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SEAWEED

**A VERSATILE INGREDIENT IN A CHANGING MARKET
-COLLABORATION WITH SOUTH KOERA**

2024

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FOREWORD

- **There is a sound a timely opportunity for Denmark and South Korea to collaborate in the field of seaweed which is a largely untapped bio ressource with high potential to bring sustainable food solutions for the future.**

Innovation Centre Denmark in Seoul is pleased to present an outlook for collaboration opportunities in the area of seaweed and sustainable food innovation between Korea and Denmark.

The aim of this report is to introduce the relevance of seaweed in green transition and an important food staple in sustainable global food system. The focus on seaweed and algae for human consumption is only emerging in Europe whereas it has been known, grown and used in Asia for centuries.

South Korea is the 3rd largest seaweed producer globally and has leading industrial know-how on seaweed production at scale, as well as a flourishing seaweed food market and gastronomy which the country is interested to promote internationally.

In Denmark, seaweed is overall a novelty in foods but rapidly picking up, and Europe has the largest amount of seaweed startups and equity investments globally. However the region has no real domestic production of seaweed.

Denmark is showing the way for a sustainable food paradigm with plantbased food innovation strength as well as a globally leading food- and bio sector known for high food safety and quality.

In unison, the Korean and Danish innovation ecosystems spanning from research over commercialization to broader industry innovation can benefit from complementary strengths and mutual interest in tapping into the growing global demand for solutions including seaweed.

Denmark and South Korea have a mutual interest in boosting the application of seaweed in high value markets and modernizing the seaweed production industry with focus on sustainability, smart farming techniques and scaled production outside of Asia.

The strategic foundation for increased collaboration between Korea and Denmark rests on strong bilateral commitments for supporting green growth as well as science and technology cooperation.

The goal of this outlook is to inspire further joint actions between Korea and Denmark and dynamize existing collaboration such as the Danish Korean Blue Bioeconomy Alliance.

The report has been carried out by Innovation Centre Denmark Seoul with ample inputs from current collaborators, especially the Mokpo Marine Center of South Korea as well as members of the Danish Korean Blue Bioeconomy Alliance.

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EXECUTIVE SUMMARY

Seaweed is an underutilized and understudied bio resource globally that holds large potential to provide new and sustainable solutions for food and feed as well as other industries. Simultaneously seaweed farming presents several built-in environmental advantages and is a promising climate solution. This has spurred increasing interest among governments, researchers and companies across the globe to tap into emerging markets for seaweed products.

Ten new markets for seaweed are projected to grow the sector additionally by 11,8 billion dollar by 2030 in i.e biostimulants, nutraceuticals, alternative proteins, feed, pharma, bioplastics and construction. Their development and acceleration require R&D and investments as well as consideration of ecosystem service value. Importantly the regulatory framework and international standards in the seaweed industry are also crucial for the new markets' development.

The global production of seaweed is a bottleneck and presents a major challenge to the ambitions for new seaweed industries. The production is concentrated in a few Asian countries, including South Korea, that has important industrial strongholds in large scale seaweed production as well as mature traditional markets and use. The production of seaweed must find new locations in order to be able to meet the global demand, as Asian production is challenged to scale sufficiently in its current form.

Europe is one of the top importers of seaweed today with a projected increase in demand as well as large interest in the new applications and uses of seaweed as a sustainable solution across industries. Europe has the highest number of new companies and investments in seaweed businesses, but focus is however on downstream applications while production is increasing slowly. Only with substantial investments can Europe be able to supply around one third of the regional demand by 2030.

Collaboration between Europe and Asia is called for to seize the opportunities in new seaweed markets and modernization and increase of the production. There is sound potential for collaboration between Denmark and South Korea which hold complementary strengths in food and bio industry and seaweed research and that represent bot the traditional as well as emerging seaweed nations. Existing collaborative networks, bilateral green growth collaboration and South Korea's entry into Horizon Europe from 2025 are levers for such as collaboration.

1. INTRODUCTION

- Seaweed is gaining global attention as a potent but underutilized bio resource due to its many qualities as well as built-in positive environmental impact
- New markets are opening up driven by the quest for sustainability and levered by new technology that can unlock the value of seaweed across industries
- The emerging markets call for research and innovation as well as collaboration with Asia that dominates the large-scale production of seaweed and Denmark and Korea can lead the way

A HIDDEN CHAMPION OF THE OCEAN

Seaweed, or macroalgae, grows under the water and its magnitude is largely hidden to the human eye. But in recent years there has been increasing global interest in this fascinating and highly potent biomass that is much more than what we see washed up on the beach or eat around our sushi-rolls.

Actually seaweed accounts for more than 54% of the global marine aquaculture production volume today, equating to ~36,5 million tonnes. This is a three-fold increase in twenty years and the fastest growing food production market (FAO 2024).

One of the reasons that this may be “hidden” is that the cultivation happens almost exclusively in a handful of countries in Asia and barely exists as an industry in the Western world.

This could be changing with the ambitions of governments in EU, North America and other regions that are seizing up the potential for developing both production and industries around seaweed and microalgae.

But why are seaweed markets growing and why does it happen now? To highlight three important reasons:

- Seaweed is a largely untapped bio resource which could be increased enormously without use of land space
- Advances in biotechnology and frameworks of blue bioeconomy opens up new opportunities to utilize seaweed across different industries
- Cultivation of seaweed has a number of built-in benefits for the environment and provides important ecosystem services

Untapped resource

Firstly seaweed is a greatly underutilized and understudied bio resource. We simply haven't contemplated or fully understood this biomass that is as diverse as a rainforest but growing in water:

Out of more than 12.000 registered species, only a few handfuls of these are being grown at industrial scale today, and with traditional use in food, feed and as bio stimulants. Around twenty algae species are approved for food and supplements use in EU.

The potential to increase this biomass is enormous; it is estimated in a model study that 1,8% of the global ocean surface is indeed suitable for seaweed cultivation which roughly equals an area ten times the size of Russia (650 million km²).

“The EU is a top global importer of seaweed products in terms of value, so there is clearly a strong demand for seaweed products in Europe. This demand is set to increase in line with health and sustainability trends”

EU Commission 2022

If 0,03 % of the ocean surface was farmed, this could theoretically replace a staggering 10% of the human diet by 2050 (Spiliadis 2022).

The sheer potential of adding valuable biomass without land and fertilizer use is compelling, and in general seaweed offers a healthy nutrition profile with vitamins, omega 3 fatty acids which could partly substitute e.g. use of soy protein and fish oil.

New markets and uses

Secondly, seaweed is being rediscovered in a time where modern biotechnology allows for many new uses and applications of the biomass. In the era of blue bioeconomy seaweed can become useful not only as food and feed but emerging markets are opening with applications in e.g. pharma, cosmetics, bioplastics, biofuels, textile, construction etc.

With rapid growth rates and large yields seaweeds are indeed more suitable for biorefinery applications compared to terrestrial plants (Farghali 2022). Some kelp species can famously grow up to half a meter per day.

These new markets are main drivers of the projected growth in the seaweed industry value, as they represent a more highvalue use than the traditional seaweed markets.

Short term the agro-food industry can most readily tap into the seaweed sources with sustainability, alternative proteins and climate solutions as strong drivers.

The estimated industry value was 17 billion dollars in 2022, but is projected to grow by additional 11 billion dollars towards 2030 (Kuech et.al 2023, Worldbank 2023, Vincent et. al 2020).

Built-in climate solutions

Thirdly, increased seaweed cultivation entails several built-in advantages for global sustainability challenges termed ecosystem services.

Seaweed cultivation in other words has positive effects on its surrounding marine ecosystem and can support climate change mitigation (Duarte et.al 2021).

Seaweed grows wild in ocean shorelines worldwide and is the most effective natural way of absorbing carbon emissions from the environment. At the same time seaweed removes nutrients and can absorb pollutants from the water, helping the overall marine health.

In sum seaweed holds a compelling value proposition to a range of the global sustainability challenges, and the market projection support an increased demand for this biomass across industries.

So why aren't seaweed farms shooting up at every shore and why aren't we consuming more seaweed products already? As compelling as this “hidden champion of the ocean” may seem there remains many challenges across technology, knowledge and regulation, and market to realize new seaweed solutions, and projections and model studies entail obvious insecurities.

Seaweed is not a “silver bullet”, but it will for sure be a larger part of a blue-green transition in years to come and at a global scale, and therefore it should be seen as an important part of driving sustainable food innovation.

On a green food mission

In 2022 Denmark launched Agrifoodture which is a partnership comprising more than 70 Danish companies and researchers, to create a roadmap outlining innovation and development needs for a sustainable agriculture and food sector.(2)

With a budget of more than 200 mio. DKK the AgroFoodture partnership is advancing solutions targeted to the challenges within select focus areas: Land use, animal production, plant-based production and biotechnology.

Mission critical?

- About 60% of Denmark's land is being used for agriculture, making it among the most intensely farmed countries worldwide. Optimized land use is necessary as less, not more, land can be used for future agricultural produce.
- The meat and dairy production in which Denmark holds particular strength, is associated with methane emissions from cows. Reducing the methane, along with producing alternative animal proteins from e.g. aquaculture, is envisioned.
- The plant-based food production is in global demand with annual two-digit growth rates, driven by increasing awareness of health and sustainability impact along with a fast developing gastronomy making plant-based diets more attractive to consumers. Denmark wants to take leading position in this market.

- Biotechnology-based food production is widely seen an enabler for more sustainable production through e.g. biorefining processes and new functional ingredients. Improving both functional and sensoric qualities of foods with e.g. enzymes and through fermentation processes opens up to both new foods and production methods.

How could seaweed apply?

Whereas aquaculture and seaweed is not mentioned as a separate work track there are several direct and indirect value propositions of seaweed to the Danish ambitions and innovation roadmap:

- Seaweed cultivation does not compete for land use and needs no fertilizer as it takes up nutrients from the ocean
- Seaweed is known for its many bioactive contents and holds great potential across new functional ingredients including for nutraceutical use
- Specifically, seaweed extracts have shown great effect in ruminant feed, demonstrating methane reduction of up to 90%
- The sensoric and nutrition qualities of seaweed is a great asset to value-added plant-based products and gastronomy
- Potential increased production in Denmark with a coastline of 7.300 km. and between 350-500 species of seaweed out of which about 10 are immediate cultivatable and commercially relevant(5)

FURTHER INSIGHT

For further insights from the Agrifoodture partnership and the roadmap as well as open calls see: <https://agrifoodture.com/>

DENMARK'S FOOD AND BIO STRONGHOLD

Denmark has firmly established itself as a leading food nation, renowned for its innovation, sustainability, high quality, and collaborative approach across the entire food value chain.

The Danish food cluster is the third most concentrated food-exporting cluster globally, relative to its size, underscoring the nation's capacity for efficient production and innovation. This concentration allows Danish companies to leverage a local ecosystem of expertise, making them highly effective partners in international ventures

World leading ingredient supplier

Denmark's ingredient sector is a global frontrunner, exporting 70% of its production and capturing a significant share of the world market for feed and food ingredients. Danish companies are leaders in developing enzymes, cultures, proteins, and functional ingredients that enhance the nutritional profile, shelf life, and sensory qualities of food products.

With a strong emphasis on sustainability, the Danish ingredient industry also excels in utilizing raw materials efficiently, such as turning whey from cheese production into high-value proteins or repurposing fish processing trimmings into nutrient-rich fishmeal.

Seafood and aquaculture

Denmark is a leading seafood exporter within the EU, with exports reaching over 115 countries. The Danish seafood industry operates under a zero-waste philosophy, aiming to utilize nearly 100% of fish trimmings for high-value products like fishmeal and fish oil.

The country also leads in aquaculture innovation with its Recirculating Aquaculture Systems (RAS), which use up to 100 times less water than traditional methods, reflecting Denmark's commitment to minimizing environmental impact.

Safe, smart and sustainable

Denmark's food safety standards are among the highest globally, underpinned by comprehensive regulatory frameworks and a proactive "own controls" system. This approach ensures that all food producers rigorously document safety and hygiene practices, going beyond EU requirements.

Denmark is at the forefront of food technology, particularly in processing and automation. Danish companies provide advanced solutions for seafood processing, optimizing every stage from slaughtering to packaging while ensuring compliance with the highest environmental and quality standards

Denmark's commitment to sustainability is evident in its agricultural practices and food production strategies. The country has reduced its greenhouse gas emissions by 17% since 1990 while increasing food production by 30%. This achievement is due to innovative use of resources and technologies, such as biorefining to produce plant-based proteins from grass and other crops, which support both human consumption and livestock feed.

New and green gastronomy

Danish gastronomy, highlighted by the New Nordic Cuisine movement, has placed the country on the global culinary map. This approach emphasizes the use of local, seasonal, and sustainable ingredients, aligning with Denmark's broader environmental goals. Denmark is home to numerous Michelin-starred restaurants, and its culinary innovations showcase the country's blend of tradition and modernity in food culture.

EU ALGAE INITIATIVE

The "Future of the EU Algae Sector" report (Kuech et.al 2023), outlines the European Union's strategy to harness the potential of seaweed and microalgae as part of the Blue Bioeconomy. The EU launched its first Algae Initiative in 2022 to foster a modern algae industry.

The rationale behind this initiative is multifaceted, focusing primarily on enhancing food security, promoting sustainable aquaculture, and contributing to climate change mitigation as part of the European Green Deal.

The main goals of the EU Algae Initiative are to develop a robust algae sector by addressing current challenges and leveraging opportunities.

This includes improving the governance framework, enhancing the business environment, fostering research and innovation (R&I), and developing market opportunities for algae products.

To achieve these goals, the initiative proposes 23 targeted actions, such as streamlining regulations, increasing consumer awareness, and supporting the development of sustainable algae farming practices. These actions are scheduled for implementation from 2023 to 2027, with specific milestones set to evaluate progress

Key initiatives include promoting integrated multi-trophic aquaculture (IMTA) systems, which combine different species to create sustainable and productive aquaculture environments, and supporting the development of algae-based products as alternative proteins for food and feed.

The initiative also aims to increase algae production in the EU by 100% by 2025 and to fill knowledge gaps regarding the environmental benefits and impacts of algae cultivation, which are essential for informed decision-making and sustainable growth of the sector.

Figure 4: Europe's Challenges and opportunities of a new Algae Industry

PROBLEMS

- High production costs
- Low-scale production
- Limited knowledge of the impacts of seaweed cultivation
- Fragmented governance framework

OBJECTIVES

- Increasing sustainable production, safe consumption and innovative use of algae-based products
- Upscaling regenerative algae cultivation
- Developing and mainstreaming markets for food and non-food applications

ACTIONS

- Improve the governance framework and legislation
- Support improvement of business environment
- Close knowledge, technological and innovation gaps
- Increase social awareness and acceptance of algae products

Source: Adapted from EU Commission 2022

2. WHAT IS SEAWEED?

- Seaweed is an underutilized biomass pertaining to the algae classification with more than 12.000 species
- With the enormous variety of species, seaweed has different characteristics and is generally rich in bioactive compounds that offer advantages to human health
- Seaweed has a big role to play in marine ecosystems and also can be used to improve environmental conditions

WHAT IS SEAWEED?

Seaweeds, also known as macroalgae, are abundant in coastal areas and are organisms that thrive in saltwater or freshwater environments rich in bioactive molecules. All seaweeds need sunlight to survive and grow mainly at the edges of oceans. Unlike higher plants, they lack a true root system, leaves, or vascular system, and they obtain nutrients through osmosis.

