D4.1.1 Study on existing market for algal food applications

Part A: Seaweed

Deliverable D4.1.1
Part of ValgOrize WP4 Valorisation
Executed by Stichting Noordzeeboerderij/ North Sea Farm Foundation
September 2019

Preface

This report is part of the Interreg 2 seas project ValgOrize. The project is coordinated by Own Capital Flanders Research Institute for Agriculture and Fisheries (BE) and includes 11 other partners among which; Flemish Institute for Technological Research (BE), Royal Netherlands Institute for Sea Research (NL), HZ University of Applied Sciences (NL), North Sea Farm foundation (NL), Zeewaar BV (NL), University of Littoral Côte d'Opale (FR), University of Lille (FR), University of Greenwich (UK), Marine Biological Association of the United Kingdom (UK), Texel Saline BV (NL), Nausicaa (FR).
The ValgOrize project runs for a period of four years, started in 2018 and is funded by Europe via the Interreg 2 Seas Programme.

This report is a co-production of several team members of the North Sea Farm Foundation; Lotte Bronswijk, Mila Vlottes, Marlies Draisma, Eef Brouwers and Frederik van Baelen. The North Sea Farm Foundation is a non-profit organisation aimed at realising a sustainable seaweed industry in the Netherlands and surrounding EU countries.

In the ValgOrize project, the North Sea Farm Foundation is leading the study on valorisation aimed at supporting and accelerating the development of a technically and commercially viable seaweed supply chain for food applications, and the development of a roadmap towards sustainable production of micro-algae for food applications.

Contact information

Questions and remarks about the report and the project can be shared with Marlies Draisma (marlies@noordzeeboerderij.nl) from the North Sea Farm Foundation.

Disclaimer

Table of content

1 Introduction

1.1 Introduction to the project and report

This report is part of the Interreg ValgOrize project for the European Union. The project aims at enhancing innovation in the algal sector, by creating an interdisciplinary platform for sustainable production of flavoursome, high quality algal foods that meet the requirements of the European market. For more information about the project and the role of North Sea Farm Foundation (Stichting Noordzeeboerderij), see annex 1.

The project comprises of 6 work packages:

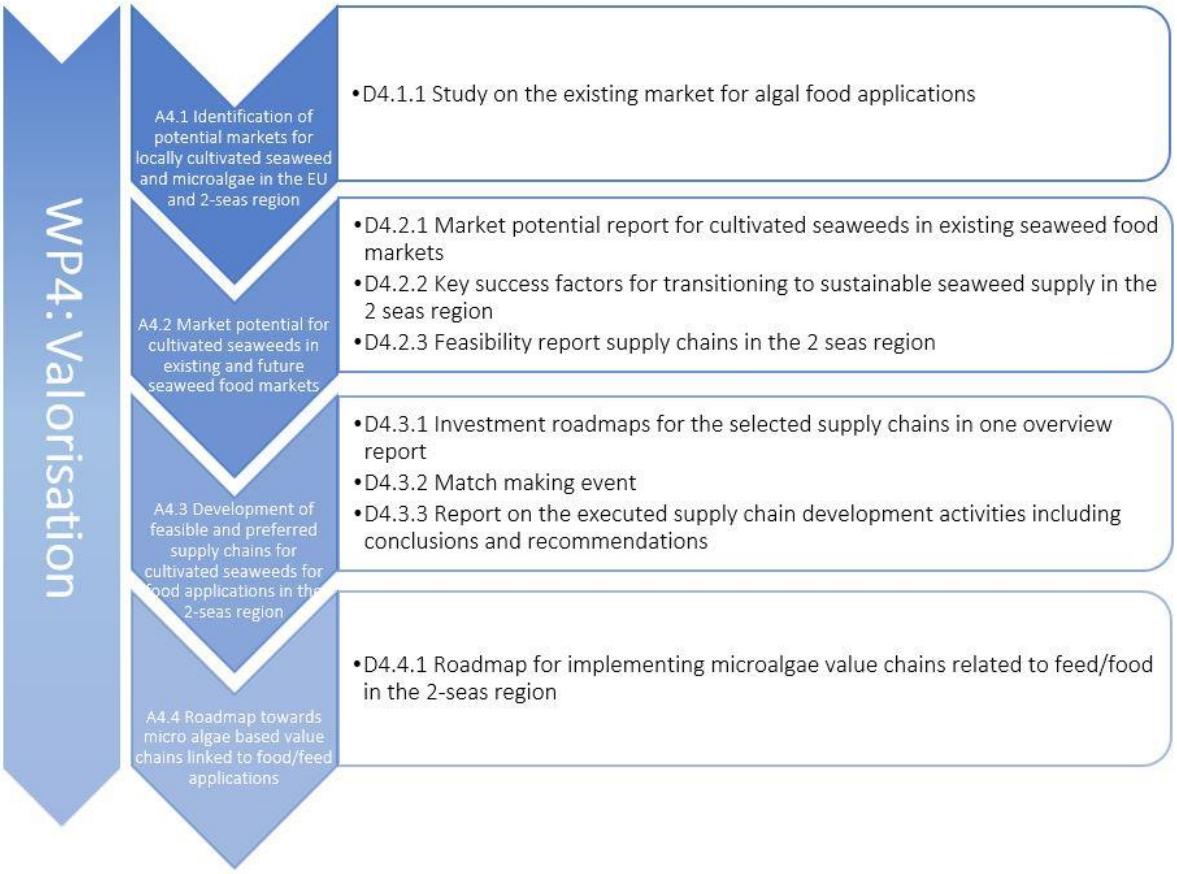
- Work Package 1: Macroalgae cultivation; optimized macroalgal growth conditions (quality, reproducibility and reliability) for best food parameters.
- Work Package 2: Microalgae cultivation; optimization of cultivation methods for maximal productivity and yield of biochemicals and markers of taste.
- Work Package 3: Acceptance of the produced micro/macroalgal biomass and algae products for consumption; assessing algal safety, quality (as food product), optimal taste, product development, sustainable/zero waste.
- Work package 4: Valorisation; support and accelerate the development of a technically and commercially viable seaweed supply chain for food applications, and the development of a roadmap towards sustainable production of micro-algae for food applications.
- Work Package 5: Project management
- Work package 6: Communication

