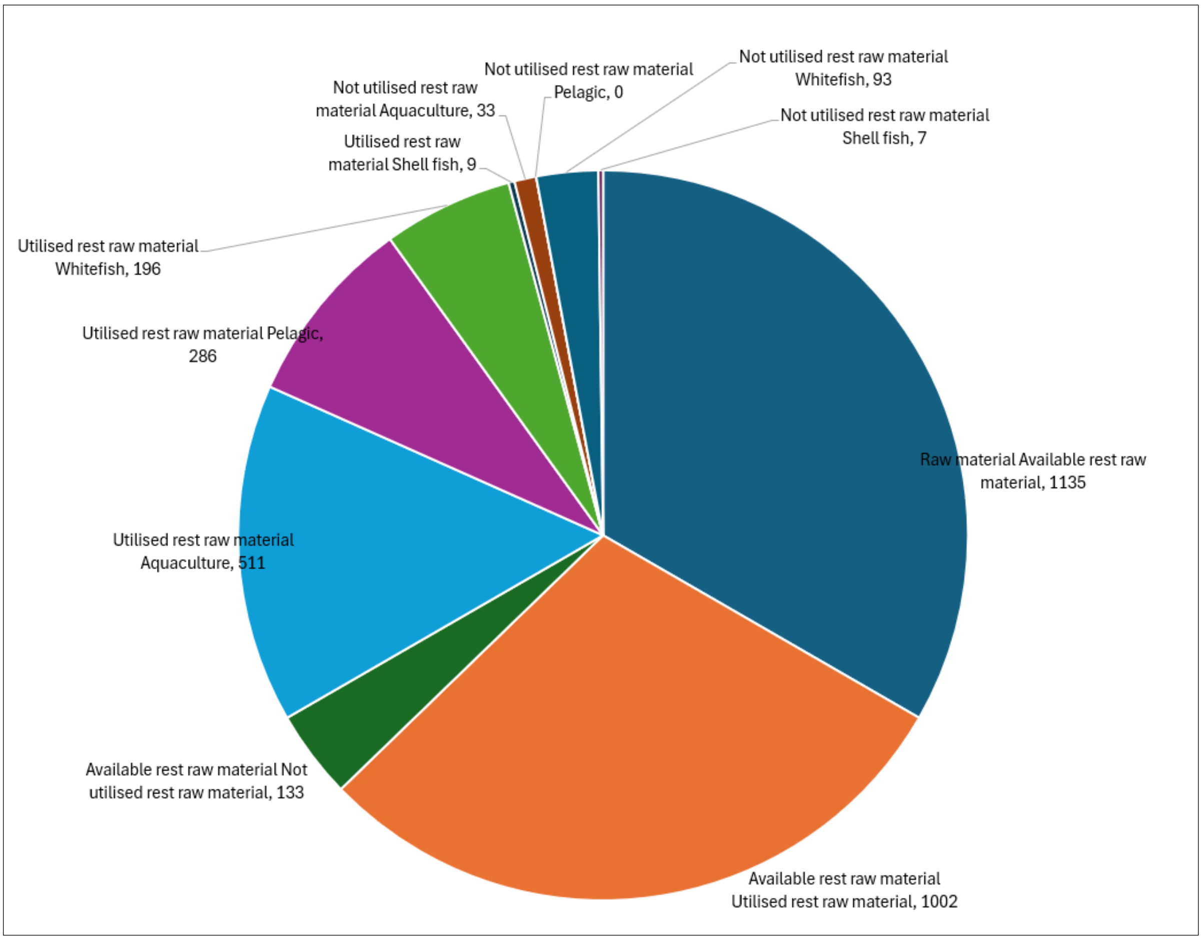


Figure 6: Utilization of fish residuals 2023 (1000 tons) (FHF, 2023)

Traditionally, Norway's white fish industry has focused on primary products, with significant portions of the catch—such as heads, bones, and viscera—often underutilized or processed into low-value products like animal feed or fertilizers. This approach has led to missed opportunities for maximizing the potential of these biomass resources that today are treated as residuals.

Efforts to enhance the utilization of white fish side streams have been bolstered by initiatives like the BIOSIRKEL project where the aim is to develop a platform for connecting different actors within the marine industry to increase the utilization of raw materials. This platform fosters collaboration among research institutions, businesses, and the public sector to develop new bioeconomic value chains. By connecting entities dealing with waste streams with those capable of utilizing them, BIOSIRKEL aims to improve resource efficiency and sustainability (NORCE, 2024).

Recent developments include:

1. Innovative Processing Techniques: Research initiatives, such as the VALORISH project led by Nofima, are exploring data-driven technologies to optimize the utilization of fish residuals. By developing methods and enzymes through AI technology, the project aims to transform side streams into high-value products for food, nutraceuticals, and dietary supplements (Nofima, 2025).

2. Regulatory and Market Navigation: Efforts have been made to assist seafood companies in navigating complex regulations and market structures. Comprehensive reports provide overviews of relevant regulations, certifications, and market challenges, facilitating the development of new products from residual raw materials and underutilized species (Nofima, 2021).

3. Sustainable Feed Initiatives: Projects like BlueMusselFeed are exploring the use of blue mussels as a sustainable feed ingredient for poultry. This approach not only recycles nutrients but also reduces reliance on imported feed, thereby decreasing the environmental footprint of Norwegian poultry production (NCE Seafood Innovation, 2023).

4. Collagen and Gelatin Production: Studies have demonstrated the potential of extracting high-quality collagen and gelatin from fish skins and bones. These products are in demand in the pharmaceutical, dietary, nutrition, and cosmetic industries, offering a profitable avenue for utilizing fish residues (Krogness, 2024). Ongoing projects and collaborations indicate a positive trend towards better utilization of these resources.

While innovative processing methods exist, implementing them on a large scale requires significant investment in technology and infrastructure. Many fishing vessels and processing facilities need upgrades to handle and preserve residual materials effectively.

Navigating the complex regulatory landscape for new products derived from fish side streams can be daunting. Companies often face challenges related to product classification, customs regulations, and obtaining necessary health certifications, which can impede market entry and expansion. There is a need to create and develop markets for products made from fish residuals. Consumer awareness and acceptance are crucial for the success of these products, necessitating targeted marketing strategies and education.

Addressing these gaps requires a continuous collaborative approach involving industry stakeholders, researchers, and policymakers to foster innovation, streamline regulations, and develop sustainable markets for high-value products derived from Norway's residuals from white fish exploitation.

Even if Norway's blue bioeconomy demonstrates resilience amidst challenges, with a notable emphasis on improving the sustainability and profitability of the white fish sector through innovative use of residuals from white fish processing, the work towards a stronger inclusion and collaboration with other countries and EU partners is essential. On a macro level, knowledge sharing and experience between BBC partners across all blue bio value chains give valuable insight and may speed up development for all member states. Also, for each BBC partner on a micro level basis, the BBC collaboration gives inspiration and ideas to strengthen relevant and targeted cluster activities in building a strong blue bio economy.

In light of the changes in the geopolitical landscape during the last months and the perspectives of a far less open global economy, the development of not only the Norwegian but also other BBC partners' blue bioeconomy is at risk. All blue bioeconomy value chains are highly dependent on a well-functioning global marketplace.

3.7 Portugal

Blue Bioeconomy activities in Portugal have been traditionally focused on fisheries for human consumption. The highest performing Blue Bioeconomy subsectors in the past decade were fisheries, aquaculture and canned products, which were mostly driven by the continuous increase in the value of export products. Portugal has a long tradition of consumption of white fish. The sources of these species are from national producers (aquaculture and fisheries), and also through imports. Portugal has the highest fish consumption in Europe, at 56.5 kg per capita (European Commission, 2023). This high consumption is largely driven by white fish, which has long been a staple of the Portuguese diet. White fish is valued for its high protein content and low fat. Frozen products dominate the market, with cod and hake being the most widely consumed species (MSC, 2024).

Blue Bioeconomy activities in Portugal have been increasing in areas such as biotechnology and the valorisation of byproducts from the seafood industry. With over 90% of its territory covered by the sea, Portugal has been advancing studies, research, and innovation across various industries to maximize the value of its bioresources. Portugal's main bioresources include bacteria, fungi, other microorganisms, microalgae, macroalgae, sponges, molluscs, other invertebrates, fish, and co-products from the fish industry. While there is growing interest in the Blue

Bioeconomy and the use of biotechnology for economic activities, fish remains the primary bioresource, utilized by 37% of stakeholders (see Fig. 7). However, only 8% focus on fish industry co-products. Microorganisms (bacteria, and fungi) are used by 36% of stakeholders, while algae (both micro- and macroalgae) account for 31%, primarily among SMEs and research institutions (Vasconcelos et al., 2019).

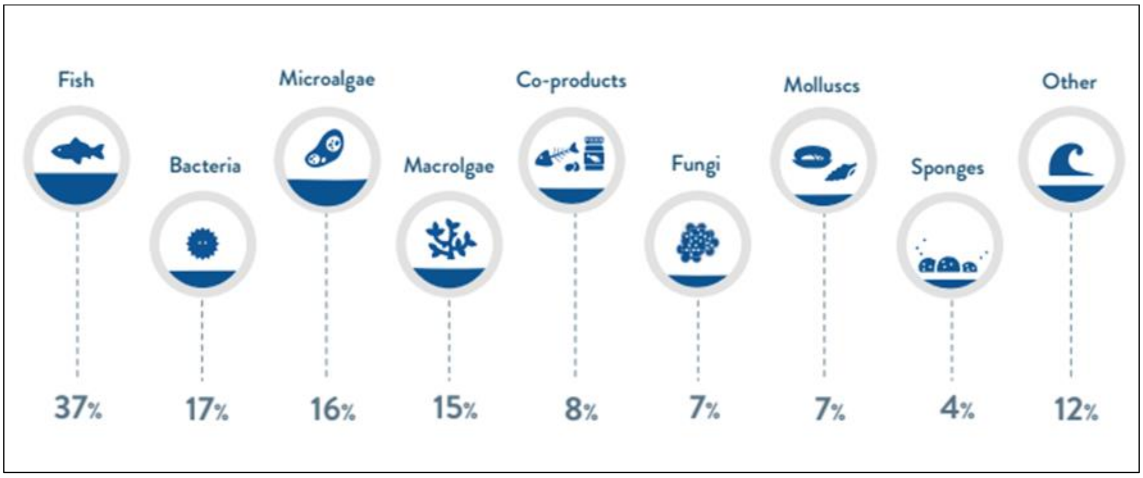


Fig. 7. Prevalence of different bioresources used by Portuguese Blue Bioeconomy stakeholders. Note that a single entity can use more than one bioresource (Vasconcelos et al., 2019).