There are over 12,000 species of seaweeds,¹ all with different sizes and colors and about nine times more seaweeds in the oceans than there are plants on the land (Spiliaris 2022).

Algae are the ultimate source of nutrients and energy for other organisms living in aquatic ecosystems. Although not considered plants, algae are photosynthetic in nature and produce over 70% of the global oxygen content. In comparison, rainforests make up 28% of oxygen production.

Seaweed types

Seaweed is classified into three main groups: Red (about 6.000 registered), green (about 1.200 registered), and brown (around 2000 registered): Green seaweeds can be found in shallow waters in warm, tropical climates.

Brown seaweeds are much bigger than the green seaweeds and live at greater depths. Red seaweeds can grow in both cold and warm waters that is either shallow or deep.

Some seaweeds are tiny, others are massive, such as the giant kelp (brown algae) that can become up to 100 meter long and grow around 50 centimeters per day. However most seaweeds are of moderate size, and frequently wash ashore on beaches and coastlines around the world.

Seaweed availability and growth is dependent on the local conditions such as salinity and temperature of the water as well as other factors including currents and waves (Farghali et. al 2022).

Species in Denmark and Korea

In South Korea over 908 species of seaweeds have been reported including 123 greens, 193 browns, and 592 reds (Hwang et. al 2020). In Denmark it is estimated that around 350-500 species are available in the Northern waters whereas it is less in the southern part. The most common seaweed species in Denmark include saccharine, ulva, vesicular and palmeria (Hermund et. al 2022).

¹: There is some variety in the literature references as to the number of seaweeds registered. It is pointed out by e.g. Sultana 2022 that a global taxonomic standard for algae classification is still missing. The number 12.000 is therefore not an exact number but oftentimes referenced in newer research articles.

ECOSYSTEM SERVICES

Seaweed grows wild in ocean shorelines worldwide and plays a big role not just as a biomass and as food source, but also for the broader marine health and global environment. This is often termed ecosystem services.

Climate change

Seaweed is the most effective natural way of absorbing carbon emissions from the environment. At the same time seaweed removes nutrients and can absorb pollutants from the water, helping the overall marine health.

Seaweed farming plays a significant role in carbon sequestration, a critical process for mitigating climate change. Through photosynthesis, seaweed absorbs carbon dioxide (CO₂) from the atmosphere, effectively removing it and storing it in its biomass. This carbon can then be buried in sediments or transported to deep ocean waters, effectively removing it from the carbon cycle.

Research estimates that seaweed farms can sequester about 1,500 tons of CO₂ per square kilometer annually, making a substantial contribution to global carbon reduction efforts (Duarte).

Environment

Seaweed is highly effective in bioremediation, which involves the use of biological organisms to remove or neutralize pollutants from the environment. One of the most important services provided by seaweed is the absorption of excess nutrients such as nitrogen and phosphorus from surrounding waters.

These nutrients, often originating from agricultural runoff, can lead to harmful algal blooms, and the creation of dead zones. By absorbing these excess nutrients, seaweed helps to improve water quality and restore ecological balance in coastal waters.

Moreover, seaweed can be employed in wastewater treatment processes. It can absorb and remove various contaminants, including heavy metals and organic pollutants, from wastewater, thus preventing these harmful substances from entering marine ecosystems. This capability is particularly valuable for managing pollution in areas adjacent to industrial and agricultural activities, contributing to cleaner water bodies and healthier marine environments.

Biodiversity

Seaweed farms provide essential habitats that support marine biodiversity. The complex structures formed by seaweed offer shelter and breeding grounds for various marine species, including fish, invertebrates, and juvenile stages of economically important species. This habitat provision enhances local biodiversity and can contribute to the recovery of overfished or degraded ecosystems. By fostering rich marine life, seaweed farms also support the broader marine food web, contributing to healthier and more resilient ocean ecosystems.

Ocean health

In addition to their role in mitigating climate change, seaweed farms also support climate change adaptation through coastal protection. Seaweed beds reduce wave energy, which helps protect shorelines from erosion and mitigate the impacts of storm surges. This service is particularly valuable in areas vulnerable to sea-level rise and increased storm activity due to climate change. Furthermore, seaweed can help combat ocean acidification by locally raising pH levels in surrounding waters, creating more favorable conditions for marine organisms that rely on calcium carbonate, such as shellfish and corals.

COMPOSITION AND PROPERTIES

Seaweed, often called "sea vegetables," provides diverse health benefits due to its rich nutritional profile, which varies by species. Like land plants, seaweed contains five main components:

- Moisture: water content
- Fats: lipids and fatty acids
- Proteins: amino acids
- Carbohydrates: sugars
- Ash: minerals and metals

The nutrient makeup differs across red, green, and brown seaweeds, with red seaweed containing about 60% water and brown seaweed up to 85-90%. On a dry basis, seaweed can have 12.8–60.6% carbohydrates, 1.1–26.8% proteins, and 0.6–11.5% lipids. Red varieties like *Palmaria palmata* are protein-rich, while brown species like *Ascophyllum nodosum* are carbohydrate-dense. Seaweed proteins have a balanced amino acid profile and high nutritional value, with digestibility improved by treatments like enzymatic pre-treatment (Juul et al., 2023).

Vitamins and minerals

Seaweed is highly nutrient-dense, rich in vitamins A, C, E, and various B vitamins, as well as minerals like iodine, calcium, magnesium, potassium, and iron. Brown seaweeds are notable for iodine, supporting thyroid function, while red and green seaweeds provide essential minerals.

Certain red and brown seaweeds also contain omega-3 fatty acids, beneficial for heart, brain, and reducing inflammation, with brown varieties generally having higher levels.

Nutritional content varies among species: brown seaweeds like *Laminaria digitata* are high in iodine, while red species like *Porphyra* (nori) are protein-rich. Green seaweeds like *Ulva lactuca* (sea lettuce) offer a balanced nutrient profile, ideal for culinary use (Sultana, 2022).

Food safety

The high iodine levels in seaweed can pose safety risks, as excessive intake may harm humans. There are no global safety standards, and only about 20 species are currently approved on the EU's non-novel food list for use in food products.

Asia's coastal regions, especially in China, South Korea, and Japan, have ideal temperate waters for seaweed cultivation. This environment supports the growth of species like *Saccharina japonica* (kelp), *Pyropia* spp. (nori), and *Undaria pinnatifida* (wakame). South Korea's nutrient-rich waters and long coastlines make *Pyropia* the most valuable seaweed crop, boosting the national economy (Hwang, 2020).²

3. QUEST FOR KOREAN DANISH COLLABORATION

A QUEST FOR COLLABORATION

There is broad consensus that the future needs more seaweed - but which kinds, how and where should they be cultivated and how can we unlock most bioeconomic value of the new biomass? These are questions asked with slightly different accentuation in both Asia and Europe.

Increase global production

Firstly it is paramount to realizing the new markets to scale the global production of seaweed significantly:

98% of the global seaweed production takes place in Asia, and after decades of high growth in volume, the production is stagnating across more species.

The current cultivation industry is facing challenges in relation to further scaling of the current production sites. Furthermore they are challenged by productivity and in need of modernization as well as adaptation to climate changes that are impacting the growth conditions.

Meanwhile the production outside of Asia is not scaling up in the needed speed. In a high ambition scenario, Europe could supply only around one third of its regional seaweed demand by 2030.

Therefore the quest is to accelerate the growing of seaweed in more places in the World without tradition for seaweed or existing industrial production.

This bottleneck of future supply is accentuated considering that Europe and North America have most new seaweed startups and investments while they are mostly focused on the product development rather than production.

Research and innovation

Secondly, the knowledge and innovation gaps are broad spectred calling for international and transdisciplinary collaboration:

Seaweed cultivation of tomorrow must be both environmentally safe and economically feasible in order to scale. Carefully adapted to the local marine ecosystem -to help, not disturb- and considering optimal species, locations and cultivation systems (Campbell et.al 2019).

Seaweed cultivation must further modernize with automation and new farming techniques for better productivity and price points. This goes across cultivation, harvest as well as postharvest treatment such as drying which is an energy intensive process (van den Burg et. al 2021).

There are many studies into the properties and bioactive compounds of seaweeds which are promising for both food, pharma and nutraceuticals but securing quality grade and uniformity in supply is of high importance (Sanjewa et. al 2024, Zhang et. al 2022).

Likewise the new product development, and acceptance by consumers and industry needs a lot more insight.

For the individual food company wanting to know which seaweed to start using and how it impacts the products' sustainability: for investors looking into business cases and future markets; or for authorities incentivizing and regulating the industry alike, the need for sound knowledge and insights are of utmost importance.

Framework conditions

Thirdly, seaweed framework conditions are rather scattered at a global level, since there has not been an explicit and strategic approach to the algae industry in most countries.

Seaweed has thus far been understudied in its own right, and often falls in between chairs when it comes to setting strategies for fx plantbased foods or in the regulatory framework because of being a "nor fish or plant" but anyways regarded as a vegetable of the sea.

The lack of harmonized standards and certifications when it comes to approvals, food safety etc. can bring insecurity to producers as well as inhibit investments due to risks.

In sum these innovation challenge complexes are substantial and wide reaching - and so to speak complement the beforementioned potentials of increased seaweed production and use!

Korea and Denmark can lead the way

Korea and Denmark are well positioned to pursue collaboration in developing sustainable seaweed cultivation and high-value products for a global market with use of modern biotechnology.

Denmark is a world leading food producing nation with no significant seaweed industry, and South Korea is a leading seaweed cultivating nation but with little arable land and the lowest food self sufficiency in OECD.

Seaweed is one of Korea's most important food exports and in some categories (Gim) South Korea holds 70% of the global export (Seo 2024a).



Source: Innovation Centre Denmark 2023

While looking to both scale and advance its seaweed production and industry, South Korea is also challenged to modernize and innovate the industry to tap into the global demand and emerging markets that are fuelled by the quest for sustainability and powered by high-tech blue bioeconomy.

The current production and market is optimized to traditional food and feed purposes and environmental concerns along with rising ocean temperatures create an impetus for international outlook and partnerships.

Complementary strongholds

Considering the strongholds and innovation needs in relation to sustainable food and agriculture, seaweed could be an area of a highly complementary partnership leveraging the strong relations between the countries:

- Korea holds great industrial know-how in cultivation of seaweed including seeding, harvesting and processing
- Denmark has little experience with seaweed cultivation at large-scale but a documented potential and a world leading ingredient industry that uses seaweed
- Korea has established consumer markets for seaweed, a rich gastronomic tradition for its use and is the nation in the world that consumes more seaweed on average
- Denmark has no traditional consumption of seaweed but an emerging plant-based gastronomy with potential to utilize seaweed more for both sensoric and functional food qualities
- Korea has a strong and growing export of certain seaweed products and an interest in understanding Western palate and consumer preference for diversification
- Denmark is at the forefront of green gastronomy innovation with a strong food startup scene and offers an attractive bridge to European and Western palate and consumption

Existing platform for collaboration

Since 2021 there has been active collaboration in the area of seaweed and bioeconomy through the establishment of the Danish Korean Blue Bioeconomy Alliance. Led by Aarhus University, the activities have included participation by several universities and companies across Denmark and Korea.

The alliance initiated knowledge exchange in use of seaweed in areas of food, feed and nutraceutical, and through site visits in 2022-2023 important institutions and ecosystems have been connected.

Innovation Center Denmark in Seoul supports the Blue Bioeconomy Alliance between Denmark and Korea, and it is foreseen that more activities in areas of biotech and biomanufacturing for future food will initiate in the coming years.

This is both spurred by interest from the research and innovation ecosystem and in line with the bilateral priorities.

“Somewhere in the world, there is the perfect food business partner for you. The Danish food and agricultural cluster can help grow your business in the global food arena”

Food Nation

The Danish food sector and its rich innovation ecosystem is geared to engage in international collaboration and provides a great “bridge” into European market, cultural taste pallet as well as a globally relevant hub for plantbased innovation.

EMERGING EUROPEAN SEAWEED FARMING

Aquaculture is needed

While Europe’s seaweed farming is only emerging and far from being able to supply the current of future domestic needs, several initiatives and pilots have been launched in recent years to promote and stimulate European seaweed farming and industry.

To enhance the sustainability of seaweed production and lessen the environmental impact of harvesting wild stocks, shifting from wild harvesting to seaweed aquaculture presents a significant opportunity for the sector's growth.

Additionally, cultivating macroalgae through aquaculture can be pivotal in advancing Integrated Multi-Trophic Aquaculture (IMTA) systems. These systems, employed by about 10% of European aquaculture companies, involve the simultaneous cultivation of multiple species from different trophic levels, such as finfish, shellfish, and seaweeds, within the same farm site.

Seaweed for Europe is a Coalition seeking to accelerate and scale the European seaweed industry by driving innovation and investment, with the ultimate aim of unlocking significant economic, environmental and social benefits. The coalition brings together a range of stakeholders from the seaweed value chain, the investment world, and science and civil society thought leaders.

In the report “Hidden Champion of the Ocean” the potential for European seaweed farming is modelled with a best case scenario to be able to supply 30% of the European market demand by 2030.

This will entail scaling the production to 8,3 million tonnes of fresh weight seaweed and require farming in marine farms as well as onshore farms. It is estimated this will require up to 26.000 hectares of marine farms and 1.000 hectares of onshore farms.

An example of emerging seaweed farmers is North Sea Farmers (NSF). NSF is a non-profit organization dedicated to fostering success in the European seaweed industry. Servicing more than 100 members, NSF work across the entire seaweed value chain, promoting sustainability, education, research, and innovation.

Emerging farmers

A range of pilot projects in the North Sea region test offshore seaweed production co-located with windfarms and as nature restoration. One such example is the Wind&Wier project which looks at future opportunities in the greater North Sea region.

This is a proposition that has also been researched and quantified with Danish research contribution concluding that co-location with the offshore projects in the North sea hold a significant potential (Duarte et.al 2021)

Rethinking cultivation

To make seaweed production more economically viable it is for example being piloted in connection with off-shore wind projects in Denmark and the North Sea region. The co-location can make production more economically viable in so far as infrastructure and maintenance costs can be lowered with co-location. The Dutch government is proposing setting aside 400 sq km of its territorial waters in the North Sea for large-scale seaweed cultivation.

Several Danish and European research and innovation projects are looking into the feasibility of establishing more seaweed farming in Europe and in particular the North Sea where many offshore wind projects are established.

Seaweed can be integrated with fish and seafood aquaculture, and Denmark is working on plug-and-play solutions to support this. Pilot projects cover a broad scope, addressing environmental, economic, and social factors. Key focuses include selecting optimal seaweed types, meeting market demand, and advancing technology for feasible offshore farming.

- **Denmark's stronghold in food production and bioeconomy along with Korea's stronghold in seaweed cultivation and industry is a strong foundation for new seaweed markets innovation**
- **There are good opportunities for Danish-Korean collaboration and established platforms and instruments available**

Why Denmark and Korea?

In 2021, Danish and Korean researchers formed a network to explore collaborative research in seaweed and its use in various bioeconomic industries. This network introduced several stakeholders and their solutions through a series of workshops and delegation visits.

The activities confirmed not only mutual interest in sustainable seaweed cultivation and new market applications but demonstrated the complementary strongholds of the two nations: Korea is a leading seaweed producer and consumer market, and Denmark at the forefront of sustainable food production and development of bioeconomy solutions with circularity and biorefinery at the core.

Both Korea and Denmark have high ambitions to address the global market demand for more plant based foods as well a high innovation capacity across the technology fields needed to modernize cultivation and processing in a modern seaweed industry.