This report is part of Work Package 4: Valorisation; support and accelerate the development of a technically and commercially viable seaweed supply chain for food applications, and the development of a roadmap towards sustainable production of micro-algae for food applications. Within the work package, the results and insights as obtained in WP1, 2 and WP3 will be valorised. This specific report constitutes the required deliverable D4.1.1 'Study on the existing market for algal food applications' as part of activity A4.1 'Identification of the potential markets for locally cultivated seaweed and microalgae in the EU and 2 seas region'.

Project information:
Website: https://www.interreg2seas.eu/en/ValgOrize
Financing: Interreg 2 Seas
Start date: 12/07/2018
End date: 31/03/2022
Partners: VITO-Vlaamse Instelling voor Technologisch Onderzoek, Royal Netherlands Institute for Sea Research, HZ University of Applied Sciences, Stichting Noordzeeboerderij, Zeewaar BV, ULCO - Université du Littoral Côte d'Opale, Université de Lille, University of Greenwich, Marine Biological Association of the United Kingdom, Texel Saline BV, Nausicaa
Contact: Marlies Draisma

1.2 Activities and deliverables for Work Package 4

Figure 1: Activities and deliverables for Work Package 4: Valorisation (Stichting Noordzeeboerderij, 2019).



1.3 Scope for Deliverable D4.1.1

For Deliverable D4.1.1. 'Study on the existing market for algal food applications' an insight in the existing market for seaweed as food in Europe and specifically the 2 seas region has been provided and the current status of locally cultivated seaweed in this market has been investigated. This report covers the existing market for seaweed food applications. The existing market for microalgae is elaborated on in a separate report.

By means of desk research and interviews it has been assessed: **What is the existing market for seaweed food applications?** The following sub questions have been composed in order to answer the main question, all focussing on Europe and the 2 seas region:

- What are the characteristics of the current seaweed food market?
- How is the seaweed (food) market currently being supplied?
- What are the trends and developments related to seaweed as food?

The approach has been used to answer the questions below for Europe and the 2 seas region:

- What is the origin of the seaweed used in food applications?
- What are the production methods for seaweed for food applications?
- What species of seaweed are used in food applications?
- What types of seaweed food applications are currently available on the market?
- What is the production volume of the seaweed intended for the food market?
- What are the most relevant stakeholders in the seaweed food market?