The Blue Bioeconomy Roadmap for Portugal (Vasconcelos et al., 2019) outlines the growing importance of side-streams and co-products. These materials can either be used directly as final products or serve as raw materials for a wide range of applications. This process allows fishery stakeholders and aquaculture companies to unlock new chemical and structural diversity from bioresources, including microorganisms (like bacteria and microalgae) and macroorganisms (such as invertebrates, fish, and macroalgae). The potential of these side-streams is significant, with industries exploring them for a variety of applications, such as pharmaceutical research and development.

A wide range of industries, including pharmaceuticals, nutraceuticals, cosmetics, and feed, could benefit from converting waste streams into valuable products. This includes extracting chitin from crustaceans or developing bio-based chemicals and enzymes that contribute to more efficient and cost-effective transformation processes. The stakeholders in Portugal's Blue Bioeconomy are involved in numerous sectors, from food to bioplastics, medical devices, and textiles, with a significant number of businesses in the process of diversifying their application areas.

While food remains the dominant focus, accounting for nearly 50% of stakeholders, other fields like pharmaceuticals, cosmetics, feed, and nutraceuticals are also growing, each representing about 18% of the sector. There is increasing interest in the development of sustainable materials, such as bioplastics and biomaterials, driven by environmental concerns. Most of the stakeholders exploring these areas are SMEs and academic institutions, signaling the potential for innovation and expansion in these rapidly evolving fields (Vasconcelos et al., 2019).

Stakeholders in the Portuguese Blue Bioeconomy face several challenges throughout the value chain (Vasconcelos et al., 2019). A primary barrier is related to science, technology, and logistics, where gaps in knowledge, training, and scientific development hinder the creation, scaling, and implementation of new products and processes.

Cooperation is another major challenge, as there is limited exchange of data and resources between stakeholders, which prevents innovation and progress in the development of Blue Bioeconomy products. Communication and marketing difficulties also hold back the sector, with many stakeholders struggling to effectively promote their products, engage clients, and communicate their value. Similarly, market and consumer demand issues arise from a lack of understanding of how to develop products that meet market needs, as well as navigating competitor products and raising consumer awareness.

When it comes to funding and operational costs, stakeholders face challenges in accessing appropriate funding and developing cost-efficient processes that don't undermine business viability. Lastly, legal and regulatory barriers, including licensing, intellectual property concerns, and bottlenecks with public authorities, complicate the process of developing and commercializing new products.

3.8 Scotland

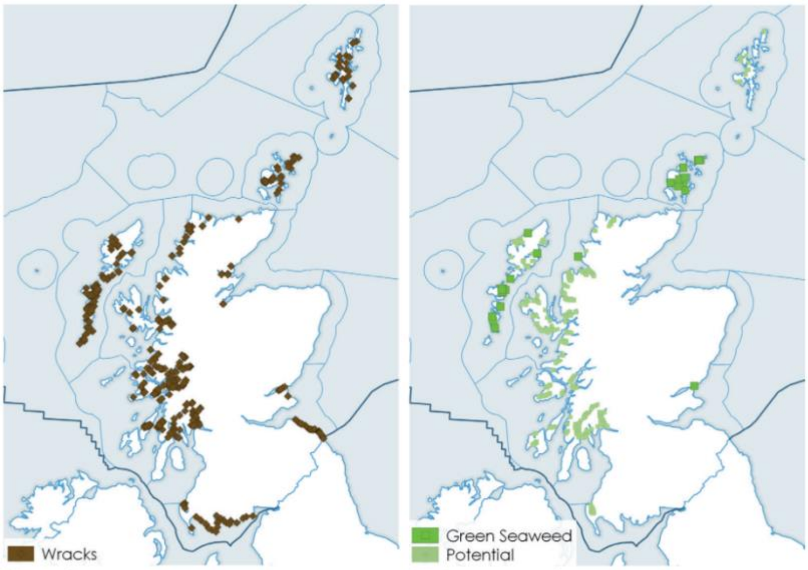
The Scottish blue bioeconomy is a dynamic sector with rapid developments and significant potential to utilize the country’s marine resources sustainably. In 2024, the Industrial Biotechnology Innovation Centre (IBioIC) secured another 10 years of funding (£35 million) to support the Scottish blue bioeconomy, indicating the momentum that the sector currently generates.

Scotland's shellfish farming sector plays an important role in growing the blue bioeconomy. In 2023, the industry achieved notable growth, with an estimated value of £14.1 million, a 36% increase from the previous year. The main species produced—common mussels and Pacific oysters—remained the focus, although production levels varied, with common mussel output reaching record highs (10,311 tonnes, an increase of 13%) and Pacific oyster production seeing a slight decrease (of 4%). While king scallop production fell, native oysters saw a modest increase. The number of mussel farming sites with sufficient spat settlement necessary for production purposes decreased from 88 to 54, and employment in the sector fell by 4%, with 246 staff members working in full-time, part-time, and casual roles. Despite these challenges, the sector continues to demonstrate resilience and growth (Marine Directorate, 2024).

Beyond shellfish farming for the market, there is also increased interest in restoring native oysters for re-wilding projects and to improve water quality. For example, the

Dornoch Environmental Enhancement Project (DEEP) which was launched in 2014 by Glenmorangie Distillery in partnership with Heriot-Watt University and the Marine Conservation Society is restoring native oyster reefs in the Dornoch Firth. They aimed to reintroduce 200,000 oysters by 2024 and want to establish a 40-hectare reef with four million oysters by 2030. These oysters will help purify water by filtering out waste, i.e. from the distillery's by-products, improving water quality and enhancing biodiversity. By 2023, the project had successfully introduced over 90,000 oysters, contributing to the restoration of the Firth's natural habitats and helping mitigate the environmental impact of distillation by-products (Drinks Initiative, 2024).

The macroalgae industry is another dynamic sector in Scotland's marine bioeconomy. Macroalgae occur naturally in Scotland and are particularly abundant in three geographical areas around the West and North of Scotland: in the Outer Hebrides, the Minch and Inner Hebrides, and the North coast of Orkney (see Fig. 8) (Marine Scotland, 2020).



(a) Wracks (b) Green seaweed

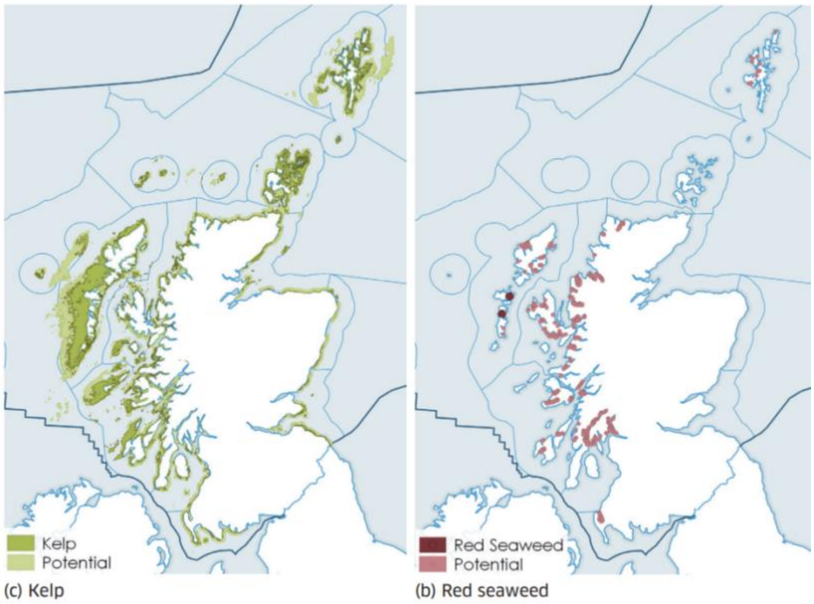


Fig. 8. Seaweed resource areas from 2016 Strategic Environmental Assessment (SEA) of wild seaweed harvesting (Marine Scotland, 2020).

However, seaweed harvesting and cultivation is currently limited in scale with many SMEs and micro-SMEs making up the majority of the sector. In 2020, the seaweed industry in Scotland was valued at an estimated £510,000 in Gross Value Added (GVA) per year and provided 59 jobs. The products derived from seaweed varied significantly, from lower-value processed forms used for example in animal feed to higher-end products such as foods for human consumption, biostimulants, and bioactive ingredients for the cosmetic, nutraceutical, and pharmaceutical industries (Marine Directorate, 2022). Recently most of the Scottish seaweed sector focus is on production of biostimulants and developing biorefinery approaches. There are also reports of first experiments with the production of biochar towards the end of the value chain, i.e. when varied other parts of the macroalgae and elements extracted had been used for higher value products.

Although there is significant interest in seaweed cultivation and development of various products, commercial farming in Scotland remains at an early stage. However, the number of applications for marine licenses and approved sites for seaweed cultivation is on the rise (Marine Directorate, 2022).

Though there are increasing numbers of new entrants to the market, transparency about their production processes remains an issue. This is in part due to micro-SMEs not being required to report their detailed operations which makes this rapidly developing and changing sector hard to track.

A key player in the seaweed cosmetics industry is Ishga, a company based in Stornoway in the Outer Hebrides, that uses wild-harvested seaweed species such as Fucus serratus (commonly known as Toothed wrack), Ascophyllum nodosum (Knotted wrack), and Pelvetia canaliculata (Channelled wrack) for their high-value skincare products (Ishga, 2025).

In addition to producers, there are a wide range of organisations involved in supporting and developing the seaweed industry in Scotland through research and development (R&D), innovation and enterprise, such as the iBioIC. The tenth Scottish Seaweed Industry Association (SSIA) conference, of which the Scottish Association for Marine Science is a member, was held in Oban in November 2024 and brought together industry stakeholders seaweed growers and scientists from across the UK and beyond to discuss the seaweed sector and its future (Scottish Seaweed Industry Association, n.d.). Several key challenges facing the sector were highlighted: Gaps in regulation and licensing continue to present barriers to growth, limiting the potential for expansion. While there is growing interest in developing high-value products and biorefinery concepts, establishing reliable markets remains difficult. Growers are unable to guarantee consistent volumes, making buyers hesitant to agree to long-term contracts, which hinders the industry's ability to scale up.