The North Sea which surrounds Denmark has been identified as one the world's top 25 marine habitats that would benefit from seaweed cultivation (Theuerkauf et.al 2019).

Increased collaboration on seaweed applications in the agri-food sector as well as sustainable seaweed cultivation can be a desirable focus, both given the shared agenda for sustainable food as well as considering the short and midterm market demand and commercialization focus of startups (World bank 2023, Kuech et.al 2022, Vincent et.al 2020).

Pathway and stepping stones

The pathway to increased collaboration can leverage the strategic partnerships between Denmark and Korea, which entails a comprehensive green growth partnership since 2011 and provides a strong bilateral commitment to finding solutions to global sustainability challenges.

The science and innovation collaboration further builds on ministerial collaboration where biotech is a focus area for joint actions now and in the coming years. In the food, health and energy ministries there are similarly advanced collaboration at a governmental and institutional level, which provides a rich platform to work with seaweed and blue bioeconomy.

Connecting the two countries' stakeholders in seaweed science and innovation happens with the purpose of increasing joint activities and increased collaboration in both research and commercial partnerships.

From 2025 Korea will be the first Asian country to become fully affiliated to Europe's research and innovation program Horizon Europe. This means that Korean and Danish researchers and innovation stakeholders can collaborate within a joint funding scheme and make Korea a more accessible partner.

This also means that Korea is now looking to Europe for increased innovation partners building a fertile momentum for collaboration.



In March 2023 Korea and Denmark signed a letter of intent to collaborate on the green transformation of the Agrifood sector including focus on research and innovation. Ministers Hwang-Keun Chung and Jakob Jensen.

4. CULTIVATION AND USE

- **Asia is dominating the global seaweed production with 98% but the cultivation is slowing down creating a bottle neck for the global market demand**
- **Seaweed has traditionally found use in the food and feed and as biostimulant with only five species groups accounting for 95% of the valorized production today**
- **Other regions including Europe are mobilizing to establish a modern and sustainable seaweed production but the cultivation industry is but nascent**

CULTIVATION AND USE

Naturally occurring in the ocean, seaweed can be harvested wild which is characteristic of European production. However, the vast majority of today's seaweed is cultivated near shore, also known as mariculture, and 98% of this comes from Asia, with China, Indonesia and Korea as the largest global producers.

Global production in Asia

The global production is today 35 million tonnes yearly, and seaweed makes up around one third the total aquaculture production (FAO 2024).

The cultivated seaweed today is largely concentrated on a few handful of species across brown, red and green types with primary use as fish feed, human food and food industry where it is used as e.g. thickening agent (agar).

With rich tradition for using seaweed, countries like South Korea have not only great expertise in seaweed cultivation and processing but also well established markets and downstream industries as well as framework conditions across regulation, research and innovation. Seaweed is one of Korea's most important food export goods.

But compared to other marine products like fish and seafood, seaweed is however not a highvalue product - yet, which makes investments into the production limited.

Will there be enough supply?

The seaweed cultivation industry is furthermore facing a range of challenges to growth and innovation, and the current industry is in need of modernization in terms of automation, development of offshore cultivation and further sustainability focus.

While the global demand for seaweed is projected to grow heavily the production volume growth is slowing down in the Asian countries and large scale production is not picking up elsewhere at the needed speed, which can seem paradoxical.

In recognition of the potential of a modern seaweed industry, as well as the increasing global demand, other nations are starting to eye the opportunities in seaweed cultivation. The European Commission launched its first ever initiative in 2022 called the Algae Initiative, focusing both on seaweed and microalgae (EU Commission 2022).

Rethinking cultivation and production

The interest in fostering a new seaweed industry is closely connected with both the sustainability and climate agenda as well as the blue bioeconomy where technology enables more efficient use of biomass in biorefineries. This means that biomass can become much more useful across industries and be better utilized in all parts which is important for both the economic and environmental feasibility of investments into a new industry.

In terms of establishing seaweed large-scale seaweed cultivation, Europe is therefore also going new ways, including looking at cultivation further into the sea as well as on-land in symbiotic connection with fish aquaculture.

Bioactive compounds

Seaweed is packed with natural compounds that provide several health benefits, especially in fighting inflammation. This makes seaweed interest both to the functional food ingredient industry as well as the pharma industry.

One of the key groups of compounds in seaweed are sulfated polysaccharides. These are special types of sugars found in different kinds of seaweed: for example, fucoidan in brown seaweed, ulvan in green seaweed, and carrageenan in red seaweed. These compounds can help reduce inflammation by blocking certain pathways in the body that trigger an inflammatory response.

Seaweed also contains phlorotannins, found mainly in brown seaweed, which are known to fight off harmful molecules in the body that can trigger inflammation.

Another beneficial group includes carotenoids and omega-3 fatty acids, which are healthy fats. These fats can help regulate the body's inflammatory response and improve overall health.

Thanks to these compounds, seaweed may help prevent or manage several chronic conditions linked to inflammation, such as heart disease, arthritis, diabetes, digestive issues, and even some neurodegenerative diseases.

Because these natural compounds have fewer side effects than synthetic drugs, they offer a promising natural alternative for those looking to manage inflammation and improve their health

The North Sea is in particular apt for seaweed and countries like Denmark are actively piloting seaweed cultivation in numerous locations.

Examples of pharmaceutical studies

There are many ongoing studies into seaweed's bioactive compounds and to mention a few from a recent compilation (Farghali et. al 2022):

1. **Anti-Inflammatory Effects of Fucoidan:** A study on fucoidan, a compound found in brown seaweed, demonstrated its ability to reduce inflammation by blocking specific inflammatory pathways in the body, suggesting its potential in managing chronic inflammatory diseases like arthritis and cardiovascular disease.
2. **Carrageenan's Role in Digestive Health:** Research on carrageenan, a substance derived from red seaweed, showed its effectiveness in soothing inflammation in the digestive tract relevant to Crohn's disease and ulcerative colitis.
3. **Phlorotannins and Neuroprotection:** A study highlighted the neuroprotective effects of phlorotannins, which are found in brown seaweed. Potentially offering protective benefits against neurodegenerative diseases like Alzheimer's and Parkinson's.
4. **Omega-3 Fatty Acids for Cardiovascular Health:** The research demonstrated that regular consumption of seaweed could improve heart health by reducing inflammation, lowering cholesterol levels, and improving overall vascular function.

In traditional Korean medicine seaweed has long been used for its health benefits including for blood circulation, weight loss and anti-aging.

4. NEW SEAWEED MARKETS

- **New emerging markets for seaweed across industries are driven by global challenges and powered by blue bioeconomy and new technologies**
- **Food and new ingredients focus short and midterm with use across value chain with plantbased as a major market driver**
- **New companies and trends with seaweed are emerging**

NEW EMERGING MARKETS

As outlined in the previous sections seaweed is a highly potent biomass that has currently been underutilized in large part of the World but that offers interesting contributions to both a sustainable food system as well as products in a broader bioeconomy. With the many bioactive compounds seaweed has potential both in nutraceutical, cosmetic and pharma industries, which are high-value markets.

This is driving global interest and demand for seaweed, which goes beyond the existing traditional markets and simultaneously poses new demands on scaled but safe and sustainable production as outlined in the previous section.

Several reports outline and describe the new markets (e.g. Worldbank 2023, FAO 2022, Seaweed for Europe 2023) and there is broad consensus about the emerging markets and drivers.

While seaweed has future potential as both bioplastics, fabric and construction material the short and midterm potential includes not least use in food and agro sector, from biostimulants in fields, over feed additives, to human consumption in food, alternative proteins and functional ingredients.

The number of investments and new businesses confirm the interest in seaweed to fuel a more sustainable, plant based and healthy diet across the globe, with EU and North America fueling the development of downstream applications in the food sector. However also countries such as South Korea is leading new seaweed based innovations.

The Global Seaweed New and Emerging Markets Report (Worldbank 2023), identifies ten key emerging markets for seaweed applications, anticipated to grow significantly by 2030, with the potential to add an additional USD 11.8 billion to the global economy.

Additional 11 billion USD towards 2030

These markets are projected to reach a combined market size of billions of dollars by 2030, driven by factors such as the rising demand for sustainable products, advances in biotechnological processing, and the increasing awareness of seaweed's environmental and health benefits.

For example, biostimulants are expected to see an annual growth rate of 10%, while the alternative proteins market could become a major player as the world seeks to address food security and sustainability.

Additionally, the growing consumer preference for natural and eco-friendly products in sectors like textiles and packaging further fuels the demand for seaweed-based solutions. These sectors represent a diverse range of applications, from agriculture to pharmaceuticals, each offering unique opportunities for innovation, economic growth, and environmental sustainability.

The World Bank report also emphasizes the market for commercializing seaweed's ecosystem services. This market focuses on monetizing the environmental benefits provided by seaweed cultivation, such as carbon sequestration, nutrient removal, and biodiversity enhancement.

GLOBAL SUPPLY A BOTTLENECK TO NEW MARKETS?

The global cultivation of seaweed is currently stagnating and sufficient and diversified production could become a bottleneck to realizing many new products with seaweed biomass as well as the positive environmental effects of seaweed cultivation.

Current production under pressure

As highlighted in various studies and recently documented by farmers' own perception of challenges (Hatch, 2023) the following challenges and innovation needs are in need of address:

- Climate change is creating shorter seasons and warmer waters that cause a decrease in yields.
- Extreme weather conditions and events more frequently cause slow growth, cause diseases, increase epiphytes or can even destroy entire farm sites.
- Many of the major farming regions have reached maximum carrying capacity in the nearshore areas where the cultivation takes place.
- Labour costs are increasing and the seaweed farming workforce is aging, stressing the need for automation and technology solutions for the cultivation sector
- The lack of quality seed supply – reduces yields and makes the crop more vulnerable to diseases and epiphytes, stressing the need for continued research and development of breeding

However, there are promising opportunities for growth in seaweed production in other regions. Zanzibar (Tanzania) and Chile are emerging producers. Additionally, Europe, the USA, Australia, and New Zealand are making strong commitments to developing their seaweed industries, with some pioneering farms already showing early success.

Chicken and egg situation

There are also challenges in developing a seaweed cultivation of scale outside of Asia which is not picking up at any speed comparable to the industry's growth in Asia.

- Europe's current niche production has a lot higher production price and the investments go into downstream businesses rather than cultivation
- Establishing seaweed cultivation is a burdensome process in terms of licensing and environmental assessments due to lack of regulative framework
- The "chicken and egg" dilemma of uncertain markets prevent production of scale

The fast expansion that created Asia's seaweed production is not a replicable pathway as the situation is highly different.

Smart sustainable scaling

There are also strong voices against the focus on linear focus of just growing more seaweed volume.⁴ Scaling up seaweed production and competing with other producers and uses of the space can strain the marine environment and introduce unknown risks, potentially driving down raw material prices if supply outpaces demand.

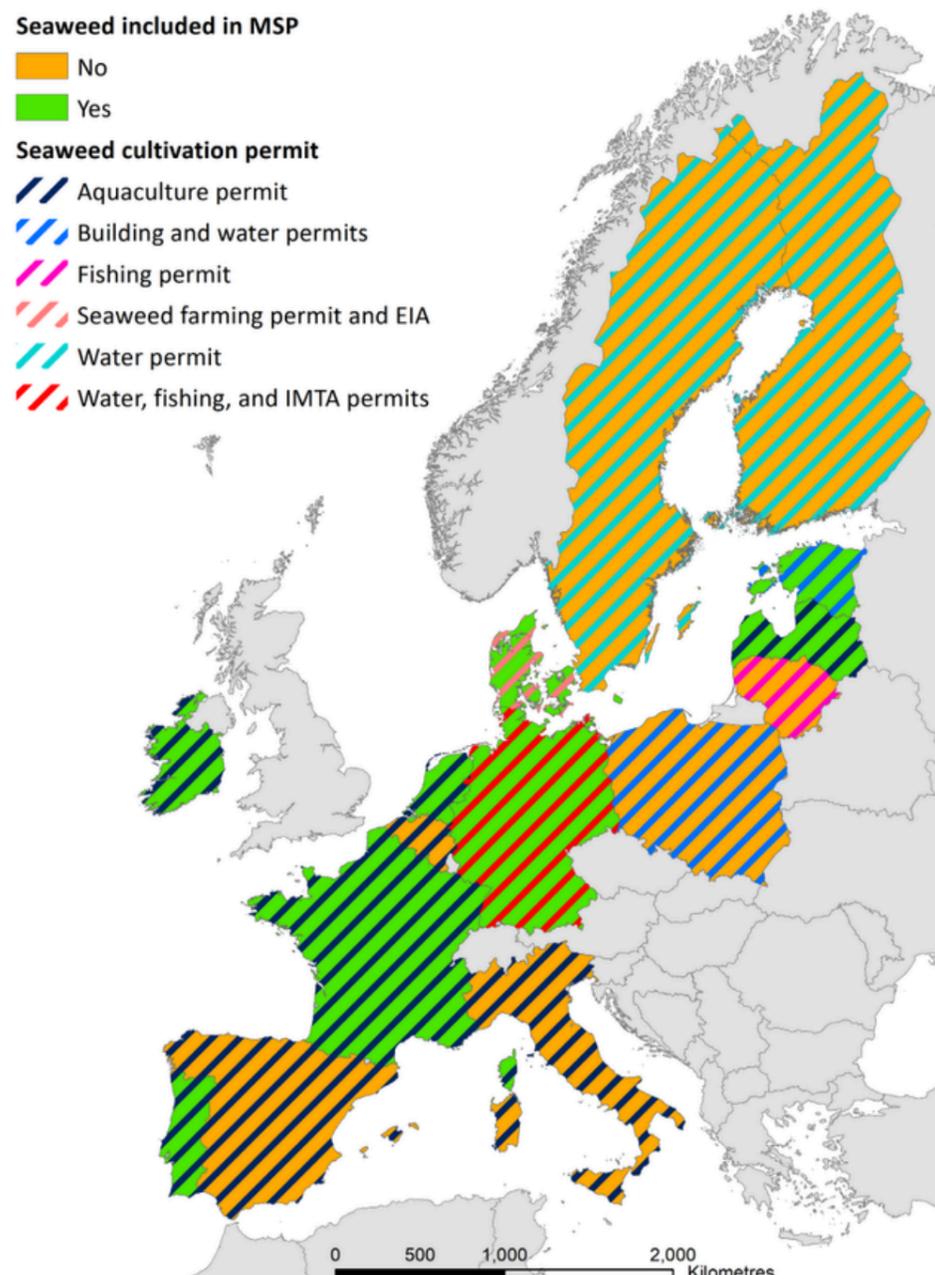
Instead of focusing solely on large-scale farming, the emphasis should be on innovation, creating high-value products, and maximizing economic and social benefits for society. But the slow ramp-up of production of seaweed outside of Asia, in combination with the current low growth in Asian volumes, creates a bottleneck in supply of seaweed for new markets, effectively slowing down the development of these. The impetus for a smart, sustainable seaweed industry as part of blue bioeconomy remains though.

EUROPE'S NEW ALGAE INDUSTRY?

The outlook for a sustainable and high-value seaweed industry in Europe is helped by strong drivers for sustainability and the advent of new biotechnology that can unlock more value from the biomass.

The slow-down of production in Asia along with the strong concentration of global value chain control in few countries brings impetus to increase cultivation outside of Asia.