2 Methodology

In order to answer the above questions, literature/desk research from publicly available sources has been performed as well as semi-structured interviews with relevant stakeholders. The aim was to get an insight into the general trends and developments in Europe, concerning seaweed for food and to obtain information about the seaweed for food market globally, in Europe and specifically in the 2 seas countries (Belgium, France, the Netherlands and the United Kingdom). Providing an insight in the global seaweed food market is considered important in order to measure the European market against the global standards and developments.

For the literature search, publicly available, reliable and recent sources have been consulted, such as among others the FAO and World Bank reports (world), Netalgae and Pegasus reports (Europe) and data from specific countries in the 2 seas region from e.g. CEVA (France) and CEFAS (UK).

As a consequence of the literature search, gaps in data and knowledge have been identified. As is stated in the application form, very limited verifiable information is available on the actual markets of seaweeds for food applications within the EU and EER. Therefore, the scientific knowledge has been complemented with in-depth, semi-structured interviews with (observing) partners of ValgOrize and several other relevant stakeholders. To achieve contact with relevant stakeholders, snowball sampling has been used. The aim of conducting these interviews has been to obtain additional market insights of the existing market for seaweed as food.
Stakeholders from different seaweed producing countries within the EU and EER and with different expertise within the seaweed supply chain have been interviewed. For a complete overview of the interviewed parties, see annex 2. Several different interview protocols have been created, suiting the different stakeholder categories. Questions during the interview have been divided into three main categories: Information about [the company], [the company] and seaweed, and more general seaweed market information. A summary of the interview protocol can be found in annex 3. All interviews have been conducted by telephone, recorded and condensed in a report which was sent to the interviewee for a revision and agreement.

The dataset that has been obtained by the literature search and supplemented with the results of the interviews is presented in the following chapters.

3 Characteristics of the current seaweed market

3.1 About seaweed

Algae are much older than terrestrial plants and are among the first forms of life on earth. Seaweed has been used as food in coastal areas all over the world for thousands of years. Asia has a particularly rich history with the consumption of seaweed and in Japan, seaweed even constitutes up to 10% of the population's total nutritional intake. However, European countries and regions, such as Ireland, Wales, Scotland, Brittany and the Nordic countries, also have a historical connection with seaweed.