To support the sector, SAMS Enterprise has developed the Seaweed Academy, a course for seaweed farmers and potential industry entrants on business development, licensing, seaweed seeding, cultivation and disease management. The Academy aims to build capacity and expertise within the industry to help overcome some of the challenges it faces. (Seaweed Academy, 2024).

3.9 Sweden

Sweden's blue bioeconomy is gaining momentum, with Västra Götaland standing out as a key region for marine industries. The West Coast has become a significant center for marine research and innovation, hosting a large proportion of the country's biomarine companies. Many of these businesses, especially in aquaculture and marine biotechnology, are small start-ups. Despite their size, they benefit from strong connections to academic institutions, which have facilitated the creation of spin-off companies. While the largest revenue still comes from the traditional fishing industry and larger processing companies, the region has a growing entrepreneurial spirit, particularly in sectors like cultivation and aquaculture. Much of the focus in Sweden's blue bioeconomy has been on food value chains, driven by the need to increase consumption and secure domestic food supply. Yet, the seafood industry faces challenges in consumer awareness and product diversification. The market remains heavily reliant on imported seafood, despite the availability of low-trophic species and land-based seafood options.

To address these gaps, initiatives such as Blue Food – Center for the Future of Seafood are working to boost consumer knowledge and support seafood innovation. A national seafood campaign is under development to encourage Swedes to increase seafood consumption, which has declined over the past decade—despite the Nordic Nutrition Recommendations (NNR) advising people to eat seafood at least three times a week. Schools, for example, struggle to source fatty fish, which is supposed to be a staple in school meals due to its nutritional value. At the same time, mussels, seaweed and herring processing side-streams such as "herring mince" have gained attention both as a sustainable food source and as an economically viable ingredient for alternative protein products such as in balls and burgers. Several startups are developing new technologies and new ingredients to enhance the utilization of mussels and other low-trophic species.

One of the key challenges in seafood processing is the fragmentation of the industry. While several sectors such as fisheries, aquaculture, and seafood processing are engaged in primary processing, their facilities are geographically dispersed and focus only on initial processing steps—not on secondary processing or value-added production. This disconnect weakens knowledge transfer, limits cross-sector synergies, and slows the development of high-value products and circular solutions. A major issue is that new species cultivated, such as seaweed, require different processing methods than traditional seafood. However, due to relatively small current cultivation volumes, it remains too costly to invest in dedicated primary processing facilities. As production scales up, there will be greater incentives to build specialized processing facilities or establish regional processing hubs that can handle various types of marine biomass efficiently.

Beyond processing, product development faces significant challenges. There is a lack of knowledge and expertise in working with new and diverse seafood ingredients, making it difficult for food producers to incorporate these materials into market-ready products. This is closely linked to limited innovation in processing techniques, as many companies struggle to adapt to the textures, sensory properties, and functional characteristics of emerging seafood ingredients.

Consumer perceptions of seafood also remain narrow. Many people associate seafood with a few well-known species, and there is little awareness of alternative species or new ways to consume them. To drive diversification in the industry, there is a need to broaden the definition of seafood, introduce new species into consumer diets, and develop innovative product formats that make seafood more accessible and appealing.

Additionally, the regulatory environment presents challenges, with permit processes for land-based and sea-based aquaculture creating significant bottlenecks. Current legislation is not always aligned with circular business models, further complicating efforts to scale sustainable practices.

Meanwhile, despite Sweden’s strong commitment to environmental sustainability, the industry still lacks structured collaboration mechanisms that would allow actors across the value chain to work together more effectively. The lack of collaboration in the seafood industry stems from its structure, where a few large companies thrive, for example in the herring fisheries sector, while many smaller businesses struggle to survive. Conflicts between organisations make it even more challenging to find common ground. However, through the BBC project we have been able to bring together actors from the entire seafood value chain to discuss ways of increasing collaboration and are now taking the first steps to developing a seafood industry company network - the birth of perhaps a Sweden Ocean Cluster, similar to Iceland. There are many efforts ongoing including the initiative to create an annual seafood industry meeting forum - the Nordic Seafood Summit. It has been gaining momentum, running 3 years in a row and seeing an increase from 500 to 1500 participants over that time. The blue bioeconomy has a chance to find more collaboration through efforts such as these.

Despite these challenges, there are significant opportunities for growth within the blue bioeconomy. Sweden may never have the same volumes or economic revenues as Norway when it comes to fish - but there is a chance for Sweden to take a position in technology development related to RAS and land-based cultivation systems. There are already major initiatives and companies working in this space - Gårdsfisk, Big Akwa, Smögen Lax and more. There is interest in freshwater fish cultivation of arctic char, rainbow trout and other species having the potential to grow and diversify current fish eaten in Sweden. There are also some food tech start-ups and technology developments using waste streams and other waste products from the seafood industry. Increased automation and digitization could address labor shortages and improve efficiency.

However, competition remains intense, making product development, marketing, and consumer engagement essential for success. Securing financing and venture capital is also critical to supporting innovation. In Sweden, both public and private financing available to the blue bioeconomy is low in comparison to more established bioeconomy sectors like forestry and agriculture. To address this, new national strategies are being developed that could provide the necessary incentives for change and the dedication of more financing and resources to both innovation and development of the sector. A study conducted in collaboration with Norway and Denmark examined investor perspectives on the ocean economy. One key finding is that there is a low level of understanding of the sector, coupled with a high perceived risk associated with ocean-based technologies. To mobilize private capital, we need to both educate investors and support market development to de-risk investment opportunities.

To fully unlock the sector’s potential, companies, research institutions, and policymakers must work together to strengthen cross-sector partnerships, create shared infrastructure, and foster a more integrated approach to value chain development. By bridging the gaps between traditional and emerging industries, West Sweden can enhance its competitiveness and establish itself as a leader in the sustainable blue economy.

3.10. Value chains across the BBC Regions

During the BBC consortium project kick-off meeting, an internal workshop was held (October 2022) to determine the value chains from each of the biomasses – what the inputs were, what kind of processing (transformation) was used and which products were sold on which end markets, as well as considering ecosystem services of the systems. Over the next year (2022-2023), the consortium discussed and added detail to these value chains. Figures 9 – 14 are a summary of the information collated. This information was also used to develop a facilitation tool, available in Deliverable 2.2 of the BBC project.

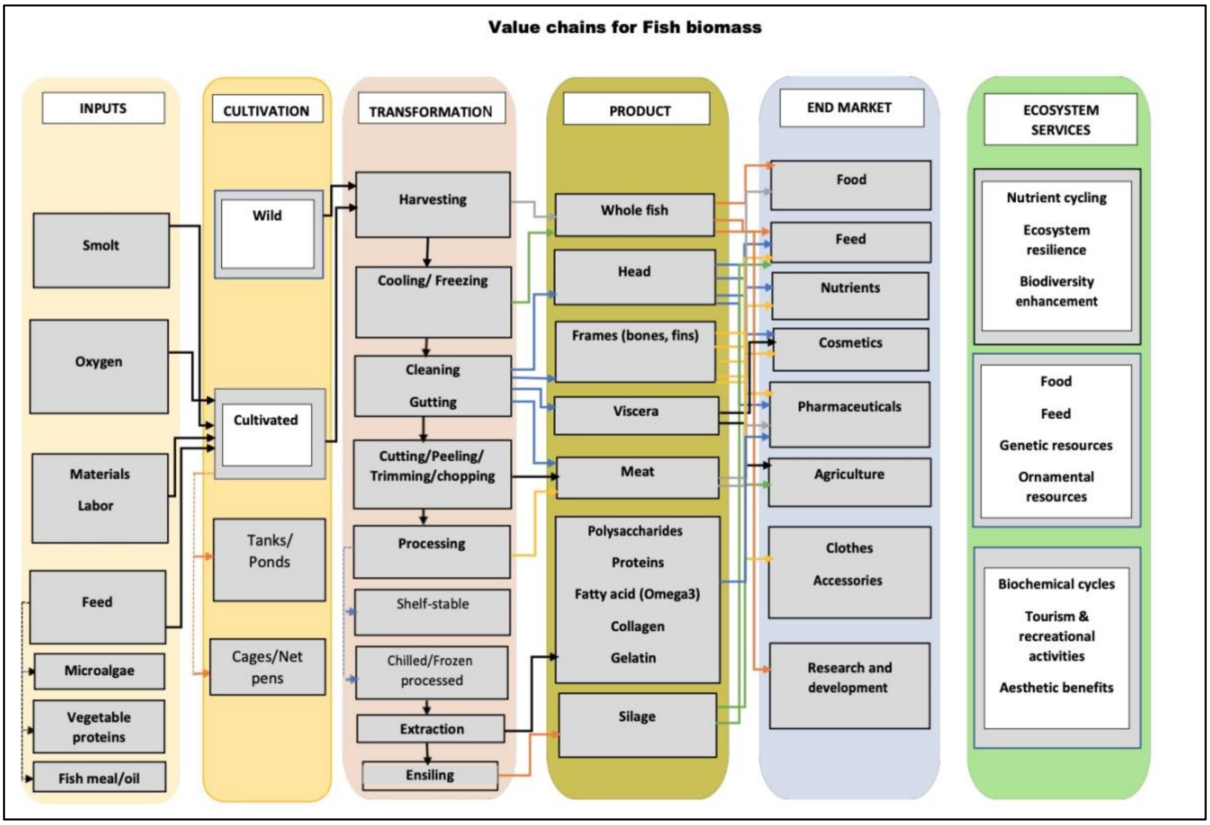


Fig. 9 Value chains for Fish biomass across the BBC partner regions.