Figure 20: Different seaweed regulation in EU member states



Source: Reproduced from Kuech et.al 2023

More and smarter production

As has been highlighted by the EU commission, researchers and the Seaweed for Europe, the model studies show that seaweed cultivation in particular the North sea and smartly co-located with e.g. windfarms or other fish aquaculture (IMTA) provides the opportunity to radically increase seaweed production in Europe.

High-value biorefinery approach

The seaweed biomass must be economically optimized in new high-value markets for production to be economically viable. This is necessary as the production cost is currently high compared to the global market price.

With promising applications in health and plant-based foods, as well as nutraceuticals and methane-reducing feed additives it is estimated that European demand could grow up to 9 billion Euros by 2030. Especially in agro-food applications that are short and midterm available.

Algae on the agenda

The EU Algae Initiative from 2022 marks the need to consider algae (seaweed and microalgae) industry in itself with distinct needs for framework development, knowledge and innovation as well as industry support.

In many ways Europe is starting from "scratch" with great regional differences in e.g. ocean spatial planning (figure 20) and no real established domestic production beyond wild harvest and emerging cultivation dominated by pilot scale initiatives.

Accelerating growth

The seaweed startup rate in Europe shows interest and public and private investments are going into the industry albeit in smaller scale than the US (Hermans 2023).

To attract more investments EU and member countries must accelerate the framework conditions to remove risks and make it attractive to invest in seaweed industry. This can be levered with e.g. climate taxation and compensation for ecosystem services.

But improvement must also be made in terms of approvals and standards on i.e. species and mineral levels. EU recently added more species to the list of seaweed that can be used in food. The number of food and drink items containing seaweed or seaweed flavours on the European market increased by 147% between 2011 to 2015 (Mintel 2016).

The acceleration of knowledge and innovation remain crucial to realizing the new seaweed industry and attracting companies and investors to the field. Knowledge gaps cut across both understanding the environmental benefits as well as impacts of seaweed cultivation, market development and technologies.

In the cultivation this is not least optimization of various processes in harvest and stabilization along with breeding of high quality and resilient species. In the processing and biorefinery of seaweed it is about the optimization and diversification of the seaweed products and continued documentation and refinement of seaweed products in new industries.

Actions and initiatives

In pursuit of a modern algae industry in Europe, the 23 actions towards 2027 have been specified across government framework, business environment, R&D and social awareness. Further details of the initiative described in Future of EU Algae Industry (EU 2022, Kuech et.al 2023)

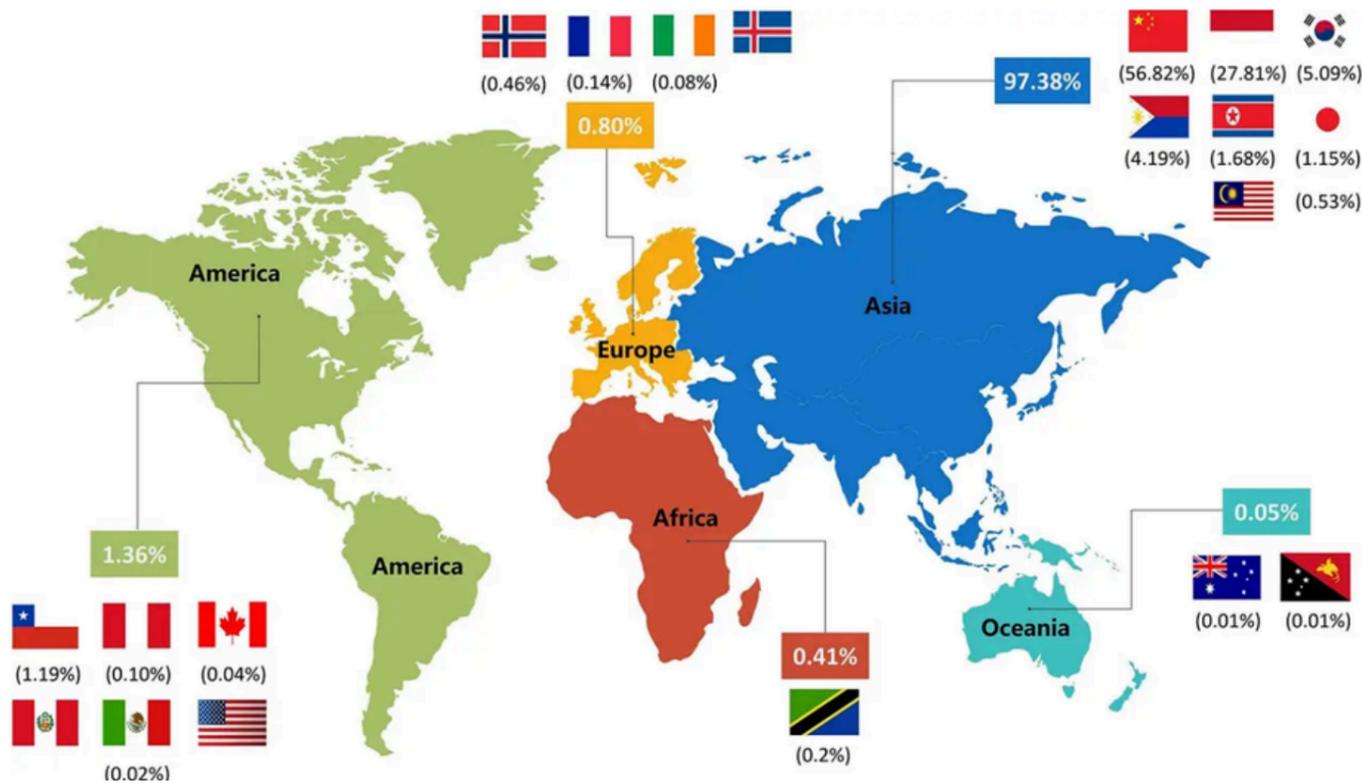
x: See https://maritime-forum.ec.europa.eu/extension-list-algae-species-authorized-food_en
xx. <https://www.cbi.eu/market-information/fish-seafood/seaweed/market-potential>

ASIAN DOMINANCE IN GLOBAL SEAWEED PRODUCTION

Global seaweed production has seen significant volume growth since the 1960s, with Asia maintaining an overwhelming dominance in the industry. In 1969, the 2.2 million tonnes of world seaweed production was evenly divided between wild collection and cultivation. A half century later, however, while wild collection remained at 1.1 million tonnes in 2019, seaweed cultivation increased to 34.7 million tonnes, which accounted for 97 percent of world seaweed production. This production has tripled over just two decades. Red seaweed accounts for 52% of world production, browns for 47,3 while green seaweeds only account for 0,5 %. While reds and browns are increasing, the trend for green seaweed is trending downwards (Cai et.al 2021).

China is the largest producer contributing more than half of the total global seaweed production, while Indonesia and Korea rank second and third. The Americas and Europe contributed, respectively, 1.4 percent and 0.8 percent of world seaweed production in 2019. Seaweed production in these two regions was primarily fulfilled by wild collection. In contrast, cultivation was the main source of seaweed production in Africa and Oceania, although their contribution to world seaweed production was only 0.4 percent and 0.05 percent.

Figure 9: Map of Global Seaweed Production



Source: Reproduced from Zhang et.al 2022

Part of food culture

With growing populations, Asian countries are motivated to develop sustainable food sources like seaweed, a nutrient-rich, low-calorie food packed with vitamins, minerals, and essential fatty acids. Seaweed farming also supports millions of coastal residents, especially in Indonesia and the Philippines, where it drives local economies, creates jobs, and helps reduce poverty in rural communities.

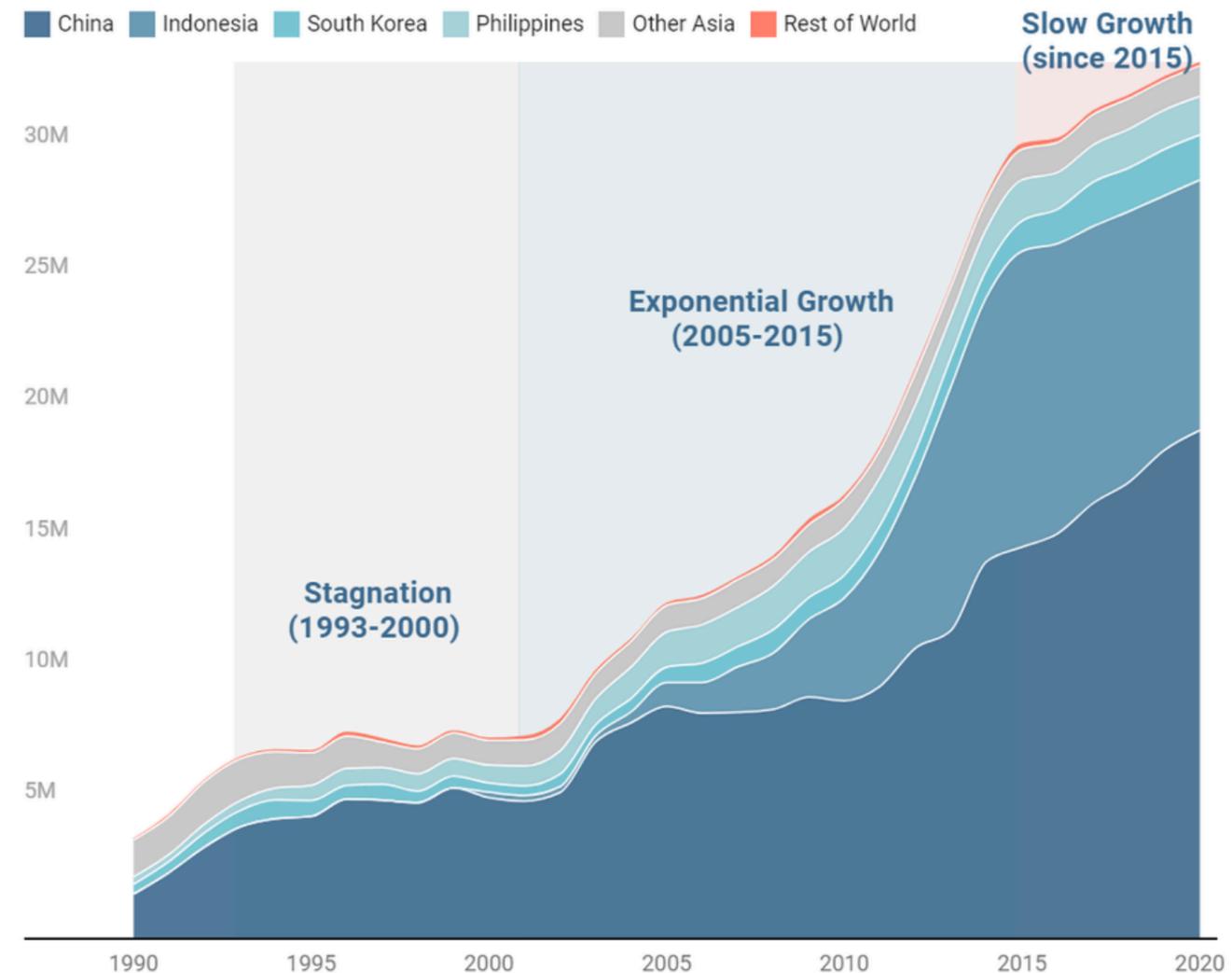
Excellence and know-how

Asia leads in seaweed breeding and cultivation innovations, with China, Japan, and South Korea investing in R&D to enhance yields and create disease-resistant varieties. Techniques like hybridization and selective breeding have produced high-quality seaweed tailored to market demands. In Korea, breeding advancements have developed resilient strains to withstand environmental changes, ensuring consistent supply for domestic and global markets (Cai, 2021).

Slow growth projected

Asia's seaweed industry expanded rapidly from the 1960s with the industrialization of cultivation. China remains the largest producer, though Indonesia's output has surged since the early 2000s, much of which is exported to China for processing. Since 2015, production growth has slowed due to challenges, as the industry has traditionally relied on cheap labor, accessible licensing, and favorable climates—all now undergoing change (Rieve, 2023).

Figure 10: Seaweed production 1990-2020 by country (in tonnes wet weight)



Source: Reproduced from Hatch 2023

TOP 3 COUNTRIES

China: The global leader in seaweed production

China is the world's largest producer of seaweed, contributing over half of the global production. China's role in the seaweed value chain is extensive, encompassing cultivation, processing, and export.

Cultivation: China's seaweed farms are predominantly located along its eastern coast, where favorable environmental conditions such as nutrient-rich waters and appropriate temperatures enable large-scale cultivation. Various cultivation techniques, including longline and raft systems, are used to maximize yield. *Laminaria japonica* is particularly significant, accounting for a large portion of China's seaweed output, which is used both for domestic consumption and export.

Processing and Trade: After harvesting, seaweed in China undergoes extensive processing to produce various products, including alginate, agar, and carrageenan. These hydrocolloids are critical in the global food industry as gelling, thickening, and stabilizing agents. China not only dominates production but also plays a central role in the global trade of seaweed products, exporting to countries worldwide. China's ability to produce at scale allows it to influence global seaweed prices, making it a pivotal player in the market.

Indonesia: Powerhouse of carrageenan production

Indonesia is the world's second-largest seaweed producer, with a particular focus on *Kappaphycus* and *Euclima* species, which are primarily used for carrageenan production. The Indonesian seaweed industry is vital for the country's economy, particularly in coastal communities where seaweed farming provides a significant source of income.

Cultivation: Seaweed farming in Indonesia is predominantly small-scale, involving numerous coastal communities across the archipelago. The warm tropical waters around Indonesia provide ideal conditions for the rapid growth of carrageenan-rich species. Farmers typically use simple, low-cost methods such as off-bottom farming, where seaweed is anchored to the seabed in shallow waters.

Processing and Trade: Indonesia exports large quantities of raw and semi-processed seaweed, particularly to China, the Philippines, and the United States. The country is a key supplier of carrageenan, a vital ingredient in the global food industry, used in products ranging from dairy to processed meats. While much of Indonesia's seaweed is exported in its raw form, there is a growing trend toward local processing to add value and increase economic returns.

South Korea: Hub for high-value seaweed production

South Korea's seaweed cultivation is concentrated in the southern coastal regions, where the clean, nutrient-rich waters provide ideal conditions for growth.

Cultivation: South Korea employs advanced cultivation techniques, including the use of floating rope systems and integrated multi-trophic aquaculture (IMTA), where seaweed is farmed alongside other marine species like fish and shellfish. This approach not only boosts productivity but also enhances environmental sustainability. *Porphyra* is particularly significant in South Korea, where it is a staple in the Korean diet and a major export product.

Processing and Export: South Korea has developed a sophisticated processing industry for seaweed, producing a wide range of products, from dried seaweed sheets used in sushi to seaweed-based snacks and condiments. The country is a leading exporter of high-value seaweed products, with key markets in Japan, the United States, and Europe. South Korea's focus on quality and innovation in product development has positioned it as a leader in the premium seaweed market.

The South Korean government is actively promoting the expansion of the seaweed industry as part of its blue economy strategy. Efforts are being made to enhance the sustainability of seaweed farming practices and to develop new applications for seaweed, including biofuels and biodegradable materials.

PRODUCTION OUTSIDE ASIA

While Asia dominates global seaweed production, other regions are increasingly recognizing the value of seaweed cultivation. Europe focuses on high-value, sustainable applications, while the Americas are beginning to explore aquaculture alongside traditional wild harvesting. In Africa, seaweed farming provides essential economic benefits to coastal communities, and Oceania is emerging as a potential leader in sustainable seaweed farming with a focus on innovation. As global demand for seaweed continues to grow, these regions are likely to play an increasingly important role in the global seaweed industry, driven by sustainability, social impact, and technological advancements. The future of seaweed production outside Asia will likely hinge on the ability to integrate seaweed farming into broader environmental and economic strategies, ensuring that these regions contribute meaningfully to global food security and environmental resilience.