3.2 Cultivation and harvest of seaweed

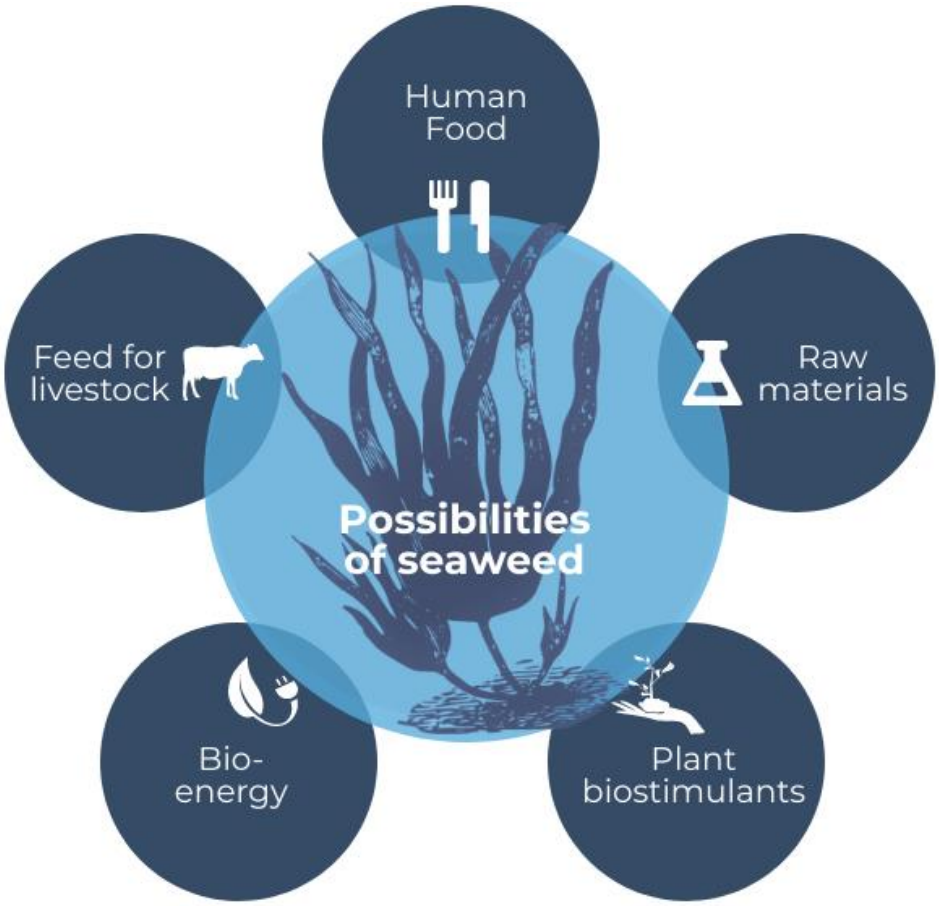
Seaweed can be wild harvested or cultivated. Globally, 96% of the seaweed originates from cultivated sources (Rebours, et al., 2014). In contrast, 99% of seaweed production in Europe originates from wild harvest (Mac Monagail, Cornish, Morrison, Araújo, & Critchley, 2017). Wild harvest occurs by collecting natural populations directly from the ocean, gathered mechanically or manually, on- and offshore. Potential consequential disturbances caused to the ecosystem are dependent on the regularity of occurrence, intensity, and the amount of the biomass that is removed (Foster & Barilotti, 1990; Vásquez, 1995). The strong European reliance on natural stocks currently may result in significant disturbances to the ecosystem if wild harvesting practices increase in order to meet future demand.
The cultivation of seaweed has the potential to offer a variety of environmental benefits. A method to measure the influence of aquaculture in the marine environment is the ecosystem services approach. A case study provided by Hasselström et al. (2018) showed that a majority of ecosystem services are unaffected or positively affected by the introduction of seaweed cultivation in an ecosystem. Examples of such services include nutrients cycles, habitat creation and food provisioning (Hasselström, Visch, Gröndahl, Nylund, & Pavia, 2018).

In order to secure a stable and sustainable supply, the cultivation of seaweed is increasingly seen as the way forward. A growing number of seaweed species are cultivated on suspended ropes or nets, kept in place by poles, buoys or weights. The cultivation has little to no freshwater and nutrient requirements and could potentially far exceed the grow rates of many terrestrial plants (Stévant, Rebours, & Chapman, 2017).
Most cultivation activities occur onshore, nearshore or inshore; in sheltered waters close to the coast or in bays or fjords. Moreover, offshore cultivation offers up-scaling possibilities and is currently in development. The North Sea Farm Foundation performs pilot tests on the Dutch North Sea.

3.3 Seaweed applications

Seaweed has many different applications. Apart from being a source of food, seaweed can be a substantial feedstock for among others biomass, biofuel production and animal feed (Tiwari & Troy, 2015). According to CEN/TC 454 Algae and Algae products (Unpublished): *"The interest in algae and algae-based products or intermediates has increased significantly in Europe as a valuable source including but not limited to, carbohydrates, proteins, lipids, and several pigments. These materials are suitable for use in a wide range of applications from food and feed purposes to other sectors, such as textile, cosmetics, biopolymers, biofuel and fertilizer/biostimulants."*
Although seaweed is suitable for a wide range of applications, by far the largest part of the worldwide seaweed production is intended for food (FAO, 2018).

Figure 2: Possibilities of seaweed. The central seaweed icon is sourced from Roadmap 2030, developed by North Sea Farm Foundation (Stichting Noordzeeboerderij, 2019).



3.4 Seaweed species

In total, there are more than 10,000 different species of seaweeds, growing in range of different climate zones and habitats. The appearance of seaweed is dependent on its natural habitat to which it is adapted and can therefore vary enormously between species. Nonetheless, three groups of seaweed can be distinguished, based on the colour of the seaweed: green algae, red algae and brown algae. The colour is determined by the amount of pigments in the seaweed (Mourtisen, 2013).

Out of the 10,000 species, only 221 seaweed species are commercially relevant (FAO, 2018). The species and application selection of the seaweed is dependent on a wide range of economic, environmental, regulatory and compositional factors. In the food market, additional parameters such as the palatability are taken into account. In total, approximately 145 species of seaweed are being used for food applications (FAO, 2018).