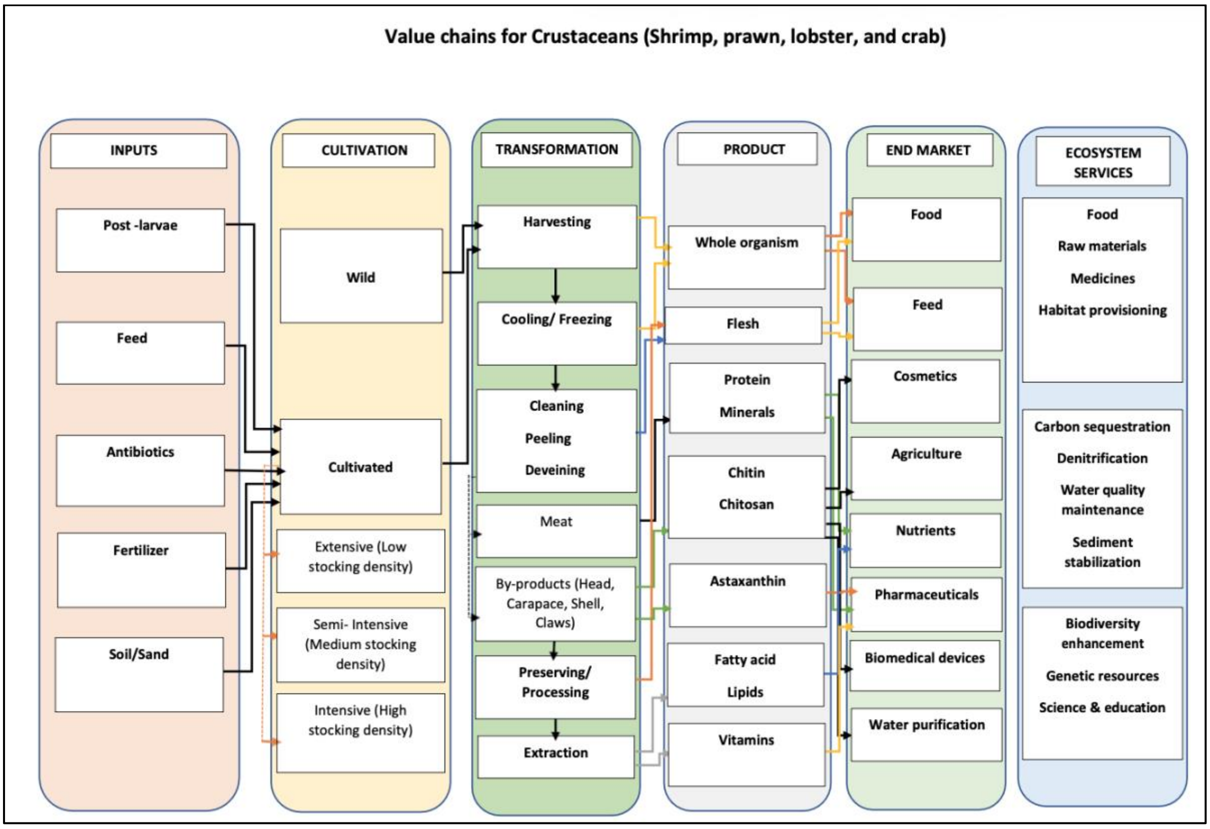


Fig. 10 Value chains for Crustaceans biomass across the BBC partner regions.

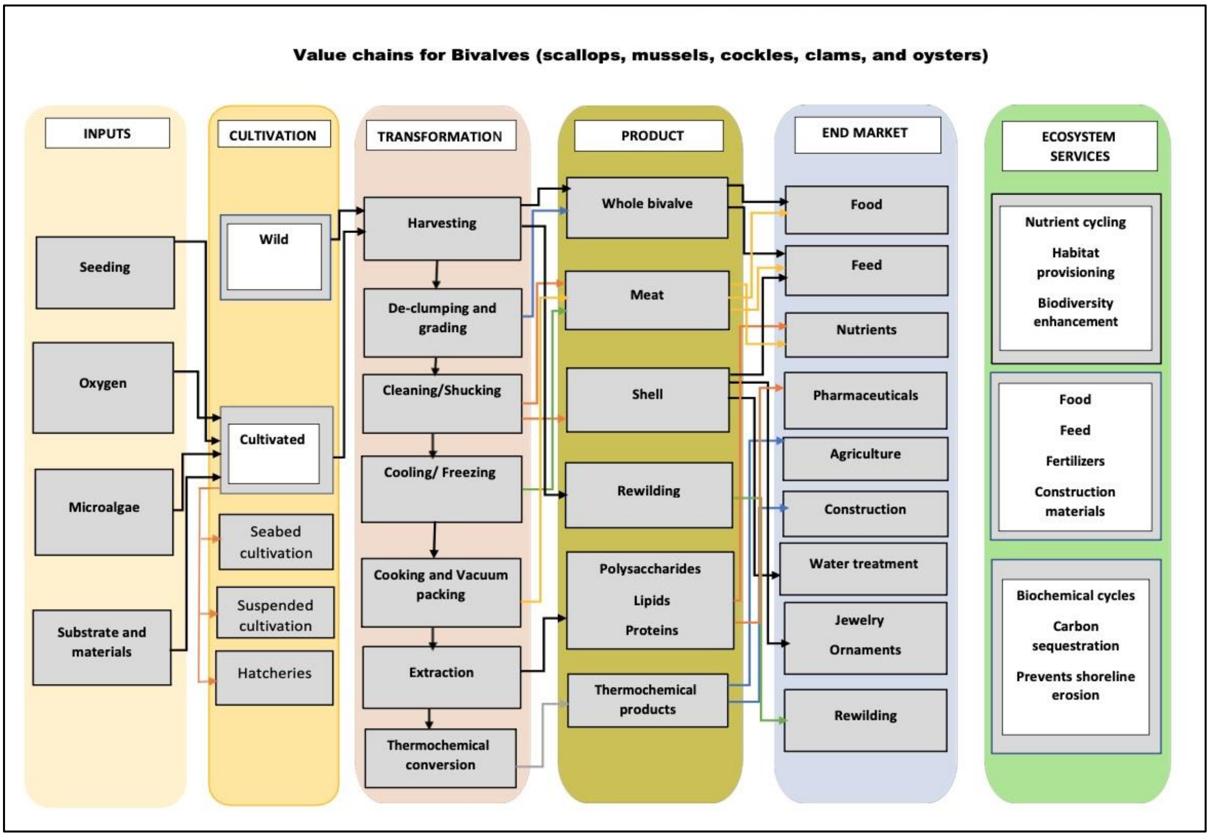


Fig. 11 Value chains for Bivalves biomass across the BBC partner regions.

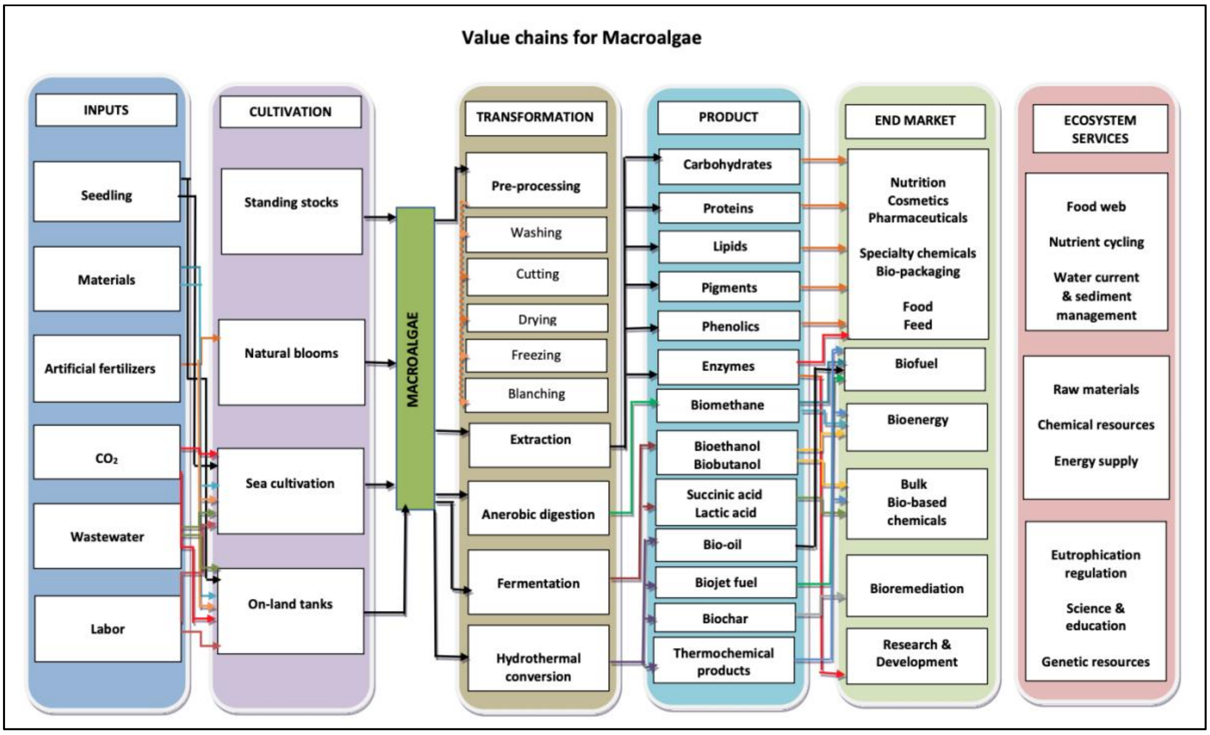


Fig. 12 Value chains for Macroalgae biomass across the BBC partner regions.

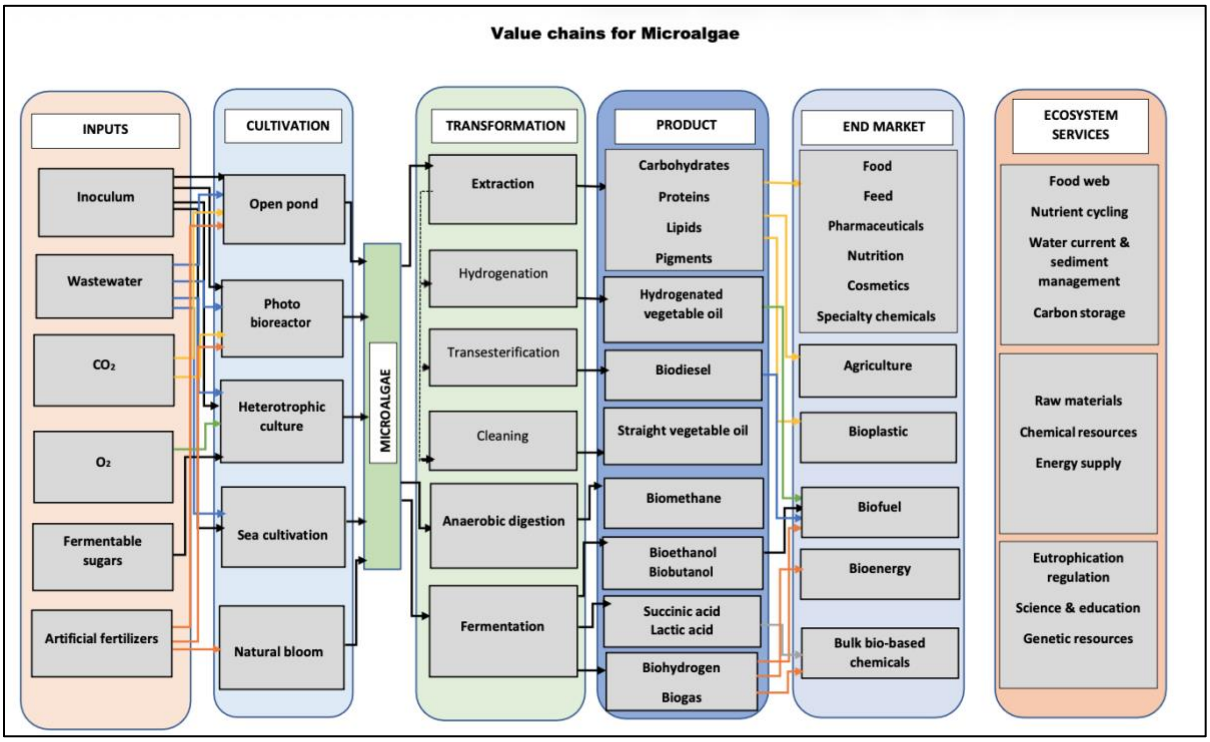


Fig. 13 Value chains for Microalgae biomass across the BBC partner regions.