Seaweed cultivation in Europe is small compared to Asia, contributing less than 1% of global production. However, Europe is known for its high-value seaweed applications, particularly in the food, cosmetics, and biotechnology industries.

Key species cultivated include *Saccharina latissima* (sugar kelp) and *Alaria esculenta* (winged kelp), which are primarily used in food products and as raw materials for alginate extraction.

The European seaweed industry is increasingly focusing on sustainability and innovation, with countries like Norway, France, and Ireland leading the charge.

European seaweed is often processed into specialty products, such as organic fertilizers, bioplastics, and nutraceuticals, catering to the growing demand for sustainable and eco-friendly products.

Additionally, Europe is exploring the potential of integrating seaweed farming with other forms of aquaculture and coastal management, aiming to create holistic and sustainable marine ecosystems.

Americas: Wild harvest towards aquaculture

In the Americas, seaweed production is mainly driven by wild harvesting, with Chile being the leading producer.

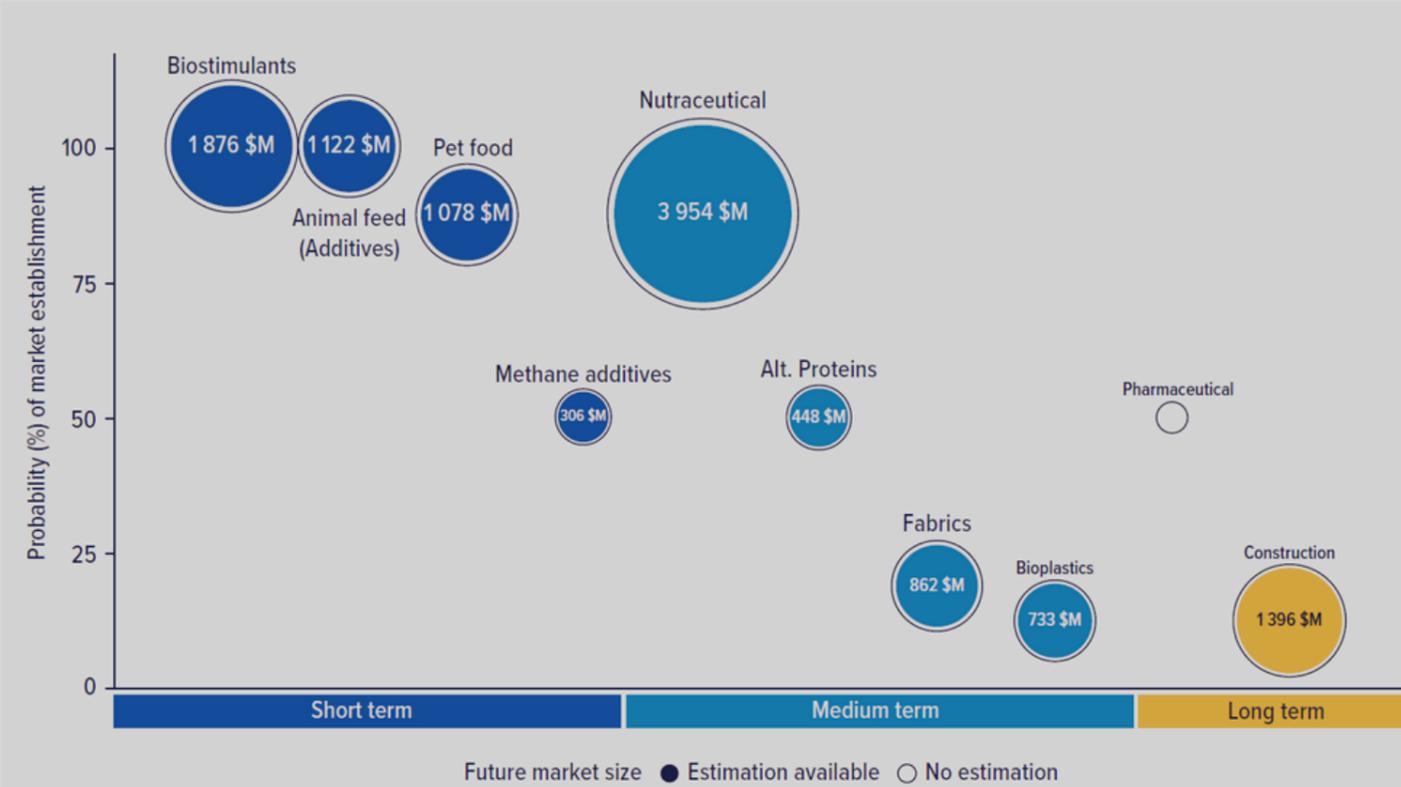
Chile focuses on species such as *Gracilaria chilensis* and *Lessonia nigrescens*, which are primarily used for agar and alginate production, respectively. The wild-harvested seaweed is also used as a raw material for the global food and cosmetic industries.

However, there is a growing interest in developing seaweed aquaculture, particularly in North America, where companies are beginning to explore the potential of cultivating species like *Saccharina latissima* and *Macrocystis pyrifera* (giant kelp) for food, biofuels, and environmental remediation.

The U.S. and Canada are seeing an increase in small-scale seaweed farms, often integrated with other forms of aquaculture to create more sustainable and efficient systems. In addition, there is a growing focus on using seaweed for carbon sequestration and habitat restoration, making the Americas a key region for innovative and environmentally focused seaweed initiatives.

NEW SEAWEED MARKETS

Figure 15 : Predicted seaweed markets by 2030



Source: Reproduced from Worldbank, 2023

1. Biostimulants:

- Seaweed-based biostimulants are becoming increasingly important in sustainable agriculture due to their ability to enhance soil health and crop yields under various stress conditions. The market for biostimulants is expected to grow significantly as farmers seek alternatives to traditional fertilizers amid rising costs and environmental concerns.

2. Animal Feed Additives

- Seaweed is rich in essential nutrients and bioactive compounds that can improve animal health and productivity. Seaweed-based additives are seen as a sustainable alternative to synthetic feed ingredients, offering benefits like enhanced growth rates and disease resistance in livestock.

3. Pet Food

- The pet food market is witnessing a trend towards natural and organic ingredients. Seaweed, with its high nutritional value and health benefits, is gaining popularity as an ingredient in premium pet foods, driven by increasing consumer awareness and demand for healthier pet diets.

4. Methane-Reducing Feed Supplements

- Addressing methane emissions from livestock is critical in combating climate change. Seaweed-based feed supplements have shown promise in significantly reducing methane production in ruminants, offering a potential solution to a major environmental challenge.

5. Nutraceuticals

- Seaweed is a rich source of bioactive compounds with potential health benefits, including anti-inflammatory, antioxidant, and anti-cancer properties. The nutraceutical market is expected to grow as consumers increasingly seek natural and functional foods that promote health and well-being.

6. Alternative Proteins

- As global demand for protein increases, seaweed offers a sustainable alternative to traditional animal and plant-based proteins. Seaweed's high protein content and its potential to be produced with minimal environmental impact make it an attractive option in the alternative protein market.

7. Fabrics

- The textile industry is exploring sustainable materials, and seaweed-based fabrics are emerging as a viable alternative. These fabrics offer unique properties, such as biodegradability and a reduced environmental footprint, aligning with the growing demand for sustainable fashion.

8. Bioplastics

- The global shift towards reducing plastic pollution has spurred interest in bioplastics. Seaweed is a promising raw material for producing biodegradable plastics, which can help address the environmental issues associated with traditional petroleum-based plastics.

9. Pharmaceuticals

- Seaweed contains a variety of bioactive compounds that have potential therapeutic applications.

The pharmaceutical industry is increasingly exploring seaweed-derived compounds for drug development, particularly in areas like anti-inflammatory and antiviral treatments.

10. Construction Materials

- Rationale: The construction industry is exploring sustainable building materials, and seaweed-based products, such as insulation and composites, are gaining attention. These materials offer environmental benefits, such as carbon sequestration and reduced reliance on non-renewable resources.

Ecosystem services

- By leveraging mechanisms like carbon credits, bioremediation payments, and biodiversity credits, the report highlights how these services can be translated into economic value. For instance, seaweed farming can be rewarded through voluntary carbon markets, where companies pay for carbon sequestration services.

SEAWEED INSIGHTS - RESSOURCE

Seaweed statistics are imperfect

The global seaweed production may be less than the official numbers due to data insecurity from some of the producing countries, according to analysis by Hatch Innovation (figure 11).

The webpage seaweedinsights.com is a useful resource to get behind some of the numbers of global seaweed production and understand the differences between species and use. It provides a comprehensive overview including trends across the main cultivated species and the main producing countries.

Based on data from FAO the site provides ample visulation, benchmark and and explanations into developments.

Farmers' insights and outlook

The insights further build on more than 100 interviews with seaweed farmers from China, South Korea, Japan and Indonesia to provide overview of the full value chain from the seaweed farmer to the market place, with insights into sites, farm deigns, seeding, grow out, harvest, post-harvest and sales.

The insights from farmers show both common traits in some of the main challenges to develop the seaweed farms but also shed light on differences both between the countries as well as between the species.

Below are some examples of [Seaweed insights](#), highlighting challenges to the future of seaweed farming across species.

Saccarina

“There is an urgent need to develop processes with a higher level of automation or mechanisation. Fewer people are willing to do physically demanding farm work, and labour costs are rising and challenging the profitability of farms. New and efficient systems that utilise labour saving technologies across all processes are desired by the farmers”

Undaria

“The top three challenges across all Undaria farming regions we surveyed are the changing ocean environment, overcrowded farm spaces and rising labour costs ... n order to expand, farmers in South Korea and China would have to move further offshore which makes the farming process more expensive and requires new technologies. Moreover environmental feasibility studies are required for new farm sites.”

Pyropia

“Climate change is becoming a greater concern for farmers as warming waters and severe weather events become more frequent – and make them more vulnerable to its impacts. Farmers mention that the seasons for Pyropia farming are becoming shorter and consequently they complete fewer harvests per year”

Eucheumatoids

“Nearly every farmer we spoke to had ambitions to expand their farm. The primary factor that limited their expansion was lack of capital. Farmers usually prefer to borrow money from local collectors or relatives instead of having formal arrangements. These loans and payment systems make farmers dependent on the buyers.”

Gracilaria

“Gracilaria farmers use ropes for cultivation. This requires a lot of manual labour, especially when seeding, harvesting and processing. Farmers report that younger generations are not interested in doing this type of work, so finding labour is a recurring challenge for the industry”

Country		 Undaria	 Saccharina	 Pyropia	 Gracilaria	 Eucheumatoids
South Korea		Realistic	Realistic	Realistic		
Japan		Realistic	Realistic	Realistic		
China		Inconsistent	Inconsistent	Realistic	Inconsistent	Unknown
Indonesia					Inconsistent	Inconsistent
Philippines						Inconsistent
Malaysia						Inconsistent

Source:Hatch at seaweedinsights.com

Source: seaweedinsights.com

Figure 16 : Predicted seaweed markets in Europe

♥ Health benefit 🌿 Environmental benefit

Segment	Example application	Primary functions	Benefits
 Food	Raw salads, crisps, spaghetti, burgers	Source of energy, protein and vitamins	♥ Supports healthier diets due to high minerals, vitamins, protein and fibre contents 🌿 Lower environmental footprint than animal or land-based alternative protein sources
 Additives	Gelatine substitutes, processed meat and dairy	Provision of thickening, stabilising and emulsifying properties	♥ Natural and vegan-friendly 🌿 Lower environmental footprint than animal-based alternatives
 Animal feed	Livestock feed supplements, aquafeed supplements, pet food additives	Promotion of positive immune response and gut health; improvement of digestive processes	♥ Improvement in animal health, production yields 🌿 Reduction of methane emissions from livestock
 Biostimulants	Seed treatments	Stimulation of plant growth, protection against abiotic stress	🌿 Lower environmental footprint than nitrogen fertiliser alternatives 🌿 Promotes plant health, productivity and soil regeneration
 Pharmaceuticals & nutraceuticals	Gastrointestinal protectors, biodegradable wound care products / nutrient health supplements	Source of bioactive and nutrient-rich ingredients	♥ Disease prevention and treatment ♥ Natural health enhancers
 Cosmetics	Anti-aging moisturisers, toothpaste	Source of bioactive and nutrient-rich ingredients; provision of thickening, stabilising and emulsifying properties	♥ Natural and vegan-friendly ♥ Supports skin health
 Bio-packaging	Packaging, coatings and plastic films for food containers	Source of marine-safe and compostable plastic molecules	🌿 Replacement of substances causing environmental damage in production (fossil fuel) and after end-of-life (ocean leakage)
 Biofuels	Biodiesel for use in cars	Source of energy	🌿 Replacement for fossil fuels or land-intensive biofuels 🌿 Made from seaweed processing by-products

Significant market segments in Europe

The report "Seaweed for Europe: Hidden Champion of the Ocean" (Vincent et.al 2020) outlines the potential of the European seaweed industry to become a significant economic and environmental contributor by 2030. It highlights the rationale for unlocking this potential and identifies the most prominent emerging markets and uses for seaweed in Europe.

According to the report, European seaweed market alone is expected to grow significantly, reaching between €3.0 and €9.3 billion by 2030 across eight key segments, with feed, food, and biostimulants leading the way (figure 16).

In an optimistic scenario, this market size would surpass the value of EU aquaculture production, which was €5.1 billion in 2017, and approach the scale of the entire EU fisheries sector, which was valued at around €12-13 billion in the same year.

Food and agro sector come first

Towards 2030 it is the food and agro sector that is projected to have the highest potential demand for seaweed, accounting for approximately half of the market.

Animal feed supplements are expected to be the largest segment of the European seaweed market, valued at €540-2,220 million. This growth will mainly come from the livestock feed sector, particularly for cattle, swine, and poultry, due to the health and yield benefits of seaweed supplements. Additionally, certain seaweed species in feed can help reduce methane emissions in cattle

The European food segment is expected to grow to between €700 and €2,100 million by 2030, primarily fueled by the plant protein market and directly consumable seaweeds. The majority of growth in the seaweed food market is expected to come from the directly consumable sub-segment, which encompasses seaweed consumed raw, dried, or incorporated whole into various food products.

In the most optimistic scenario, the European market for seaweed-based biostimulants could reach €1,820 million by 2030. This target is achievable if anticipated technological advancements in processing are realized and, importantly, if the EU enforces policies that significantly increase the costs of conventional nitrogen fertilizers, including a rise in carbon pricing.

One third can be produced in Europe

When it comes to Europe's projected ability to provide domestic grown seaweed for the new markets the outlook on each category differs, but in an ambitious scenario the report estimates that Europe could produce up to about one third of the seaweed for its markets, while Asian seaweed will continue to be important and dominate in some markets (see figure 17).

FROM FOOD SECTOR TO INTEGRATED BIOECONOMY - DANISH STRATEGIES

Biosolutions in Denmark

Biosolutions encompass a range of biotechnological innovations, such as enzymes, microorganisms, and other biobased materials, which are used to improve the efficiency and sustainability of food production processes.

Companies like Novozymes and Chr. Hansen are at the forefront, producing advanced enzymes and microbial cultures that enhance food quality and safety while reducing waste and environmental impact. The biosolutions sector in Denmark currently employs approximately 6,800 people and is projected to create 7,000 new jobs by 2030 (Strategi for grønne job).