4 Seaweed as food

4.1 Species

Of the more than 70 species which have been reported in the Chinese diet, only 27 are accepted as food in Europe of which some are imported, and some locally grown. By combining literature review and interviews, an overview of the most important commercial seaweed species for the European food market has been ensembled. Before consulting the figure below, it should be taken into consideration that the seaweed food market in Europe is developing at a fast pace, rendering the overview accurate for a limited time only.

Figure 3: Most important locally occurring seaweed species for the European food market, based on stakeholder interviews and literature (Netalgae, 2012) (Barbier, et al., 2019).

Common name	Species	Cultivation (country)	Wild Harvest (country)
Atlantic wakame/ Winged kelp	*Alaria esculenta*	FR, IE, NO, NL, DK	GB, IE
Rock weed/ Knotted wrack	*Ascophyllum nodosum*		GB, IE
Irish moss	*Chondrus crispus*	FR	GB, FR, IE, ES, PT, NL
Bladderwrack	*Fucus vesculosus*		IE, GB, NL
Slender wart weed	*Gracilaria sp.*	PT	FR, NL
Sea spaghetti	*Himanthalia elongata*		GB, FR, IE, ES
Oarweed	*Laminaria digitata*	GB, FR, IE	GB, FR, IE, NO
Dulse	*Palmaria palmata*	FR, IE, DK	GB, FR, IE, PT, NO
Nori/ Purple laver/ Laverbread	*Porphyra sp.*	FR, IE, NO	GB, FR, ES
Royal Kombu/ Sugar kelp	*Saccharina latissima*	GB, FR, NO, ES, NL, IE, DK, SE	GB, FR, NO, ES, IE
Sea lettuce	*Ulva sp.*	FR, NL, PT, SE	GB, FR, IE, NO, ES, PT, NL
Wakame	*Undaria pinnatifida*	FR, ES, IE	

By analysing the figure above, it can be concluded that especially *Alaria esculenta, Laminaria digitata, Saccharina latissima and Ulva sp.* are cultivated within the 2 seas region. Furthermore, France is the country within the 2 seas region which cultivates the largest variety of species.

4.2 Taste

Because of the wide range of species, each with their own properties, it is near impossible to describe the taste of seaweed in a general sense. In addition, the preparation method that is used has a big impact on the taste and texture of seaweeds. Some seaweed species can be eaten raw when freshly harvested, but most seaweeds are more palatable when processed in some way. Drying, cooking or toasting is mostly used to improve flavour (Mourtisen, 2013). Few scientists have attempted to characterise the sensory profile of individual seaweed species (Barbier, et al., 2019). Some exceptions include a study investigating the flavouring and taste components of Irish seaweeds wherein the potential for commercial applications has been researched (Hotchkiss, 2010), and a study describing Japanese kelp, which appears to contain large amounts of monosodium glutamate which is related to its umami flavour (Ikeda, 2002).

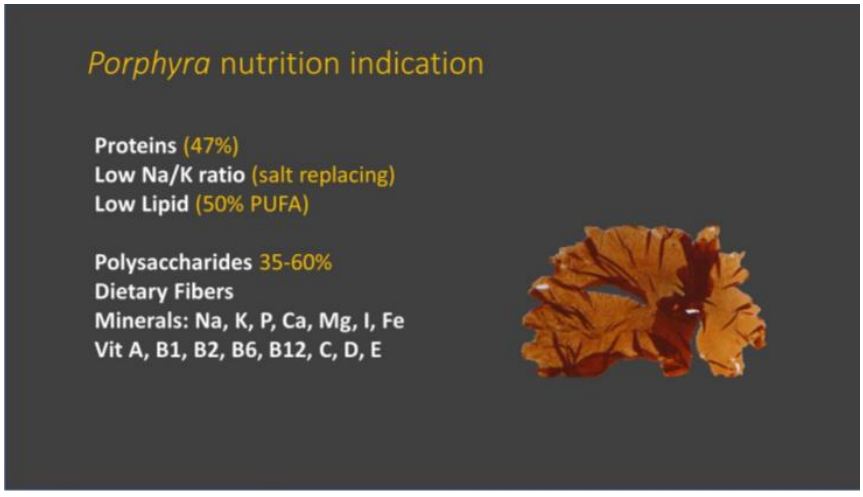
Other studies have confirmed this and found that other seaweed species also contain monosodium glutamate, similarly adding the taste of umami to food. Seaweed can therefore partially replace salt as a taste intensifier. At the same time, seaweed knows many different aromas, making it suitable as seasoning (Ole Mouritsen, 2018).