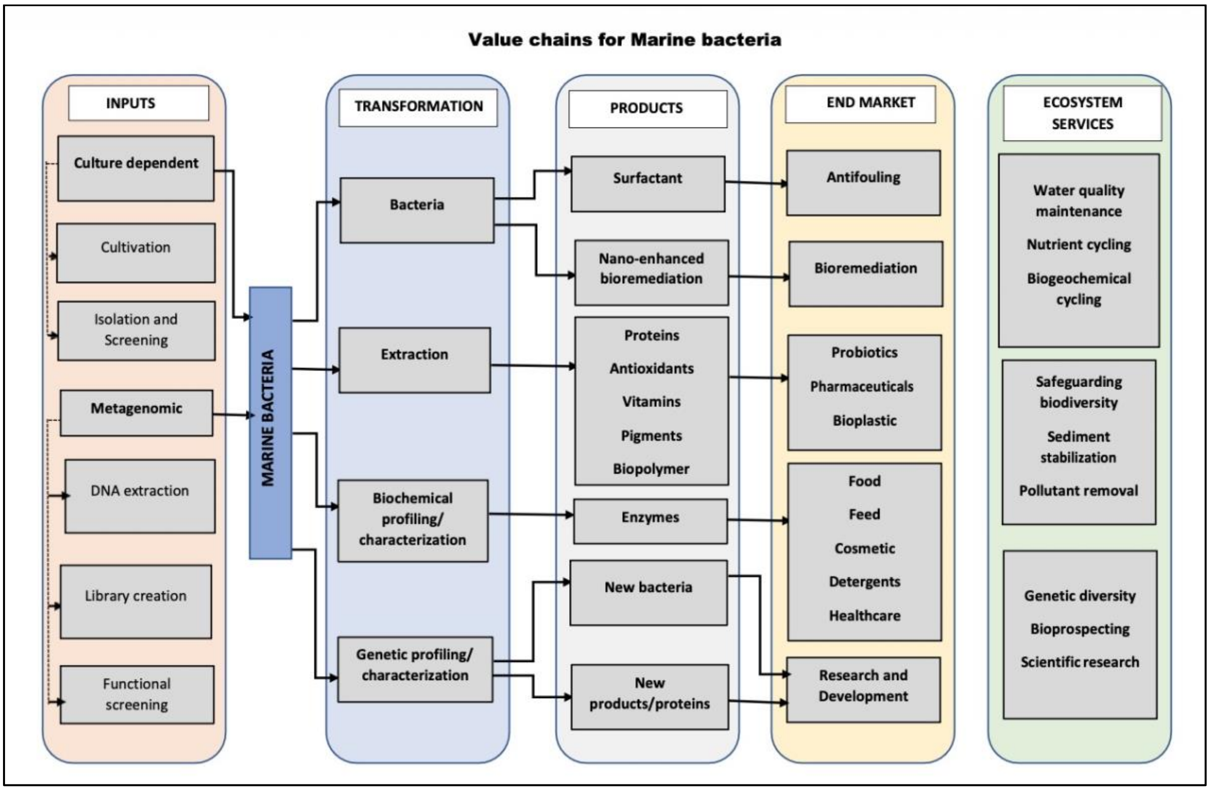


Fig. 14 Value chains for Marine Bacteria biomass across the BBC partner regions.

4. Key Challenges and Opportunities in the Blue Bioeconomy

The blue bioeconomy is a key player in the marine sector of most of the BBC partner countries and is a crucial contributor to the social sustainability of coastal communities, particularly those in more rural regions. For example, many fisheries and marine-based aquaculture operations are based out of rural, semi-rural and/or island coastal areas. Some of these biomasses, such as macroalgae, shellfish, and some fisheries, are seasonal. Diversification through side-stream innovation can enhance the value of these biomasses to the local economy, supporting an increase in the pool of high-quality local jobs and community sustainability.

Many Blue bioeconomy activities are developing at different paces across regions, but start-ups, small enterprises, and other organizations are fostering collaboration through business clusters like the Belgian Blue Cluster and the Icelandic Ocean Cluster, knowledge-sharing initiatives like the Scottish Seaweed Academy, and events such as bootcamps and incubators. These efforts aim to foster skills development, share expertise, and promote growth within the blue bioeconomy sectors.

Throughout the BBC project, we have seen significant successes in terms of blue bioeconomy activities making use of side streams, i.e. using fish skins for medical plasters in Iceland, using algal compounds for skin care in Scotland, developing seaweed-based biostimulants for agriculture in Estonia, and Norwegian white fish cutoffs used for croquettes (see full breakdown of value chains and side streams per country in Appendix I).

In many ways, the sector is currently ahead of policy frameworks that support production and processing. It is rapidly changing and forging innovative paths, i.e. using 100% of fish across value chains or finding new applications for compounds in marine algae. This means that in many cases, businesses and producers are faced with licensing difficulties as their operations are not, or not fully, covered by existing legislation and established procedures. This can pose significant problems in establishing operations, as was highlighted, for example, at the Scottish Seaweed Industry Association Conference in 2024.

The sector is evolving rapidly, with numerous new entrants. However, micro-SMEs and small businesses are harder to track, making it challenging to valorize the sector. Valorizing side streams is also challenging, as many are still in the trial phase, being tested, or applied on a small scale. There is a notable lack of estimates for side streams, either in tonnage or monetary value, across all the regions at this stage.

Overall, the BBC partner regions all reported blue bioeconomy innovation and enterprises, from micro-SMEs to larger companies developing products as well as side streams. However, many also reported the sector to be fragmented and hindered by challenges. One of the high-level challenges is that of terminology, where *blue economy, blue bioeconomy, and blue biotechnology,* are often used interchangeably, which may cause unintended consequences for business self-identification and therefore access to support and finances. The BBC Blue Bio Match platform aims to address the challenge of fragmentation and terminology, supporting improved valorization through enhancing inclusive communication across all blue bioeconomy sectors.

Table 2 shows the identified gaps and challenges across the BBC partner regions, with almost all regions reporting barriers in legislation and/or regulation of the sector. Licensing for novel activities in marine areas are challenging in many places, as well as product licensing and food regulations for innovative food products. There is scope for European and wider partnerships to collaborate on ensuring practical frameworks for blue bioeconomy actors.

Market barriers were another often cited issue, with many markets/ buyers requiring predictability in volume and quality – a challenge for most small-scale blue bio producers. For example, many macroalgae producers have difficulties establishing reliable agreements with buyers, due to unpredictable yield/ quality of biomass and/or production costs being too high to be competitive. This is an important barrier for the establishment of long-term sustainable low trophic blue bio business, where there are juxtapositions between the scale required, regulatory immaturity to handle scale, and social license to operate (which currently favours small to medium scale production in the case of seaweeds (Billing et al., 2021; Rostan et al., 2022)). Another common issue across most regions is securing public and private investments in order to finance the development of novel products, side-streams and operations. Some regions also reported barriers in collaboration between their operators and sub-sectors due to fragmentation.

The Ecosystem Approach (EA) acknowledges the complex connections within ecosystems and seeks to support their health, productivity, and resilience. Instead of focusing on single species, the EA requires a comprehensive view of a whole ecosystem, the interrelationships between its various components and human impacts on them. EA was initially conceived to reduce human impact on ecosystems but has since evolved to include regenerative practices that restore and enhance natural ecosystems and the services they provide. It now recognizes that economic activities can also have benefits for ecosystems.

Although an EA is implicit in many activities that have been presented in this report from across the BBC partner regions, it is rarely explicitly used as a term by practitioners or measured across their operations. Integrating ecosystem services into novel ecology-driven business models is ambitious and seems to be more challenging in practice, where the focus often remains on one or a few profitable species and their related side-streams. This phenomenon was also evidenced in D3.2, where 83% of participants in a survey of practitioners and experts across Europe covering all the BBC biomass value chains did not use any ecosystem services valuations. Their main challenge was related to the complexity and cost of accurately defining the ecosystem services of their biomass and associated value chains.

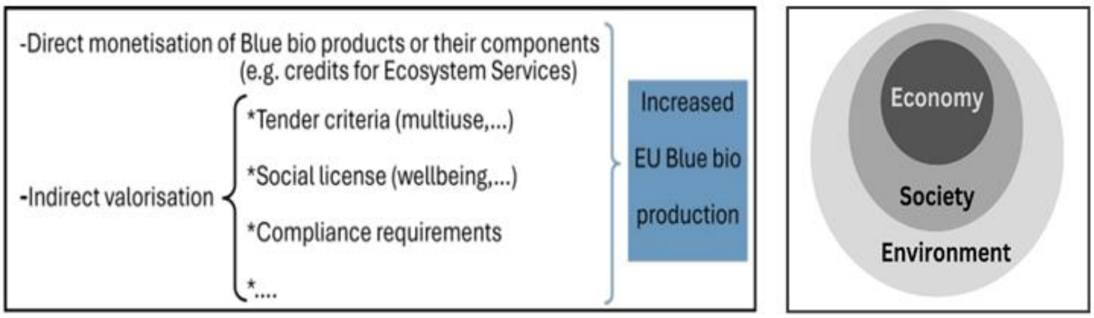


Fig. 15. Benefits of the Ecosystem Approach for Blue Bioeconomy production as reported in D6.5 (Adriaen et al., 2025) (left) and a depiction of the base of the principals of the Ecosystem Approach (right).