Biosolutions in Denmark focus on developing sustainable alternatives to conventional agricultural and food processing methods. This includes the use of enzymes and bioreactors to convert agricultural residues into valuable products, such as bioenergy, feed proteins, and even food-grade proteins.

Denmark's expertise in this area allows for the conversion of agricultural biomass (like manure, straw, and grass) into diverse products such as bioplastics, biofuels, and sustainable food ingredients.

Biosolutions are therefore central to create a more sustainable and resource-efficient food systems.

New jobs in the agricultural sector

The "Strategy for Green Jobs" (2024) in Denmark looks to promote green jobs within the agricultural sector and its associated industries. It highlights several key areas:

- **Agri-tech Innovations:** Denmark is focusing on technologies that improve resource efficiency in agriculture, such as precision farming and automated systems. These technologies help reduce emissions and optimize the use of inputs like water and fertilizers.
- **Plant-Based and Organic Food Production:** There is a strong push towards plant-based food production, aligning with global trends towards sustainable diets. Denmark aims to double its organic agricultural area by 2030 and increase exports of plant-based foods. This strategy supports green job creation and positions Denmark as a leader in sustainable food production (Strategi for grønne job).
- **Development of Biosolutions:** The biosolutions strategy emphasizes the development of biobased technologies to replace fossil-based inputs and chemical pesticides in agriculture. By using renewable resources, Denmark seeks to make its food production systems more sustainable and less reliant on traditional agricultural practices.

FURTHER INSIGHT

The national strategy for green proteins in December 2023 by the Ministry of Food and agriculture: [Green Proteins](#)

The strategy for creation of green jobs in agriculture with focus on new opportunities in biosolutions is available here: [New jobs in bioeconomy](#)

Green proteins

Denmark's "Green Protein Strategy" (2023) aims to significantly boost the production of sustainable, high-quality proteins by 2030, reducing dependence on imported proteins and fostering a more plant-based food sector. Key Initiatives include:

- **Green Biorefining:** This initiative focuses on converting green biomass, such as clover grass and lucerne, into high-value protein concentrates. Green biorefining not only extracts proteins but also utilizes residual products for feed and bioenergy, maximizing resource efficiency. The Danish government has allocated substantial funding for research and development, aiming to enhance biorefining technologies and expand biorefinery facilities across the country.
- **Exploration of New Protein Sources, Including Seaweed:** Denmark is investing in alternative protein sources such as insects, microalgae, and seaweed. Seaweed is particularly highlighted due to its rapid growth, high protein content, and

- minimal environmental impact—it requires no freshwater or fertilizers and absorbs carbon dioxide. The strategy includes enhancing seaweed cultivation and processing techniques to integrate seaweed as a viable protein source in both food and feed applications.
- **Research and Innovation:** The strategy underscores Denmark's commitment to advancing research and innovation in green proteins. This includes developing new protein sources, improving the taste and nutritional profile of plant-based proteins, and addressing regulatory challenges. The Danish government has established centers of excellence to drive innovation and foster collaboration among industry, academia, and public institutions.



5. ALL ABOUT SOUTH KOREA

SOUTH KOREA'S SEAWEED EXCELLENCE

Korea is a peninsula with rich tradition for marine economy - from seafood industry over maritime industry and lately also an aspiring offshore wind nation.

As outlined in section 3 Korea is one of the world's leading seaweed producers and highly advanced when it comes to cultivation, use and research into seaweed.

Economic and cultural importance

Seaweed is among the most important food export items from Korea along with ginseng and kimchi and accounts for 77% of the total aquaculture production in Korean marine waters. The export of pyropia reached a record high of 790 million dollars in 2023 and has grown with an average of more than 7% yearly since 2010 (Seo 2024a)

With little arable land in Korea the importance of marine products has historically prevailed, and Korea is today the nation with the highest human consumption of seaweed thanks to rich gastronomic tradition as well as traditional medicine use.

To safeguard the industry against some of the challenges like climate change, polluted waters and also to further boost the value of the industry in the light of global demand, Korea has launched a Seaweed Industry Act to develop the industry and is home to a world leading research community in e.g. breeding and cultivation.

Future fit seaweed industry

Korea continues to invest in excellence in breeding selection and development of resilient seaweed species that can cope with

the challenges. Between 2012-2023 Korea has registered 37 new varieties with plant variety protection (PVP) rights.

Specifically to find solutions to the impact of climate change to seaweed production, Korea is looking not only at resilient species but also into increased landbased aquaculture technology as well as relocation of aquafarms more offshore.

Also as part of Korea's technology and digitization strategies the development of advanced technology for seaweed processing is reflected as a specific development area to improve the efficiency of i.e. drying technology.

Korea has a dynamic startup scene and is investing heavily into acceleration of new companies across technology, food and biotech. Given the rich tradition and ecosystem around seaweed there are also many Korean emerging companies looking to create meat and seafood alternatives with seaweed and tap into high-value markets that are emerging beyond the region.

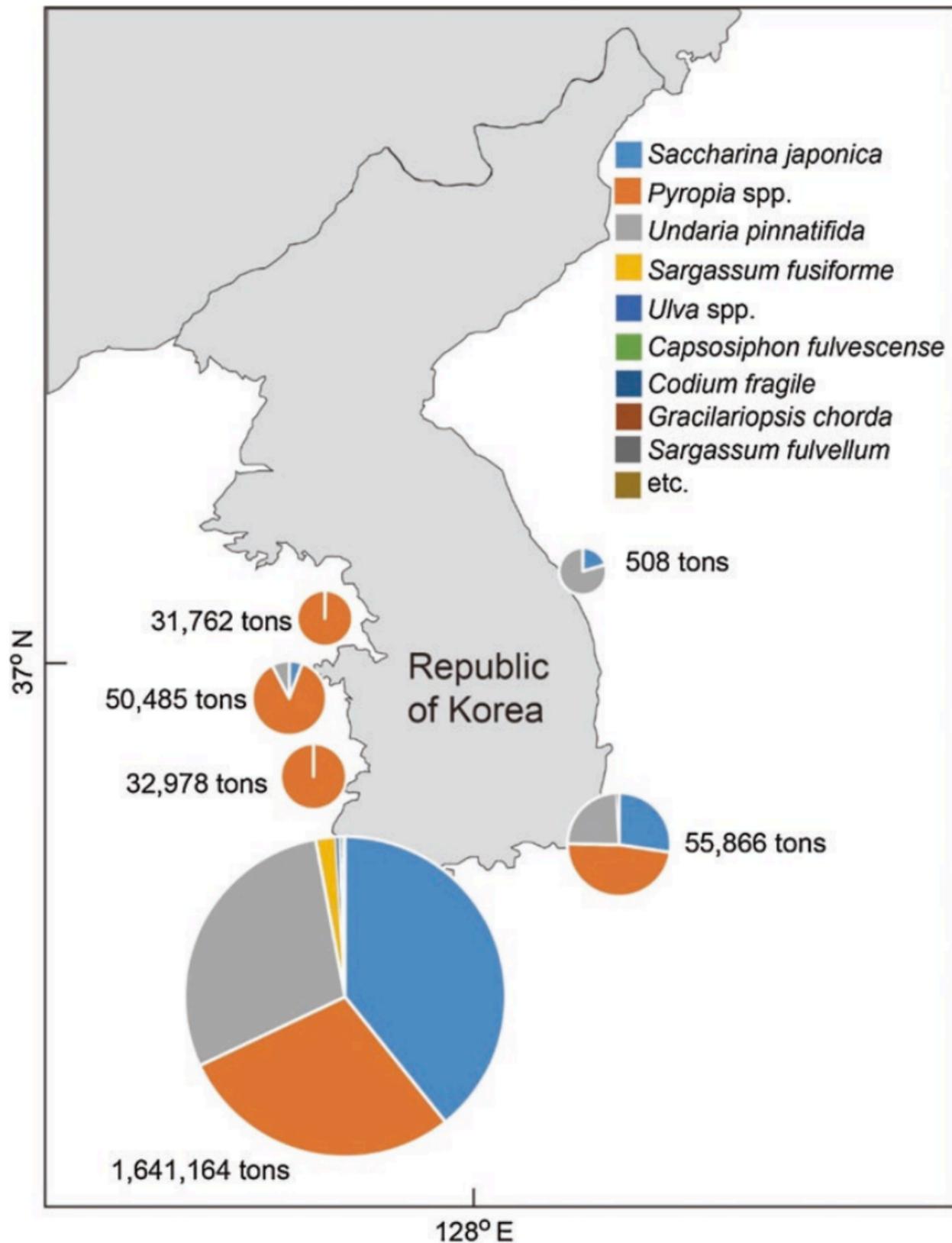
Global ambition

Leading Korean food companies such as CJ and Daesang with existing export of dried seaweed are looking into the opportunities for diversification of markets and further product development (Seo 2023).

On this backdrop Korea is both an attractive and willing partner in international collaboration for a modern, sustainable and high-value seaweed industry.



Figure 22: Seaweed farming in Korea



Source: Reproduced from Park et.al 2022

Korea's seaweed production

Seaweed cultivation in Korea has a long and rich history, dating back to the 15th century. The industry initially began with the cultivation of *Pyropia* (commonly known as laver or "Gim" in Korea), which remains the most economically valuable seaweed species in the country.

Seaweed farming in Korea is concentrated on the west side of the south coast where almost 90% of total seaweed cultivation occurs (Park et.al 2022).

Pyropia is the highest-value seaweed and the cornerstone of Korea's seaweed export industry, accounting for USD 790 million in exports in 2023. Production reached approximately 550,000 tons in 2022 and *pyropia* is the fastest growing category increasing volume with 7.4% yearly average since 2010. Only China sees higher growth rates around 8%.

Other cultivated species include *Saccharina* and *Undaria*, which are primarily used as feed in abalone farming. Despite the higher volumes, the combined value of *Saccharina* and *Undaria* is lower than that of *Pyropia*,

While *Pyropia* continues to be a significant focus due to its high value, the Korean seaweed industry has adapted over the years to meet changing demands. The sector has diversified from focusing solely on edible seaweeds for direct consumption to include other species like *Undaria* and *Saccharina*, particularly for their use in the expanding abalone aquaculture sector.

This shift was largely driven by the economic advantages of using seaweed as a low-cost feed option. Additionally, there has been an increasing demand for seaweed in various industries, including bioenergy, health supplements, and cosmetics.

This diversification has led to a more robust industry capable of responding to global trends towards sustainability and natural products (eun kyong purchased).

Innovative edge

The introduction of the International Union for the Protection of New Varieties of Plants (UPOV) system in Korea in 2012 has significantly enhanced the seaweed industry's development. This system has enabled the protection of new *Pyropia* varieties, fostering innovation in cultivation techniques. Since then, 14 new *Pyropia* cultivars have been registered, focusing on enhancing productivity, disease resistance, and environmental adaptability.

These innovations have been crucial in maintaining Korea's competitive edge in the global market, especially for high-value exports such as *Pyropia*

Looking forward, Korea's seaweed industry aims to sustain growth through innovation and sustainability. Key areas of focus include developing eco-friendly farming technologies and breeding programs for high-quality, climate-resilient seaweed varieties.

The industry is also exploring the potential of indoor cultivation systems to ensure year-round production and minimize environmental impacts. These innovations are designed to strengthen Korea's position as a leader in global seaweed production, emphasizing high-value, sustainable products to meet the growing consumer demand for natural and health-focused foods.

Seaweed in Korean diet and gastronomy

Seaweed is a fundamental part of Korean cuisine, featuring prominently in both everyday meals and special occasions. Koreans have traditionally consumed various types of seaweed, each offering unique flavors and textures that enhance a wide range of dishes.

South Korea is known for having the highest per capita consumption of seaweed. On average, a South Korean person consumes around 24.9 grams of seaweed per day.

Figure 23: Seaweed in Korean cuisine

Species name	Korean name	Preparation	Cooking method	Remark
Chlorophyceae				
<i>Monostroma</i> complex	Hotparae	f, d	Various seasoning by soy sauce	<i>M. grevillea</i> , <i>M. nitidum</i>
<i>Ulva</i> complex	Parae	f, d	Sesame oil, sometimes vinegar	<i>U. prolifera</i> , <i>U. compressa</i> , <i>U. intestinalis</i> , <i>E. linza</i> , <i>U. clathrata</i>
<i>Capsosiphon fulvescens</i>	Maesaengi	f	Boiled soup with oyster ¹⁵⁾	-
<i>Codium fragile</i>	Cheonggak	f, d	Seasoning by soy sauce and vinegar, mix to kimchi	-
Phaeophyceae				
<i>Scytosiphon lomentaria</i>	Korimae	f	Various seasoning soup, fried in oil	-
<i>Ecklonia stolonifera</i>	Kompi	f, d	Fresh salad	-
<i>Undaria pinnatifida</i>	Miyok	f, d, s	Fried in oil, boiled soup, soaked with vinegar, soy sauce and sugar in water	-
<i>U. peterseniana</i>	Nolmiyok	f, d, s	Fried in oil, boiled soup, soaked with vinegar, soy sauce and sugar in water	-
<i>Saccharina japonica</i>	Dasima	f, d	Fried in oil, soup	-
<i>Pelvetia siliquosa</i>	Thumbugi	f, d	Steamed salad	-
<i>Sargassum fusiforme</i>	Tot	f, d	Various seasoning	-
<i>S. fulvellum</i>	Mojaban	f, d	Various seasoning	-
<i>S. horneri</i>	Kwaengsaegi-mojaban	f, d	Various seasoning	-
Rhodophyceae				
<i>Pyropia</i> complex	Gim	f, d	Toasted, seasoning, rolled with rice	<i>P. yessoensis</i> , <i>P. seriata</i> , <i>P. dentata</i>
<i>Nemalion vermiculare</i>	Chamguksunamul	f	Salad	-
<i>Gelidium amansii</i>	Umutkasari	d	Extracted agar	-
<i>Pterocladia capillacea</i>	Kaeumu	d	Extracted agar	-
<i>Gloiopeltis furcata</i>	Bultunggasari	f, d	Mixed soup, seasoning	-
<i>G. tenax</i>	Pulgasari	f, d	Mixed soup, seasoning	-
<i>G. complanata</i>	Aekipulgasari	f, d	Mixed soup, seasoning	-
<i>Grateloupia asiatica</i>	Jinaejinuari	f, d	Salad	-
<i>G. subpectinata</i>	Bitsaldobak	f, d	Salad	-
<i>Gracilariopsis chorda</i>	Gaekkoshiraegi	f	Various seasoning	-
<i>Chondria crassicaulis</i>	Gaeseoshil	f, d	Various seasoning	-

Modified from the Table 2 of Sohn (1998).
f, fresh; d, dried; s, salted.

Source: Reproduced from Hwang et.al 2020



Image Source: Canva

Korean 'gim' and 'birthday soup'

Pyropia, known locally as "Gim," is the most popular seaweed in Korea. It is typically processed into dried sheets that are toasted and lightly seasoned, commonly served as a side dish or used to wrap rice and other ingredients in dishes like kimbap, a Korean-style rice roll. Gim is also enjoyed as a crispy, savory snack, making it a versatile and widely beloved component of Korean food culture.