According to The Phycomorph European Guidelines for a Sustainable Aquaculture of Seaweeds (Barbier, et al., 2019), creating a vocabulary to describe the flavour of seaweed would help the public to gain a better understanding of what they are buying, and what different seaweeds can add to their food, as a spice, taste enhancer or supplement.

4.3 Composition

Alongside taste, the composition and nutritional content of the seaweed differs not only between but also within species, as it furthermore depends on the local growth conditions (temperature and nutrients in the water), the age of the seaweeds, the amount of sun, the moment of harvesting and the way in which the seaweed is stored, processed and preserved (if applicable).
Seaweed consist for the most part of water and the moisture content of seaweeds can account for up to 94% of the biomass. Furthermore, seaweeds are known for their richness in polysaccharides, minerals and certain vitamins, as well as for containing bioactive substances like polysaccharides, proteins, lipids and polyphenols (Holdt & Kraan, 2011). The seasonal and environmental variations make it impossible to generalize the biochemical composition and bioactivity of compounds in seaweed. An indication of the nutritional elements of the seaweed species *Porphyra* is given in the figure below.

Figure 4: Indication of the nutritional elements of Porphyra sp. Adapted from Barbier et al. (2019).



4.4 Food safety

In addition to healthy nutrients, seaweed can also absorb toxic substances, such as heavy metals or radioactive substances, from the water. The amount of toxic substances in seaweeds depends on the quality of the water, the time of harvest and the processing method. The quality of the water in the North Sea has gradually improved in recent decades and a strict monitoring plan applies within the EU, making the risk of pollution smaller every year (Noordzeeloket, n.d.) (NIOZ, Deltares, Imares, Rijkswaterstaat, 2015).

Furthermore, seaweed also accumulates iodine, which is an essential nutrient for the production and regulation of thyroid hormones. These hormones are necessary for proper growth, the development of neurological and cognitive functions and metabolism (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA), 2014). In the past, Iodine deficiency was a significant public health problem in Europe. In 1994, only five European countries were considered as iodine-sufficient. Iodization of salt has been a successful intervention responsible for significant improvements of this situation. However, as the consumption of table salt of the European consumer declines, potentially so does their access to iodized salt. Therefore, iodine deficiency remains a continuous public health problem which deserves proper monitoring (Andersson, De Benoist, Darnton-Hill, & Delange, 2007; Santos, et al., 2016).

Although iodine is an essential part of our diet, it is also considered potentially harmful for our health when consumed in excess. Therefore, the EU have set guidelines for the intake of iodine, recommending a daily intake (RDA) for iodine in Europe of 0.15 µg per day (European Union, 2008). The European commission furthermore indicated that the ingestion of iodine-rich algal products, particularly dried products, can lead to dangerously excessive iodine intakes, if such products contain more than 20 mg iodine/kg dry matter and the exposed population lives in an area of endemic iodine deficiency (European Union, 2018). Iodine is highly concentrated in some brown seaweeds, which could become a limiting factor for the recommended daily intake of seaweed (Holdt & Kraan, 2011). At the same time, seaweed could be a possible alternative iodine supplementation to prevent iodine deficiency in Europe (Andersson, De Benoist, Darnton-Hill, & Delange, 2007). Therefore, research is required to gain more knowledge on the bioaccessibility of iodine from seaweeds, the influence of different processing steps (e.g. boiling, rinsing, drying) on the iodine content of seaweeds, and methods for detection of different chemical forms (Barbier, et al., 2019).

Currently, there are only guidelines but no regulation in Europe regarding the maximum allowed level of iodine in seaweeds for the use of food. For heavy metals, current European regulation concerns seaweed as dietary supplements and as animal feed.

Figure 5: The current regulations applied to seaweeds as dietary supplements in EU - Commission Regulation (EC) No 1881/2006 (European Union, 2006) and animal feed in EU - Directive 2002/32/EC (European Union, 2002).