Table 2. Challenges and gaps for the blue bioeconomy across the BBC partner regions.

	Challenges			Gaps		
Country	Policy, legislation & regulatory immaturity	Market development	Infra-structure	Collaboration across sectors/ sub-sectors	Investment and financing	General public/ consumer knowledge
Belgium	✓	✓	✓		✓	✓
Estonia	✓					✓
France	✓	✓			✓	✓
Iceland	✓	✓	✓			
Lithuania	✓			✓	✓	
Norway	✓	✓	✓	✓	✓	
Portugal	✓	✓		✓	✓	✓
Scotland	✓	✓			✓	
Sweden	✓	✓	✓	✓	✓	✓

Future work could support start-ups and SMEs to develop a valuation of their side-streams or their side-stream products, improving visibility of these sectors, contributing to improved understanding of the mechanisms that work in developing a circular blue bioeconomy, and in doing so attracting investment for research and development, and venture capital.

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Appendix I

Table 3 Blue Bioeconomy value chains for the BBC partners, updated from D2.1.

WP2.2 Value chains							
Country/Area	**Original biomass**	**Cultivated or wild harvest**	**Pre-processing**	**Processing**	**Extraction of product**	**Product**	**Side products** Other info
Belgium	macroalgae	Cultivated in Offshore windmill park	seaweed seeding lines facilities present	-	-	Food	Research project
Belgium	Mussels	Longlines cultivation in open sea	Seeding, cultivation and harvesting technology	washing and packaging		Food	Done by Colruyt Group; Possibility on Shell re-collection for use in other industry (pet food, construction, ...)
Belgium	Oysters	Cultivating beds for ecosystem services, no harvest	Seeding of adequate substrates	-	-	For coastal protection, ecosystem reinforcing	Industrial project BELREEFS
Belgium	Oysters	Cultivating inshore	Seeding	-	-	Food	Done by Oesterput
Belgium	Fish	Trout Cultivation in pond and Recirculating aquaculture system (RAS) on land	Fresh/ cleaned/ filleted	Smoking		Food -	Done by different producers
Belgium	Shrimps	Biofloc aquaculture on land	Fresh/ cleaned/			food	Done by Crevetec;
Belgium	Fish	Cultivation in pond and Recirculating aquaculture system (RAS) on land				caviar	Done by AquaBio; Possibility on sludge collction for use in other industry (agriculture...)

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Belgium	Macroalgae	Recirculating aquaculture system (RAS) on land	net harvested- small quantities. Washed sold fresh	washing and packaging	-	food	Done by Oceanbites
Belgium	microalgae	Cultivated in closed systems	Different harvesting technologies	spray-dried, freeze-dried liquid, spray, frozen paste, powde		*used as whole for Food *Extraction for nutraceuticals * high quality additives (fish feeds)	Done by different companies (Axabio, Rijtak, Heirbaut aLgriculture,...)
Belgium	Marine bacteria	Cultivated on land in bioreactor			amino acids, fatty acids, pigments (bacteriochlorophylls and carotenoids), minerals, prebiotics	*aquaculture and agriculture feed additives	Research project (possible Spin off)
Belgium	Duckweed	Cultivated on land				food	Farm Van De Steene
Belgium	marine compounds - bioprospecting				enzymes, chitin etc.	bio coatings,	
Estonia	Mussels	Cultivated on rope. Suitable harvester is under development.	Washed in fresh water and cleaned.	Ground to form a powder and the meat is removed from shells	Potential for the use of meat mass (protein powder)	Protein bars/powder/supplements and poultry and/or animal feed	Shell fragment with some protein content (~4%) - the fine fraction and protein content after milling make the material a potential source of bird feed
				Technology varies in terms of the machinery employed			Estonian Maritime Academy of Tallinn University of Technology
Estonia	Macroalgae/Seaweed	wild harvest		extraction of different compounds from macroalgae	Red colourant (Phycoerythrin), producing different seaweed extracts, compounds for	compounds to cosmetics producers	Biomass from which furcellaran has been extracted- is used as a fertiliser.

					cosmetics producers		Vetik is developing the production of a natural (marine algae based) red colourant which is healthy and has potentially skin rejuvenating properties. https://vetik.ee/ Berrichi produces variety of skincare products that contain furcellaran, which has a powerful anti-aging and deep moisturising effect. /https://berrichi.eu/
Estonia	Seaweed	wild harvest	Dried and washed	Hot extraction of furcellaran from seaweed, filtering the extract via roller-drying or gel precipitation	Extraction of furcellaran	Furcellaran can be used as stabilising, thickening and gelling agent in the food, agricultural, cosmetics and pharmaceutical industries.	Biomass from which furcellaran has been extracted- is used as a fertiliser.
							Est-Agar AS, https://estagar.ee/

Estonia	Microalgae	cultivated.		Developing the valorisation of the whole biomass of the seaweed for cosmetics and other industries e.g producing different seaweed extracts.	microalgae photobioreactor system, feed/food compounds from microalgae	cosmetic, pharmaceutical, food/feed producers	Photobioreactor ideal for research and lab experiments, as well as for small-scale algae farming for high value compounds. ALGACAP is a modular microalgae photobioreactor system, designed to be integrated into an industrial chimney for CO2 sequestration from flue gas. They can provide the system on a turnkey basis, or we can offer the technology as a flue gas cleaning service. POWER ALGAE can supply various microalgae-based ingredients for food and feed producers.

Estonia	Fish	aquaculture (Rainbow trout ~85%, the European crayfish, tench, eel, the African sharptooth catfish, carp, catfish, sturgeon, grass carp, etc.)	Fresh/ cleaned/ filleted			Food - fillets, smoked, canned, fresh	
France	Ulva vulgais (macro)	natural harvest					
France	Ulva vulgais (macro)	land based cultivation to feed abelone					
France	Cyanobacteria	land based cultivation					
France	Cyanobacteria	Cosmetics					
France	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	liquid, spray, frozen paste, powder	compounds to feed aquaculture hatcheries for fish, shrimp, and shellfish larviculture	
France	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	spray, frozen paste, powder	whole-cell microalgae as a raw material for further extractions compounds to cosmetics	

France	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	liquid, spray, frozen paste, powder	Food & nutraceuticals - whole cell, alpha-carotene/beta-carotene, Lutein, Lycopene, Omega3, Astaxanthin, fucoxanthin	
France	Microalgae	Closed (tubular / flat panel) open systems (cascade /conventional)	fermentation, autotrophic reactor, pasteurisation	Centrifuge spray dryer | raceways inoculum/production, solar dryer	paste / powder (spirulina, chlorella, Dunaliella, Nannochloropsis, Haemtococcus)	waste water treatment, biofertilisers, bioplastics, biofuels	
France	Mussels (Mytilus edulis)						
France	Macroalgae/Seaweed-chemical	Wild harvest mechanical- mostly Laminaria digitata/hyperborea Plus other brown species	Washed, “bark” from stipe peeled off or dried and ground before further processing.	Extraction of alginate through traditionally through acidification, alkaline extraction, solid/liquid separation, precipitation and drying	Range of uses, primarily as a gelling agent, surfactants		
France	Seaweed- food	Cultivated- mainly sugar kelp and Alaria esculenta - semi-mechanical technology development, still outstanding here. Line seeded through	Washed in either seawater or fresh water and cleaned.	Chopped or combined with other compounds, including sea salt, snack food	N/A		

		seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Food market is early in the season to reduce biofouling	Simple soaking is employed, but there are bubble washers coming onto the market. Dried in at low heat or dehumidifier. It can be frozen and bought at this stage by others, who will then dry the biomass				
France	Seaweed chemicals	Cultivated- mainly sugar kelp and Alaria esulenta- semi-mechanical technology development still outstanding here. Line seeded through seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest affects what the biomass is used for. Usually harvested slightly later to ensure higher carbohydrate content of the seaweed. Small amount of wild harvest	Washed in either sea water or fresh water. Dried in at low heat or dehumidifier. It can be frozen and bought at this stage by others, who will then dry the biomass. Important aspect here is wet processing. Also move to ensiling- biomass would be chopped first before being ensiled	Chopped into smaller particles. Size of particles will depend on the extraction and conversion stage	Fermentation into biopolymers for everything from single use plastics which are compostable through to vegan leather and textiles. Involves extraction with water/acid/alkaline then fermentation with a usual a bacteria. Various faction steps can also be employed to remove other compounds of interest which includes pigments for antioxidants and as potential textile dyes		

France	Fish	very limited applications done in France.					
France	Oysters	both, but mostly cultivated					
France	Shrimp	both, but mostly cultivated					
France	Ascidians	both, but mostly cultivated					
Iceland	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	liquid, spray, frozen paste, powder		
Iceland	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	spray, frozen paste, powder		
Iceland	Macroalgae & mussels	Cultivation, nearshore			dried	Food (dried seaweed broth, with spices, for sauces)	Fine Foods Islandica
Iceland	Macroalgae	Wild harvest of calcified red algae Lithothamnium calcareum in the Westfjords of Iceland, Arnafjörður			Dried, powder	Nutraceuticals, food supplements	Hafkalk
Iceland	Macroalgae	Wild harvest on Snæfellsnes peninsula, Breiðafjörður				Nutraceuticals, Food supplements (iodine powder)	Icelandorganic
Iceland	Macroalgae	Wild harvest in Breiðafjörður, Ascophyllum nodosum (rockweed) and		Geothermally dried	Dried, powder	Dried algal meal powder for food, animal feed, nutraceutical and cosmetical products	Thorverk

		Laminaria digitata (oar-kelp)					
Iceland	Macroalgae	Wild harvest of Ascophyllum nodosum, Laminaria digitata, Laminaria hyperborea, Fucus versicaulius and Palmaria palmata		Vacuum cold dried, and heat dried using geothermal heat	dried	Plant & soil nutrition	Isea
Iceland	Macroalgae	Cultivated on land		dried with geothermal energy	dried	Animal feed – livestock methane reduction	Lava Seaweed
Iceland	Demersal fisheries – Whitefish	Wild harvest at sea	Vessel dependent – some pre-processing done at sea e.g. bleed	Heading, gutting, filleting, portioning, trimming some onboard vessels mostly in land-based processing facilities.	High automated and precise processing equipment.	Fillets and portions sold/exported fresh, chilled and frozen.	Skins – fish skin leather (Nordic Fish Leather), Collagen and gelatine (Marine Collagen ehf., Langa ehf. Into nutraceutical products – Feel Iceland ehf.), skin grafts and surgical products (Kerecis). Gut – enzyme isolates (Coldzyme, Dr. Bragi, Penzin, North ehf.). Cod livers –Oil human consumption (Dropi, Lysis), Trimmings oil (Lysis). Heads – dried – (Langa ehf. Haustak ehf).
Iceland	Small Pelagic Fisheries – Capelin, Mackerell, Blue Whiting, Herring	Wild harvest at sea	none	Primarily processed into fish meal and fish oil. Some processed whole (gutted and bled)	Fish meal and oil, whole fish pickled or smoked.	Fish meal and fish oil for agricultural, and aquaculture feeds primary market. Some whole picked herring or dried into high end snack products e.g. Icelandic Responsible Foods ehf.	Few side products from this processing as fish meal and oil can convert all material.
Iceland	Northern Shrimp Fishery	Wild harvest at sea		De-shelled	Flesh removed	Whole frozen shrimp and shri p products to food retail.	Shells used in chitin and chitosan extraction by (Primex ehf. And