Other types of seaweed, such as Undaria (wakame) and Saccharina (kelp), are also integral to Korean cooking. Undaria is a key ingredient in soups, most notably in miyeok-guk, a seaweed soup that is traditionally consumed on birthdays and by new mothers for its believed health benefits, such as aiding postpartum recovery and promoting overall wellness. Saccharina is often used in Korean cuisine to make rich, flavorful broths and as a seasoning ingredient, adding a deep umami flavor to various dishes.

Convenience and new products

The culinary uses of seaweed in Korea have diversified in recent years, extending beyond traditional applications to include modern convenience foods. Products such as seaweed snacks, seaweed noodles, and powdered seaweed are now popular, catering to health-conscious consumers who appreciate seaweed's nutritional profile, which includes high levels of vitamins, minerals, and dietary fibers.

This trend towards convenience and health-focused seaweed products reflects the versatility of seaweed and its growing appeal as a nutritious and sustainable food source.

WORLD LEADING RESEARCH AND INDUSTRY ECOSYSTEM

South Korea is known for its overall excellent R&D capacity and its leading position in many technology fields. Korea has an excellent and sizeable science and innovation ecosystem as well as a global leading industry to tap into for collaboration.

Government Initiatives and National Research Centers

The South Korean government, through the Ministry of Oceans and Fisheries and the Ministry of Science and ICT, plays a significant role in promoting innovation in the seaweed sector.

The National Institute of Fisheries Science (NIFS) is a key player, focusing on breeding new seaweed varieties, enhancing cultivation techniques, and exploring applications in food, feed, and pharmaceuticals.

These efforts are complemented by government initiatives like the “Golden Seed Project,” which provide funding and resources for seaweed and broader agricultural research.

Academic Institutions and Research Centers

Several universities across South Korea are at the forefront of research in seaweed and food innovation:

- Mokpo National University: Specializes in marine biology and seaweed cultivation techniques, focusing on developing new varieties and improving disease resistance and yield.
- Pukyong National University: Offers extensive research programs in marine science and technology, with a focus on sustainable aquaculture and the utilization of marine resources, including seaweed.
- Jeju National University: Conducts research on seaweed breeding, bioactive compounds, and innovative cultivation methods suited to Jeju Island's unique marine environment.

- Korea University: Engages in multidisciplinary research encompassing food science, biotechnology, and marine biology. The university works on developing functional foods and bioactive compounds derived from seaweed.
- Seoul National University: Focuses on biotechnology and sustainable food production, including research on seaweed's nutritional and functional properties, and its application in developing new food products.
- Yonsei University: Known for its work in environmental science and biotechnology, Yonsei's research includes seaweed's potential for bioenergy and bioplastic production.
- Kangwon National University: Engages in research on aquaculture and marine biology, with projects aimed at enhancing seaweed cultivation techniques and exploring their use in animal feed and biofuels.
- Inha University: Specializes in marine and environmental sciences, conducting research on sustainable seaweed farming practices and the development of seaweed-based products.

Technoparks, Tech Transfer, and Innovation Clusters

South Korea's technoparks and technology transfer offices (TTOs), such as those at universities and public research institutions, play a vital role in bridging research and industry. Jeonnam Technopark and Gyeongbuk Technopark actively support the commercialization of research outcomes and foster collaborations between academia and industry. These technoparks offer infrastructure, funding, and mentorship to startups in the food and biotechnology sectors, including seaweed-based innovations.

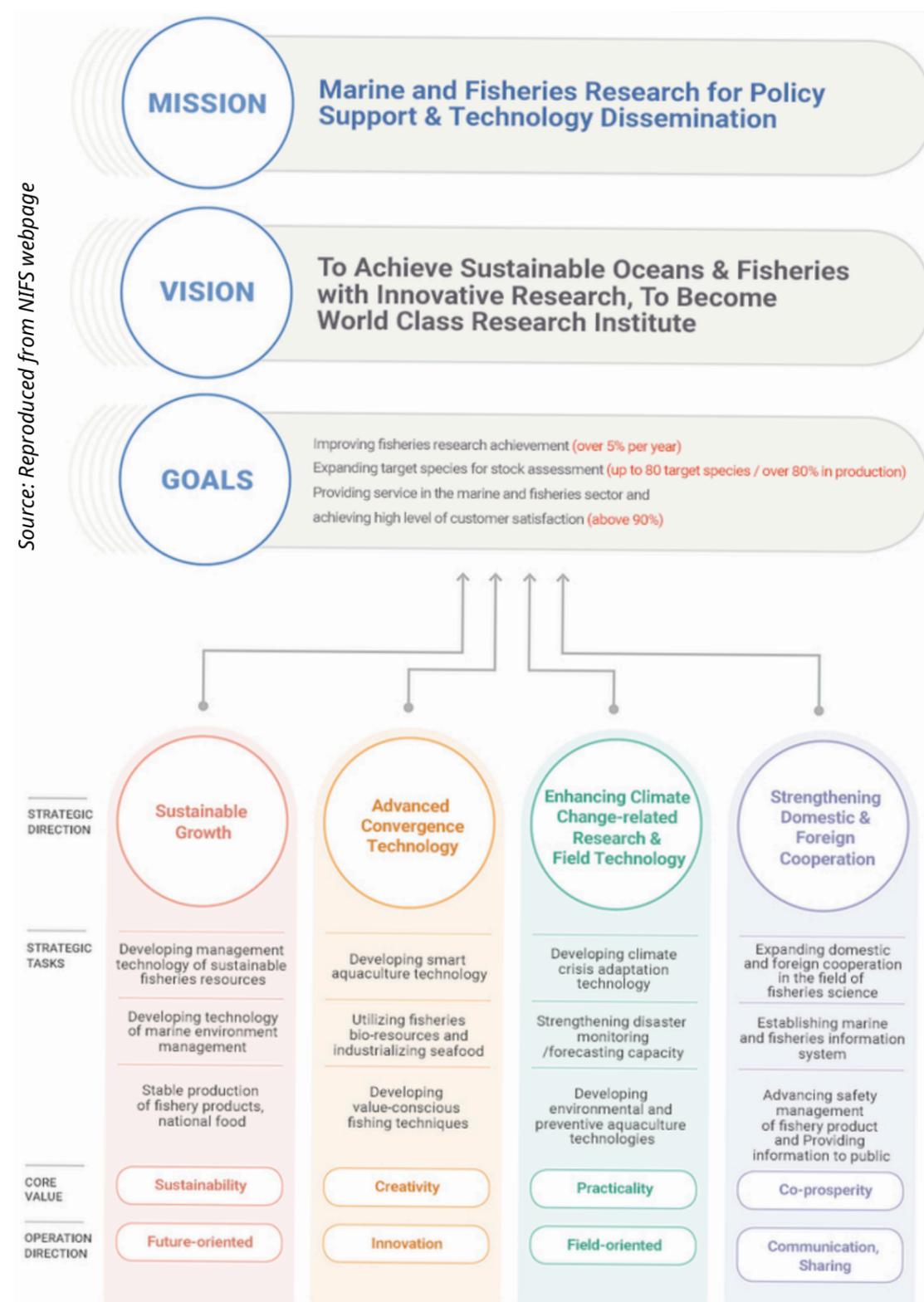


Figure 24: NIFS Seaweed Research

The National Institute of Fisheries Science (NIFS) in South Korea employs approximately 500 people, including 200 researchers dedicated to advancing sustainable fisheries and aquaculture. These researchers focus on a range of areas, including developing sustainable fisheries management technologies, marine environment management, smart aquaculture, and climate change adaptation strategies. NIFS is also actively involved in the industrialization of seafood and the utilization of fisheries bio-resources, with a particular emphasis on innovative seaweed cultivation techniques and marine resource management. The institute aims to enhance both domestic and international cooperation in fisheries science to support sustainable growth and food security.

Korea has both large corporate food companies with global export of seaweed products as well as startups using seaweed in new ways powered by biotech. CJ is Korea's largest food company and seaweed export to more than 60 countries and leading new product development for the global markets. Startup Seawith plans to transform Korea's protein production through its locally developed, meat-free food solutions and have developed cell culturing mediums and tissue scaffolds from seaweeds and microalgae.

Foodpolis: National Food Cluster

Foodpolis, the National Food Cluster located in Iksan, Jeollabuk-do, is a central hub for food innovation in South Korea. It offers state-of-the-art facilities like R&D centers, pilot plants, and quality control labs, specifically designed to support food innovation, including seaweed-based products.

Foodpolis promotes collaboration among food companies, research institutions, and startups, fostering innovation in functional foods, fermented foods, and seaweed products. It provides incentives for both foreign and domestic companies, strengthening South Korea's position as a leader in global food innovation.

Startup Support in Food and Biotechnology

Several organizations are dedicated to fostering startups in the food and biotechnology sectors. Seoul Biohub, KAIST Venture Investment Holdings, and Korea Startup Forum offer incubation services, funding, and strategic support to emerging companies. Foodpolis also plays a significant role in supporting startups, providing access to shared facilities, technical support, and business development services, particularly for innovative food products, including those based on seaweed.

Collaboration with Industry Leaders

Major industry players, such as CJ CheilJedang, Daesang, and Dongwon F&B, are deeply integrated into the innovation ecosystem. These companies collaborate closely with research institutions and benefit from government-funded programs to develop new seaweed products and processing technologies. This collaboration ensures they remain competitive in both domestic and international markets by leveraging the latest scientific advancements and market insights.

South Korea is at the forefront of integrating advanced technologies into seaweed farming and processing. Innovations such as Recirculating Aquaculture Systems (RAS), automation, and artificial intelligence are being employed to enhance sustainability and productivity. There is also a strong emphasis on sustainable practices, such as eco-friendly farming methods and certification through ASC-MSC standards, which promote environmentally responsible seaweed production.

STRATEGIC INITIATIVES FOR ADVANCING SOUTH KOREA'S SEAWEED INDUSTRY

Seaweed Act

In South Korea, the "Basic Plan for Marine and Fisheries Development" has been established to promote the development of marine and fisheries. The plan is established annually through collaboration among seven government agencies, including the Ministry of Oceans and Fisheries, the Ministry of Public Administration and Security, and the Ministry of Health and Welfare.⁵

The Korean Seaweed Industry Act covers various aspects, including the development and dissemination of Korean seaweed-related technologies, fostering specialized personnel, enhancing seaweed cultivation productivity, promoting consumption of processed seaweed products, expanding market share, supporting international exchange and cooperation, improving seaweed product quality, and designation of seaweed industry zones.

Nagoya Protocol

Korea ratified the Nagoya Protocol in 2014. It is an international agreement under the Convention on Biological Diversity (CBD) that governs the access to genetic resources and the fair sharing of benefits arising from their use. In accordance with the protocol, continuous efforts are being made to manage various genetic resources, and ongoing research relating to the discovery of novel and unrecorded species is being conducted to secure national biological sovereignty.

Smart Aquaculture

Since 2019, the Ministry of Oceans and Fisheries has been conducting the "Smart Aquaculture Cluster Project". This project seeks to transform the labor-intensive aquaculture industry into a technology-intensive knowledge industry through the integration of such advanced technologies as ICT and AI into aquaculture. The Smart Aquaculture Cluster Project is currently being implemented in six locations nationwide: Busan, Goseong-gun (Gyeongsangnam-do), Sinan-gun (Jeollanam-do), Gangwon-do, Pohang (Gyeongsangbuk-do), and Jeju-do.

Plantbased Strategy

The Ministry of Agriculture, Food and Rural Affairs is currently pushing for the support of R&D projects in alternative foods, including plant-based proteins, cell culture foundational technologies, and the development of related technologies such as culture mediums, aiming for progress by 2025. The plan includes expanding tax deductions for companies, covering up to 40% of related R&D costs and up to 15% of facility investment costs.

According to the "Food Tech Industry Development Strategy" announced by the Ministry in December 2022, the creation of a special law to support companies involved in plant-based alternatives. The government aims to nurture 30 domestic food tech-related unicorn companies by 2027. Additionally, there are plans to establish a Food Tech Convergence Research Support Center, which is expected to alleviate the initial facility costs burden for related companies.

5) 법제처. 국가법령정보센터. '김 산업의 육성 및 지원에 관한 법률'. <https://law.go.kr/LSW/lsInfoP.do?lsiSeq=224663&viewCls=lsRvsDocInfoR#>

THE LAW ON THE CULTIVATION AND SUPPORT OF KOREAN SEAWEED INDUSTRY

Scope :

The entire gim industry, encompassing industries relating to production, cultivation, processing, manufacturing, cooking, packaging, storage, transportation, distribution, export, sale, etc.

Content :

The Basic Plan, including the goals and directions for promoting the gim industry as well as the development and dissemination of technologies related to the gim industry.

1. Basic goals and directions for the promotion of the gim industry.
2. Matters pertaining to the development and dissemination of technologies relating to the gim industry.
3. Cultivation of specialized personnel in the gim industry and matters pertaining to statistics and digitization of information/data.
4. Matters pertaining to improving the productivity of gim cultivation and promoting the consumption and distribution support of gim processed products.
5. Matters pertaining to market development and promotion for expanding the sales of gim and gim processed products.
6. Matters pertaining to international exchange, cooperation, and support for expanding export markets.
7. Matters pertaining to improving the quality and management of gim and gim processed products.
8. Matters pertaining to the designation of gim industry development zones.
9. Matters pertaining to research and development of gim varieties.
10. Matters pertaining to hygiene and safety management of gim products and quality control in processing and manufacturing.
11. Any other matters deemed necessary for the promotion of the gim industry.

DANISH KOREAN COLLABORATION

Korea and Denmark are approximately 8.000 kilometers apart, but both countries are peninsulas with strong marine interests and innovation capacity, sharing the ambition to foster sustainable green growth. This is a great starting point to join forces to tap into the new markets and uses for seaweed, both as a versatile biomass with potential application in a range of industries, as well as a built-in positive climate impacts.

Considering the complementary strongholds when it comes to the nexus of seaweed in sustainable food and agriculture and the emerging global seaweed markets, Korea and Denmark can gain advantages in collaboration by combining both countries' areas of excellence and bridge the established Asian and emerging European seaweed industry.

With a solid bilateral collaboration platform spanning from science and innovation to food, health and energy the ecosystems of both countries have rich access to making connections and collaborations.

The Danish Koran Blue Bioeconomy Alliance established as a network in 2022 and exemplifies initial steps to connect researchers, clusters and companies and explore areas of shared interest.

How to get started?

There are several instruments available to foster collaboration in research and innovation between Denmark and Korea.

Under the Danish ministry of Science and Higher Education it is possible to apply for Global Innovation Network Program (GINP) 1-2 times per year. This is a grant that

supports initial network building and can facilitate costs of visits, workshop etc. See more details here: [GINP](#)

The Danish [innovation fund](#) supports both companies as well as innovation consortia in open calls (i.e. Grand Solutions) that can fund development activities with research and commercial partners involved.

Under the partnership project Agrifoodture there are similarly [open calls](#) which are posted directly at the webpage.

The Horizon Europe has several work programs with open calls for, sustainable food and blue bioeconomy where both Denmark and Korea can be partners.

For Danish startups and SMEs there are several internationalization programs available, providing incentives for i.e. market visits and connecting to potential Korean partners and market.

Innovation Centre Denmark

[Innovation Center Denmark](#) can support all entities that are interested in collaboration on a running basis and provide information and advice on both available programs and partners.

With a dedicated team in Seoul, the center facilitates collaboration and can design customized visit programs and services to meet the needs and interests of individual entities or groups.

FURTHER INSIGHT

To get in contact with partners of the Danish Korean Blue Bioeconomy Alliance partners, inquiries regarding opportunities, or requests for further information, get in contact with Innovation Centre Denmark Seoul.