	Limit (mg/kg)	
Compound	Dietary supplements	Animal feed
Arsenic	No regulation	40
Inorganic Arsenic	No regulation	2
Cadmium	3	1
Lead	3	10
Mercury	0,1	0,1
Iodine	No regulation	No regulation

The interviews revealed that stakeholders are often reluctant to produce seaweed products with a high amount of seaweed as they are afraid of passing the limits for heavy metals or iodine in foods. In addition, there appears to be an uncertainty among stakeholders about the current guidelines and regulations on seaweed as food and how to interpret them. In order to promote the use of seaweed as food, it is therefore necessary to develop clear regulations on the threshold values of different contaminants. In the current available European regulation, several gaps and points of improvement have been identified. For example, not all contaminants which are commonly present in seaweeds are currently monitored, seaweed is currently only recognized as a 'food supplement', and not as 'food'

and there is no clear description whether the threshold levels are based on dry or wet (fresh) seaweed biomass.
The European Committee for Standardisation CEN/TC 454 'Algae and Algae Products' has taken on the task to address the recommendations for algae standardisation, which includes both seaweeds and microalgae. Based on these recommendations, the European Commission (EFSA) will draft new standards for algae and algae-based products. In the future, European legislation may set threshold values for potentially undesirable compounds in seaweeds. Contaminants such as arsenic, cadmium, lead, toxins, pesticides, dioxins, PAH's, uranium and allergens will be revaluated by the CEN Technical Committee (CEN/TC 454 Algae and Algae products, Unpublished).

The work of CEN/TC 454 will help guarantee food safety aspects, such as demonstrating the maximum content of various relevant contaminants, and demonstrate the useful properties of algae, such as nutritional value. Ultimately, future standardization for algae contributes to improving the reliability of the supply chain and thereby improving the confidence of industry and consumers in algae (CEN/TC 454 Algae and Algae products, Unpublished).

However, in order to set threshold values of the contaminants commonly present in seaweed, risk-assessments are needed which assess advantages and disadvantages for public health. More knowledge is required on the toxicity and bioavailability of various elements and their chemical configurations in seaweed (Barbier, et al., 2019). Current guidelines and regulations concerning seaweed as food can be clarified by implementing this knowledge, which will contribute to the sustainable development, professionalization and commercialization of the seaweed sector.

4.5 Novel Food

Next to food safety measurements concerning contaminants, the European Union also has a Novel Food Regulation (Regulation (EU) 2015/2283). A Novel Food is defined as a food that has not been consumed to a significant degree in the EU before the 15th of May 1997. A novel food can be a newly developed innovative food, or a food which has been traditionally consumed outside of the EU. In the online 'Novel Food Catalogue', all products which are subject to the Novel Food Regulation are listed (European Commission, n.d.).
Approximately 27 seaweed species are accepted as food in Europe. Hereof, some have the status of "non-novel food" indicating that they are accepted as food because of their presence on the market before the 15th of May 1997 and therefore not subject to the Novel Foods Regulation. Seaweeds with the status of "accepted as food" successfully went through the novel food procedure and consequently are accepted as novel food in the EU novel food catalogue. Other seaweed species are "not accepted as food", since no request has been made for its authorisation as food by the regulation on novel foods (Barbier, et al., 2019; European Commission, n.d.).

Figure 6: Overview of Atlantic seaweed species and/or seaweed species on the food market in EU (Barbier, et al., 2019; European Commission, n.d.).

Common name	Scientific name	Accepted as food	Status Novel Food Catalogue
Brown			
Winged kelp	*Alaria esculenta*	YES	Non-novel food
Rockweed	*Ascophyllum nodosum*	YES	Non-novel food
Mosuku	*Cladosiphon okamuranus*	NO	Not accepted as food
Cochayuyo	*Durvillaea antarctica*	NO	Not accepted as food