							Benecta egf.) Cosmetic, nutraceutical, and biomedical applications e.g. blood clotting agents.
Iceland	Atlantic Salmon – sea cage	Farmed at sea in sea cages	Slaughter & bled	Gutted, processed whole, or fully portioned dependent on end market.	Processing facility on land.	Fillets or whole chilled and frozen fish.	Skins – Leather or into nutraceuticals e.g. Unbroken., guts primarily exported or used in hydrolysed feeds. Heads – used in pet treats or in protein hydrolysates.
Iceland	Atlantic Salmon and other Salmonids - landbased	Farmed in partial RAS and flow through land based systems	Slaughter & bled	Gutted, processed whole, or fully portioned dependent on end market.	Processing facility on land.	Fillets or whole chilled and frozen fish.	Skins – Leather or into nutraceuticals e.g. Unbroken., guts primarily exported or used in hydrolysed feeds. Heads – used in pet treats or in protein hydrolysates. Further processing is being explored for the future – with particular focus on sludge into fertiliser, biogas and biochar.
Iceland	Molluscs - Abalone	Farmed in landbased RAS		Dried or frozen whole		Developing operations to ship whole without shell	Future opportunity to use shell if processed differently.
Lithuania	Fish	wild harvested - coastal and inland fishery	sold to Latvia for further processing			Food	fish meal
Lithuania	Fish	wild harvested - open sea fishery	freezing, landed in Latvia and Denmark for further processing			Food - salted, dried, smoked, canned	fish meal and oil

Lithuania	Fish	aquaculture (carp, arctic char, African catfish, rainbow trout, grass carp, pike, sturgeon)	Cleaned			Food - sold fresh or chilled	
Lithuania	Fish	aquaculture (African catfish, sturgeon, carp, rainbow trout)	Cleaned, filleted			Food - fillets, smoked, canned	
Lithuania	Macroalgae	Wild harvest		Process described as innovative but no detail	Seaweed foam as packaging	Packaging, alternative to plastic	When used can be used as fertiliser, compost/soil improver. Start-up company; Seaweed Foam
Norway	Macroalgae/Seaweed-chemical	Wild harvest mechanical- mostly Laminaria digitata/hyperborea. Plus other brown species	Washed, “bark” from stipe peeled off	Extraction of alginate through traditionally through acidification, alkaline extraction, solid/liquid separation, precipitation and drying	Range of uses as a primarily as a gelling agent		
Norway	Seaweed- food	Cultivated- mainly sugar kelp and Alaria esculenta- semi mechanical technology development still outstanding here. Line seeded through	Washed in either sea water or fresh water and cleaned.	Chopped or combined with other compounds including seasalt, snack food	N/A	Food	

		seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Food market it is early in the season to reduce biofouling	Simple soaking employed but there are bubble washers coming on to the market. Dried in at low heat or dehumidifier. Can be frozen and bought at this stage by others who will then dry the biomass				
Norway	Seaweed chemicals	Cultivated- mainly sugar kelp and Alaria esulenta- semi mechanical technology development still outstanding here. Line seeded through seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Usually harvested slightly later to ensure higher carbohydrate content of the seaweed. Small amount of wild harvest	Washed in either sea water or fresh water. Dried in at low heat or dehumidifier. Can be frozen and bought at this stage by others who will then dry the biomass. Important aspect here is wet processing. Also move to ensiling- biomass would be chopped first before being ensiled	Chopped into smaller particles. Size of particles will depend on the extraction and conversion stage	Fermentation into biopolymers for everything from single use plastics which are compositable through to vegan leather and textiles. Involves extraction with water/acid/alkaline then fermentation with a usual a bacteria. Various faction steps can also be employed to remove other compounds of interest which includes pigments for antioxidants and as potential textile dyes	Chemical, biopolymers, compositable bioplastics and textile dying	

Norway	Scallops	Wild harvested either by dragging or hand dived. Small cultivated market and there is interested here- see other column	Washed and graded	Either sold directly in shells or will be shucked. Sold fresh or frozen. Can be depurated to remove contaminates	N/A	Food	
Norway	King Crab	Wild harvested by inshore creel	Once harvested kept in tanks for gradin g	Either sold direct into EU or processed for the meat	Potential fermentation of shells using chitin as the feedstock	Food	
Norway	Sea urchins	Considered a pest	Harvested by diving- kept on land in recirculating system until ready for market	Sold whole to restaurants	Small quantities sold	Food	
Norway	Salmon	Farming plus onland production of smolts	Graded on size and the flesh. The fish are washed and gutted.	Sold whole, sliced or smoked will depend on the market the salmon is intended for.	Potential for the use of by products including skin, trimmings, bones and dead fish at various stages of the life cycle. Extraction of omega 3 for health food market	Food	
Norway	Microalgae-aquaculture	Grown in PBRs for the marine molluscs and larval stages of fish	Harvested mainly through natural settlement to keep prices down	feed as whole cells			

Norway	Microalgae bio actives	Grown in PBRs	Harvested via centrifugation and membrane filtration	Still relatively new and extraction methods depend on the final use.	Movement towards biorefinery to help with cost of production. Extracted for bio actives, carbohydrates, lipids, pigments and proteins. Plus secondary metabolites		
			Centrifugation high energy consumption	Not yet standardised			
Norway	Fish	Wild capture fisheries with trawlers including cod, saithe, haddock, redfish, black halibut, herring, mackerel, capelin and blue whiting.	Production lines onboard the vessels. Mostly processed as headed and gutted products. Some boats have full production line for filet production to consumer packages. The heads and rest raw materials are processed for higher value purpose like fishmeal/oil and silage.	The headed and gutted fish is further processed to filets clipfish and wet salted fish, roe, milt and heads (including products like butterfly head, cheek, head loin, tongue, migas/fish meat, and gills), dried swim bladders, industrial migas and loin meat.		Food- fresh, frozen, salted, dried, smoked, canned.	Fish meal and oil. Hydrolyzed products.
Norway	Fish	Wild capture fisheries with trawlers including herring, mackerel, capelin and blue whiting.	Super chilled onboard and brought ashore for further processing or directly exported as whole fish.	Filéts or whole fish for consumer packages or bulk production.		Food - fresh, frozen, salted, dried, smoked, canned.	Fish meal and oil. Animal or fish feed.
Norway	Prawns	Wild capture	Cooked or super-chilled frozen onboard in bulk or	At prawn-peeling plants the shell is taken of the prawns.		Food- fresh, frozen, marinated, canned,	Powder made by the shell of the schrimps. Chitosan

			consumer packages				made by chitin from the shell.
Norway	Calanus Finmarchius	Wild harvest	Chilled onboard and brought ashore for further processing.	At Sortland in Vesterålen is the world's first and only factory for processing Calanus finmarchicus. The main product, the oil Zooca Calanus® Oil, is produced here. In addition to producing calanus oil for dietary supplements for humans, the factory produces various protein and ingredient products that are used in feed for farmed fish as well as dogs and cats. That way, nothing is wasted of the nutritious resource.			
Norway	Antarctic krill	Wild harvest	Enzymatic hydrolysis technology is used onboard to process the krill immediately after harvesting.	Using enzymes and low temperatures the protein in the krill is gently broken down into smaller peptides. The result is a nutrient-rich krill paste that can then be mechanically separated from the shells.	Patented enzymatic hydrolysis technology.	Omega-3 and choline	
Norway	Sugar Kelp and Winged Kelp	Cultivated	In the fall seaweed seedlings are transferred to the sea, cultivating in rope cultures. During the winter it grows rapidly. Harvesting	The harvested seaweed is dried, and then processed to different products.		Food-dried products.	

			takes place i in spring/pre-summer.				
Portugal	Seaweed	Integrated Multi-Trophic Aquaculture, IMTA	Dried | fresh excess nutrients released in fish farming	whole, flaked and flour	fresh seaweeds	nutraceutical, pet care, food, beverage cosmetics, fertilisers	Final products also mixed with microalgae for food market
Portugal	Seaweed	Wild harvesting (Asparagopsis armata, Asparagopsis taxiformis, Gongolaria abis-marina, Cystoseira humilis, Halopteris scoparia, Padina pavonica, Pterocladiella capillacea, Sargassum vulgare, Zonaria tournefortii, Gelidium,Ulva Gracilari, Fucos e Palmaria)	freeze-dried | sun dried |	no-procees (natural form) | grinded (different granulometric		cosmetics, biotech, pet food, nutraceutical	
			dried in the dark				
Portugal	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	liquid, spray, frozen paste, powder	compounds to feed aquaculture hatcheries for fish, shrimp, and shellfish larviculture	
Portugal	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	spray, frozen paste, powder	whole-cell microalgae as a raw-material for further extractions compounds to cosmetics	

Portugal	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	liquid, spray, frozen paste, powder	Food & nutraceuticals - whole cell, alpha carotene/beta-carotene, Lutein, Lycopene, Omega3, Astaxanthin, fucoxanthin	
Portugal	Microalgae	Closed (tubular / flat panel) open systems (cascade /conventional)	fermentation, autotrophic reactor, pasteurisation	centrifuge, spray dryer | raceways inoculum/production, solar dryer	paste / powder (spirulina, chlorella, Dunaliella, Nannochloropsis, Haemtococcus)	waste water treatment, biofertilisers, bioplastics, biofuels	
Portugal	Fish	aquaculture	salt water open circuit			fresh sea bass, sea bream	
Portugal	Fish	aquaculture - Recirculating Aquaculture System (RAS)				Meagre	
Portugal	Fish	onshore tanks				turbot and sole	
Portugal	Oysters	hatchery (IMTA)	depurating (filter and clean)			fresh oyster	
Portugal	clams	born in hatchery grow off-shore	larval cultivation / seed cultivation				
Scotland	Seaweed	Wild harvested-mechanical harvesting (Ascophyllum-10,000tonnes annually)	Dried by heat	Chopped into small particles and bagged. Added to sea salt and also ground to form a powder, added to capsules for health food market.	For cosmetics will usually be bought from the harvester/ processor, buyer either uses whole in products such as soaps or extracted for onward formulation- for	animal feed supplement whole chopped product. Capsules human health supplements and also added to oil for cooking and salad dressings.	