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8. High-growth seaweed companies per region
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10. Seaweed farming in Korea
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WEB RESSOURCES

- [EU4Algae](#)
- [EU Blue Bioeconomy Observatory](#)
- [Seaweed Insights by Hatch Innovation](#)
- [Seaweed for Europe](#)
- [Phyconomy by S. Hermans](#)
- [Green Wave](#)
- [North Sea Farmers](#)

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APPENDIX 1

Seaweed and food safety

A Nordic report on seaweed safety (Hogstad 2022) identifies several safety challenges related to the consumption of seaweed, particularly concerning the presence of heavy metals like arsenic, cadmium, and mercury, as well as iodine content.

Currently, there are no specific international standards or harmonized regulations governing the safety of seaweed as a food product, either globally or within the European Union. This lack of clear guidelines poses a challenge for ensuring the safety of seaweed products.



Image source: Reproduced from Norden 2022

Regulatory development

However, as of now, the general food safety regulations in the EU, which apply to all food products, also apply to seaweed. The report emphasizes the need for the development of specific maximum levels (MLs) for contaminants in seaweed, as the current standards for other foods are not fully applicable due to the unique properties of seaweed.

The Nordic countries, including Denmark, are at the forefront of addressing the challenges related to seaweed safety. Denmark, in particular, is actively involved in seaweed cultivation and has been providing guidance for both producers and consumers to mitigate safety risks.

The Danish Veterinary and Food Administration (DVFA) has issued advice on the production, harvest, and consumption of seaweed, emphasizing the need to monitor iodine and heavy metal content. Denmark, along with other Nordic countries, is advocating for a harmonized approach to seaweed regulation across the EU, one that considers the specific species and production conditions found in the Nordic region.

Nordic countries, due to their specific environmental conditions and the species of seaweed prevalent in their waters, should play a significant role in shaping future EU regulations on seaweed safety. This includes advocating for specific legislation that classifies seaweed as a distinct group of foodstuffs with subgroups based on species, which would allow for more accurate and relevant safety standards.

The Nordic approach emphasizes the importance of regional collaboration and tailored regulations that reflect the unique characteristics of seaweed as a food product.

Below are listed some resources that provide overview into area of seaweed food safety, existing legislation and discusses the development of international harmonization of standards on seaweed and food safety.



EU4ALGAE

The platform is a unique space for collaboration among European algae stakeholders, including algae farmers, producers, sellers, consumers, technology developers as well as business-support organisations, investors, public authorities, academia, researchers and NGOs.

GLOBAL SEAWEED COALITION

The Global Seaweed Coalition is a global partnership established to support the safety and sustainability of the seaweed industry as it scales up and to unite a fragmented market through a unified vision and goals. Co-founded by UN Global Compact the coalition supports various projects through yearly open calls. See: <https://www.safeseaweedcoalition.org/>



FSEAWEED FOR EUROPE

Seaweed for Europe is a Coalition seeking to accelerate and scale the European seaweed industry by driving innovation and investment, with the ultimate aim of unlocking significant economic, environmental and social benefits. The Coalition brings together a range of stakeholders from the seaweed value chain, the investment world, and science and civil society thought leaders. In their investment case the current legislative challenges are discussed: <https://www.seaweedeurope.com/wp-content/uploads/2021/10/S4E-InvestorMemo-MainReport-16OCTOBER2021.pdf>

FAO EXPERT FORUM

Despite the increasing utilization of seaweed as a food source, significant gaps exist in the regulation and standardization of food safety measures. The report highlights the need for developing specific Codex guidelines and harmonized national legislation to address potential hazards, such as heavy metals, microbiological contaminants, and physical hazards. See <https://openknowledge.fao.org/server/api/core/bitstreams/43575678-4f1c-4e24-a452-3fc3c07fa4e7/content>



APPENDIX 2

Danish promotion of seaweed use

A Danish report “Plant-Based Seafood – Seaweed and Microalgae as a Source of Omega-3 Fatty Acids, Protein, and Vitamins in Future Foods” (Hermund et.al 2023) explores the potential of seaweed and microalgae as crucial components in developing sustainable, plant-based seafood alternatives.

The report highlights the growing trend toward plant-based diets, driven by environmental and health concerns. Seaweed and microalgae are presented as viable alternatives to traditional land-based agriculture, offering a more sustainable method of producing essential nutrients while reducing environmental impact.



Image source: Reproduced from DTU 2023

Seaweed and microalgae are rich in essential nutrients, including omega-3 fatty acids, proteins, vitamins, and minerals, which are typically obtained from fish and other seafood. The report emphasizes that these marine organisms can provide a comparable nutritional profile, making them suitable substitutes in the human diet.

Consumer preference

Significantly the report addresses consumer acceptance of new plant-based foods. It emphasizes the importance of taste, appearance, and texture in ensuring the success of seaweed and microalgae-based products. The report also notes that while these products are not as widespread as other plant-based alternatives, they hold significant potential in the market, especially in the context of increasing demand for sustainable food options.

More seaweed in Denmark?

To fully realize the potential of seaweed and microalgae in the food industry, the report calls for further development of processing technologies and industrial-scale production methods. This includes improving the efficiency of cultivation and harvesting techniques, as well as developing methods for extracting and refining the valuable components of these marine resources.

Highlighting the significant potential of seaweed and microalgae to contribute to a more sustainable and nutritious food system. It calls for increased investment in research and development to overcome the current challenges in production and processing, and to ensure that these marine resources can be effectively integrated into the global food supply.

Below are some examples of Danish R&D organisations and networks that connect researchers and companies to further the innovation and uptake of seaweed - both with a lense of biorefinery methods, sustainable agro-food sector and as part of plantbased innovation.

ALGAE CENTER DENMARK

AlgeCenter Danmark

AlgaeCenter Denmark is a collaboration between four institutions: Aarhus University, Danish Technological Institute, Copenhagen University and the Kattegatcentre. The purpose of AlgeCenter Denmark is to find out how algae can be used as a new resource in a world where traditional resources are under pressure. A number of research projects serve to find out how algae can be used for sustainable energy, food, medicine and food ingredients.

SEAWEED NETWORK

The Danish non-profit organisation for seaweed stakeholders have around 500 members that collaborate and knowledge share on better understanding of seaweed and how to use and grow it in the Nordic context. The network gathers resources including ongoing projects and activities and is active in positioning Danish stakeholders in international activities as well. See website: <https://tangnet.dk/>



FOOD AND BIO CLUSTER

The national Danish cluster organisation for food and bio bridges the research, startup and industrial partners in the Danish ecosystem. Partnering in and managing a large portfolio of innovation projects, they further organize and create networks around topics such as the green protein, biorefinery processes and sustainable food production.

FOOD INNOVATION HOUSE

Located in one of Denmark's primary food regions, Food Innovation House is a place of practical experimentation in connection with both private companies and the local government institutions. A core innovation focus is plantbased foods and food innovation house is host to a range of projects co-financed by major private and public foundations.



APPENDIX 3

Social awareness and accept

One of the main barriers to uptake of seaweed is the current gap to consumer awareness and market accept. The larger trend of climate friendly and healthy plantbased innovation is an important lever for introduction of seaweed for human consumption.

The 2022 Plant-Based State of the Industry Report by the Good Food Institute (Bushnell et.al 2023) provides an in-depth analysis of the plant-based sector's developments, focusing on the rising consumer awareness and acceptance of plant-based foods, including seaweed.



Image source: Reproduced from GFI 2023

Youth are leading the change

The report highlights that social awareness regarding environmental sustainability and personal health is driving the growth of plant-based foods. This trend is particularly strong among younger consumers, who are more likely to prioritize sustainability in their food purchases.

Consumer beliefs about health, sustainability, and animal welfare are significant drivers of the plant-based food market. Health is a top motivator, with many consumers perceiving plant-based foods as healthier alternatives to animal products.

The environmental benefits of plant-based diets, such as lower greenhouse gas emissions and reduced resource usage, also resonate strongly with consumers, particularly those in younger demographics.

There are challenges related to consumer education and awareness. While many consumers are aware of the benefits of plant-based diets, there is still a lack of understanding about the nutritional content and health benefits of specific plant-based products.

Taste and price win

But taste, price, and convenience remain the most critical drivers of consumer behavior. This highlights the need for the plant-based industry to focus on improving the taste and texture of products to match or exceed those of traditional meat, dairy, and seafood. Price is another major barrier. Plant-based foods are often more expensive than their animal-based counterparts, which can deter price-sensitive consumers from making the switch.

The report highlights the government efforts of countries like Denmark and South Korea with regards to promoting plant-based foods, including seaweed. Below are listed some examples of initiatives aimed at the social awareness and market acceptance of seaweed.



EU SOCIAL CAMPAIGN

As part of the EU algae initiative social awareness and market accept of seaweed and algae one of the central pillars. In 2024 a new campaign was launched to raise awareness among consumers on seaweed and algae including nutritional profile, health benefits and practical knowhow on how to use and cook with seaweed. See: https://www.youtube.com/watch?v=X_oPjqVIuZY

ALGAEFOOD PROJECT

Addressing the social acceptance of seaweed in foods Denmark is part of a European project to stimulate increased consumption. AlgaeFood wants to bring all involved parties - from actors to institutions and interest groups, and not least the ordinary consumer - together to establish algae as a new food in our region. And with tailored marketing concepts, the project wants to target consumers' preferences and bring them closer to the benefits of algae. See: <https://www.sdu.dk/da/om-sdu/fakulteterne/naturvidenskab/nyheder-2023/algaefood>



SEAWEED IN HOSPITAL FOOD

Supported by the Danish foundation for plantbased food in 2023 a hospital in Copenhagen is experimenting with integrating seaweed in the food for patients there in line with sustainability goals. This is a pilot on how public institutions can help to break ground for new foods.

CHILDREN AND SEAWEED

As part of the Danish initiative Taste for Life, children are educated about seaweed and its practical use. The project is an interdisciplinary, nationwide research and communication centre. The aim of Taste for Life is to collect knowledge about taste and pass it on so that children, young people and adults can use taste as a resource for a good life. See: <https://www.smagforlivet.dk/>



APPENDIX 4

NEW SEAWEED COMPANIES

There is increasing interest in seaweed industry, and new companies are starting globally with Europe and North America as the most dynamic regions.

The website phyconomy.net provides a database based on open sources tracking the development of new seaweed companies and is cited by i.e. the EU Commission.

Most focus on the products

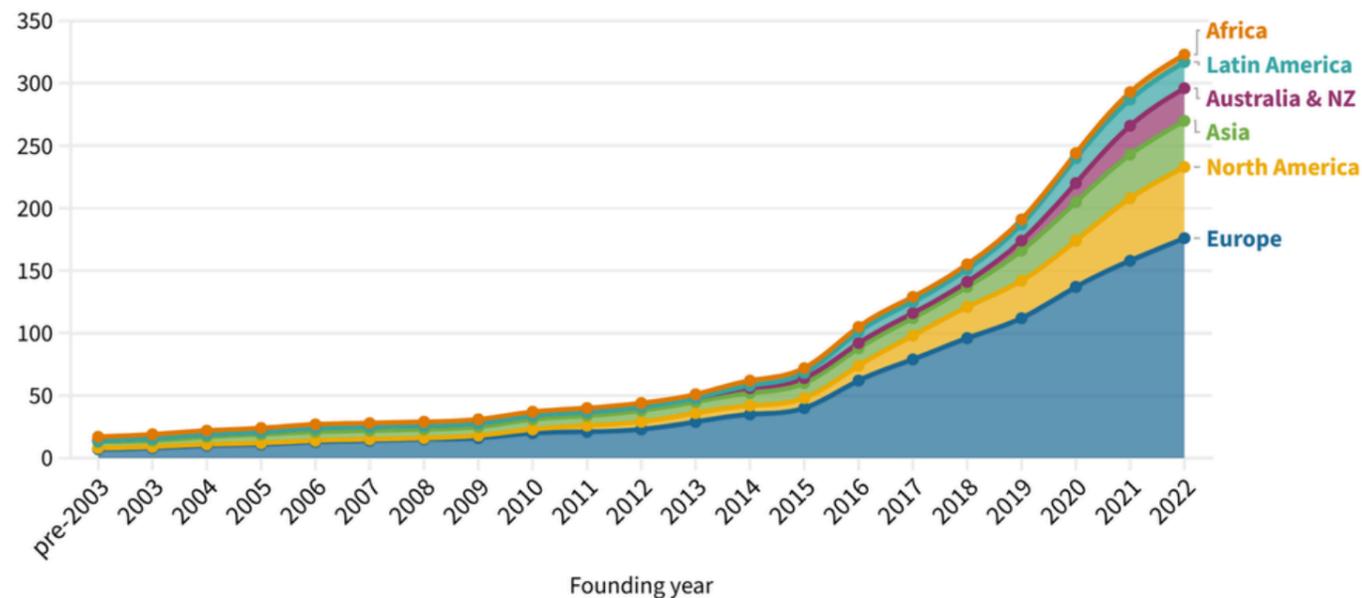
According to this source the investments into seaweed companies are mostly oriented towards applications with seaweed and biorefinery, feed and food accounting for most of the investments. While the total number of companies and investments is small because the seaweed industry is emerging, the growing trend is however clear.

In the analysis of the new companies and investments there are several gaps highlighted such as the differences between the species used by European food industry which are different from the actual species grown domestically. This is an indication of the reliance on import from Asia of the main species for food uses currently (Hermans 2023)

Cost is main barrier

Cost of seaweed production outside of Asia remains a main barrier for the market development. The potential cost-savings need to come from different innovations across energy use as well as more automatized harvest process and selective breeding of species (Coleman et.al 2022)

Figure 18: High-growth seaweed companies per region



Source: Reproduced from Phyconomy 2022

Below are listed a few examples of companies featured in the Phyconomy database across different regions and focus. The full database is available online at www.phyconomy.net



BIOREFINERY - US

The company Macro Oceans are based in California and their business is biorefinery of seaweed (kelp) from Alaska. The company has developed a technique to store the crop for up to 12 months at room temperature which eliminates the cost and energy for freezing or drying. Founded in 2020 Macro Ocean raised 5 mio. dollars investments.

VOLTA GREENTECH

FEED ADDITIVE - EU

Based in Sweden the company Volta Greentech develops a feed additive for cows. The products bioactive compounds inhibit the methane-producing microorganisms resulting in reduction up to 90%. Volta Greentech raised 32 mio. SEK investment in 2024 and cooperate with leading Nordic food companies as Coop and Orkla.

THE DUTCH WEEDBURGER



FOOD - EU

The Dutch Seaweed Burger was founded in 2012 and uses locally cultivated seaweed to produce vegan burgers, nuggets etc. The company was bought by Livekindly Collective in 2021 and intends to scale internationally in the UK, Nordics, and the US and Canadian markets; as well as enter into Asia.

BIOREFINERY - EU

Algaia is a French company producing alginates to a variety of industries. The company has received a total of €7 million for its manufacturing facility in Lannilis, Brittany, France, with another €1 million at its R&D facility in Saint-Lô, Normandy. Algia has a product line specifically designed for meat analogs and functions by improving the interaction between the protein, lipid, and water components of the food system



CULTIVATION - EU/ US

Ocean Rainforest is a Faroe Island based seaweed aquaculture company founded in 2007 that seed, grow, harvest, and process seaweed. Since 2010 they have cultivated seaweed in the waters around Faroe Island. Working with California, the company secured a USD 4.5 Million Technology to Market Plus Up award from ARPA-E as part of the MARINER Program