			Industrial conveyer or belt drier. Energy from kerosene or wood biomass boiler	Technology varies in terms of the machinery employed	fucoidan or alginate. Pigment also extracted for antioxidant market- fucoxanthin		Heavy metal content will be checked
Scotland	Seaweed	Wild harvest mechanical- mostly Ascophyllum	Dried or left wet Industrial tumble drier or belt drier. Energy from kerosene or wood biomass boiler if dried.	Ground or chopped Screw press, cell lysis under pressure	Extracted either in wet, or through acid or alkaline hydrolysis. Other technologies not currently used in Scotland include microwave and ultrasound cost is a factor here	plant growth stimulant	
Scotland	Seaweed	Variety of species- wild harvest mostly by hand	Washed and dried at low heat No specific machine for washing linked to small volumes. Dehumidifier- freeze drying may also be an option	Chopped or ground. Depending on species maybe smoked Technology varies in terms of the machinery employed	Small cosmetic market which will purchase the dried chopped product to extract (water/acid/alkaline extraction) will include alginate, pigments and other compounds with potential bioactivity?	Food/ cosmetics	Microbial loads are checked, as is heavy metal content if going into food. Also wash step important to reduce iodine content and important for removal of salt. For cosmetic market will also be necessary too carryout testing to ensure the product is safe to use- no adverse skin reactions.

<table>
<tr><td rowspan="2">Scotland</td><td rowspan="2">Seaweed- food</td><td rowspan="2">Cultivated- mainly sugar kelp Saccharina latissima and Alaria esulenta- semi mechanical technology development still outstanding here. Line seeded through seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Food market it is early in the season to reduce biofouling</td><td>Washed in either sea water or fresh water and cleaned.</td><td rowspan="2">Chopped or combined with other compounds including seasalt, snack food</td><td rowspan="2">N/A</td><td rowspan="2">Food</td><td></td></tr>
<tr><td>Simple soaking employed but there are bubble washers coming on to the market. Dried in at low heat or dehumidifier. Can be frozen and bought at this stage by others who will then dry the biomass</td><td>Microbial loads are checked, as is heavy metal content if going into food.</td></tr>
</table>

Scotland	Seaweed chemicals	Cultivated- mainly sugar kelp *Saccharina latissima* and Alaria esulenta- semi mechanical technology development still outstanding here. Line seeded through seaweed nursery either by direct or indirect methods. Uses a longline system for cultivation. Time of harvest effects what the biomass is used for. Usually harvested slightly later to ensure higher carbohydrate content of the seaweed. Small amount of wild harvest	Washed in either sea water or fresh water. Dried in at low heat or dehumidifier. Can be frozen and bought at this stage by others who will then dry the biomass. Important aspect here is wet processing. Also move to ensiling- biomass would be chopped first before being ensiled	Chopped into smaller particles. Size of particles will depend on the extraction and conversion stage	Fermentation into biopolymers for everything from single use plastics which are compositable through to vegan leather and textiles. Involves extraction with water/acid/alkaline then fermentation with a usual a bacteria. Various faction steps can also be employed to remove other compounds of interest which includes pigments for antioxidants and as potential textile dyes	Chemical, biopolymers, compositable bioplastics and textile dying	See Oceanium and Notpla

Scotland	Mussels	Cultivated on rope through natural sprat settlement. But there have been issues with the failure of sprat generation. Usually happens every 10 years.	Washed and packaged either in small batches (supermarkets) or sold directly to customers	Small batches can be smoked and sold in oil	N/A	Food	Relatively cheap to produce. Enquires an aquaculture license and there is an issue in some areas on a soft shelled species. Also there is harmful algal bloom monitoring in place to protect the public from toxins. Seen as sustainable
Scotland	Oysters	Cultivated- mainly intertidal. Spat will be obtained from a commercial hatchery and must be of the same genetic stock as the area where it will be grown	Will be washed, graded for example of size, banded and potential depuration to remove contaminates	N/A		Food	Increased interest in native oysters for re-wilding projects plus for clearing up water- improve water quality. Grown in lantern nets and not generally for the food market. Best example is the Deep project lead by the whiskey distillery Glenmorgie
Scotland	Scallops				N/A	Food	

		Wild harvested either by dragging or hand dived. Small cultivated market and there is interested here	Washed and graded	Either sold directly in shells or will be shucked. Sold fresh or frozen. Can be depurated to remove contaminates			Shells are currently a waste product. Cultivation in lantern nets is starting to increase but there is a need for a hatchery as spat is usually taken from the surrounding area. Limits again on movement within the growing area and surrounding areas out within growing site.
Scotland	Crab	Wild harvested by inshore creel	Graded on size	Either sold direct into EU or processed for the meat	Potential fermentation of shells using chitin as the feedstock	Food	Waste is in the form of the shells- some interest in the chitin the shells contain and companies like Cuantec using the shells for the production of single use plastics, pharma, cosmetics. Involves a fermentation step
Scotland	Langoustine	Wild harvested by inshore creel, also by dragging. Company in Clyde have a system that causes less damage that current conventional methods.	Graded on size	Either sold whole or cooked and the meat is removed from shells	Potential fermentation from the shells using chitin as the feedstock	Food	Waste is in the form of the shells- some interest in the chitin the shells contain and companies like Cuantec using the shells for the production of single use plastics, pharma, cosmetics. Involves a fermentation step

Scotland	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	liquid, spray, frozen paste, powder	compounds to feed aquaculture hatcheries for fish, shrimp, and shellfish larviculture	
Scotland	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	spray, frozen paste, powder	whole-cell microalgae as a raw-material for further extractions compounds to cosmetics	
Scotland	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	liquid, spray, frozen paste, powder	Food & nutraceuticals - whole cell, alpha carotene/beta-carotene, Lutein, Lycopene, Omega3, Astaxanthin, fucoxanthin	
Scotland	Salmon	Farming plus on land production of smolts	Graded on size and the flesh. The fish are washed and gutted.	Sold whole, sliced or smoked will depend on the market the salmon is intended for.	Potential for the use of by products including skin, trimmings, bones and dead fish at various stages of the life cycle	Food	At the moment it is currently unclear about whether the industry will start using the by-products for other markets. Although there is beginning to be some movement on how the waste from on land smolt production is being treated and whether value can be added here.

Sweden	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	liquid, spray, frozen paste, powder	compounds to feed aquaculture hatcheries for fish, shrimp, and shellfish larviculture	
Sweden	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	spray, frozen paste, powder	whole-cell microalgae as a raw-material for further extractions compounds to cosmetics	
Sweden	Microalgae	freshwater and marine microalgae, ranging from open to closed systems		spray-dried, freeze-dried	liquid, spray, frozen paste, powder	Food & nutraceuticals - whole cell, alpha carotene/beta-carotene, Lutein, Lycopene, Omega3, Astaxanthin, fucoxanthin	
Sweden	Microalgae - material						Waste streams are sent to bioplastic/bio packaging test facility
Sweden	Seaweed - food	cultivation in lab first (some wild), attached to ropes that are then placed in ocean for growth (sugar kelp, *Saccharina latissima*), harvested by hand onto boat	harvested kelp is rinsed first on boat then taken to land	As dried, it is chopped up for packaging in vacuum packed plastic bags. As frozen, it is sent to a industrial food processing company to be chopped for packaging in freezer.	Dried seaweed mixed with seasalt another application is in drink form making seaweed “tea” for extraction of vitamins/minerals	End product to consumer is dried or frozen packaged seaweed for use directly.	Iodine and heavy metal content is a concern. Processing practices are being examined to find if they can reduce the iodine. But also more frequent testing being done during cultivation to understand if there are ways to reduce this content in cultivation or during harvesting.

			hanged up for air drying under tents outside or sent to drying machine; Alternative is blanching then freezing (iodine reducing method)				
Sweden	Seaweed - nutrition	cultivation in lab first (some wild), attached to ropes that are then placed in ocean for growth (sugar kelp, *Saccharina latissima*), harvested by hand onto boat	harvested kelp is rinsed first on boat then taken to land hanged up for air drying under tents outside or sent to drying machine; Alternative is blanching then freezing (iodine reducing method)				
Sweden	Seaweed - materials	cultivation in lab first (some wild), attached to ropes that are then placed in ocean for growth (sugar kelp, *Saccharina latissima*), harvested by hand onto boat	harvested kelp is rinsed first on boat then taken to land hanged up for air drying under tents outside or sent to drying machine; Alternative is blanching then freezing (iodine reducing method)				
Sweden	Mussels (*Mytilus edulis*) - food						

Sweden	Mussels (*Mytilus edulis*) - nutrition						
Sweden	Mussels (*Mytilus edulis*) - materials						
Sweden	Herring (*Clupea harengus*) - food sidestreams						Zero waste production, everything is being used.
Sweden	Sea Squirts - Ciona intestinalis	The cultivating of sea squirts is very similar to that of mussel farming. Growing under the water at ropes hanging from buoys, The method is governed by environmental permissions and totally natural – there is no need of fertilisers or pesticide to make the sea squirts grow. Rope with seeds are saved from earlier harvest and when the water becomes + 10 degrees, the seeds start to reproduce themself and attach to the new ropes. The grow primarily during April - September, and then they are harvested during winter.	The ropes are being collected and transported to shore by boat. In the harbour the sea squirts are cut from the rope and then immediately boiled.	Minced meat: After boiling the solid mass are being chopped into mince meat and mixed with egg-, beetroot and pea flower. After that it is being fried and vacuum packed for selling as minced seasquirt meat.		Food - minced meat, liquid bullion extract, umami creme	
			Steam boiling	After boiling the liquid are further boiled and reduced to a, liquid bullion extract, which is bottled for selling as a food ingredient in cooking. The small solid parts that are left after the boiling-reduction are packaged in jars as seasquirt creme - that also can be used as a cooking ingredient. Both the creme and the liquid bullion extract contains a lot of umami, and is a good flavour maker in different kinds of food.			