Arame	*Eisenia bicyclis*	YES	Non-novel food
-	*Fucus evanescens*	NO	Not accepted as food
Toothed wrack	*Fucus serratus*	YES	Non-novel food
Spiral Wrack	*Fucus spiralis*	YES	Non-novel food
Bladderwrack	*Fucus vesiculosus*	YES	Non-novel food
Sea spaghetti	*Himanthalia elongata*	YES	Non-novel food
Oarweed	*Laminaria digitata*	YES	Non-novel food
Tangle	*Laminaria hyperborea*	NO	Not accepted as food
-	*Laminaria longicruris*	YES	Non-novel food
Golden kelp	*Laminaria ochroleuca*	NO	Not accepted as food
Mäerl	*Lithothamnium calcareum*	YES	Non-novel food
Kombu	*Saccharina japonica*	YES	Non-novel food
Sugar kelp	*Saccharina latissima*	YES	Non-novel food
Hizikia/Hijik	*Sargassum fusiforme*	YES	Non-novel food
Wakame	*Undaria pinnatifida*	YES	Non-novel food
Red			
Irish Moss	*Chondrus crispus*	YES	Non-novel food
Thin dragon beard plant	*Gracilaria gracilis/verrucosa*	YES	Non-novel food
-	*Grateloupia turuturu*	NO	Not accepted as food
Pepper dulse	*Osmundea pinnatifida*	NO	Not accepted as food
Nori/ laver	*Pyropia tenera*	YES	Non-novel food
Nori/ laver	*Porphyra laciniata*	YES	Accepted as food
Nori/ laver	*Porphyra umbilicalis*	YES	Accepted as food
Nori/ laver	*Pyropia yezoensis*	YES	Accepted as food
Nori/ laver	*Pyropia leucosticta*	YES	Accepted as food
Nori/ laver	*Porphyra dioica*	YES	Accepted as food
Nori/ laver	*Porphyra purpurea*	YES	Accepted as food
Dulse	*Palmaria palmata*	YES	Non-novel food
Seaweed truffle	*Vertebrata lanosa (former: Polysiphonia lanosa)*	NO	Not accepted as food
Green			
Aonori or green laver	*Enteromorpha sp*	YES	Non-novel food
Sea grapes/ green caviar	*Caulerpa lentillifera*	NO	Not accepted as food
Dead man's finger	*Codium tomentosum*	NO	Not accepted as food
Sea lettuce	*Ulva lactuca*	YES	Non-novel food
Sea lettuce	*Ulva sp*	YES	Accepted as food

Compared to Figure 3, it can be found that the main species cultivated and harvested from wild populations in Europe are either accepted as food or regarded to as novel food.

4.6 Food applications

Seaweed is available to consumers in health stores, fish shops, organic supermarkets and regular supermarkets. Due to the limited shelf life of fresh seaweed, (pre-) processing often directly occurs after harvesting. Widely used processing techniques which are applied to preserve the seaweed are

drying (e.g. nori sheets) or pickling (e.g. wakame salads). Seaweed is offered in various forms and applications, such as dried seaweed flakes, seaweed burger, seaweed crisps or seaweed salads (Mourtisen, 2013). In figure 7, some examples of seaweed products which are offered on the European market are displayed. Within all the seaweed applications for food, a clear distinction has been made:

- Seaweed as a meal component: The seaweed or seaweed product is a substantial part of the meal (e.g. seaweed spaghetti, seaweed burgers)
- Seaweed as condiment and flavouring: The seaweed or seaweed product is a small addition to the meal to enhance the flavour (e.g. aromatics, mustards)

Figure 7: Various examples of seaweed food products which are offered on the European market, for both the product categories of meal component and condiment and flavouring (Stichting Noordzeeboerderij, 2019).

A further application of seaweed includes 'seaweed as functional ingredient'. A variety of bioactive compounds in seaweed are used as functional ingredients and include hydrocolloids (alginates, agar and carrageenan), carotenoids, phlorotannins, fucoidan and peptides (Taelman, Champenois, Edwards, De Meester, & Dewulf, 2015). Benefits that can be derived from these ingredients include weight loss, supplements of minerals and vitamins and much more. Other applications of functional ingredients include thickening and rising agents for (non) food products and pharmaceutical products. Seaweeds are an important component of the hydrocolloid market as 40% of hydrocolloids originate from a seaweed base (FAO, 2018).

It has been decided not to include 'seaweed as functional ingredient' in the market analysis for this report. Despite it being considered an important market for seaweed for food, as has been aforementioned, the use of seaweed as functional ingredients includes non-food applications as well. To avoid confusion and the presentation of inaccurate market information, this application has been excluded from the report.

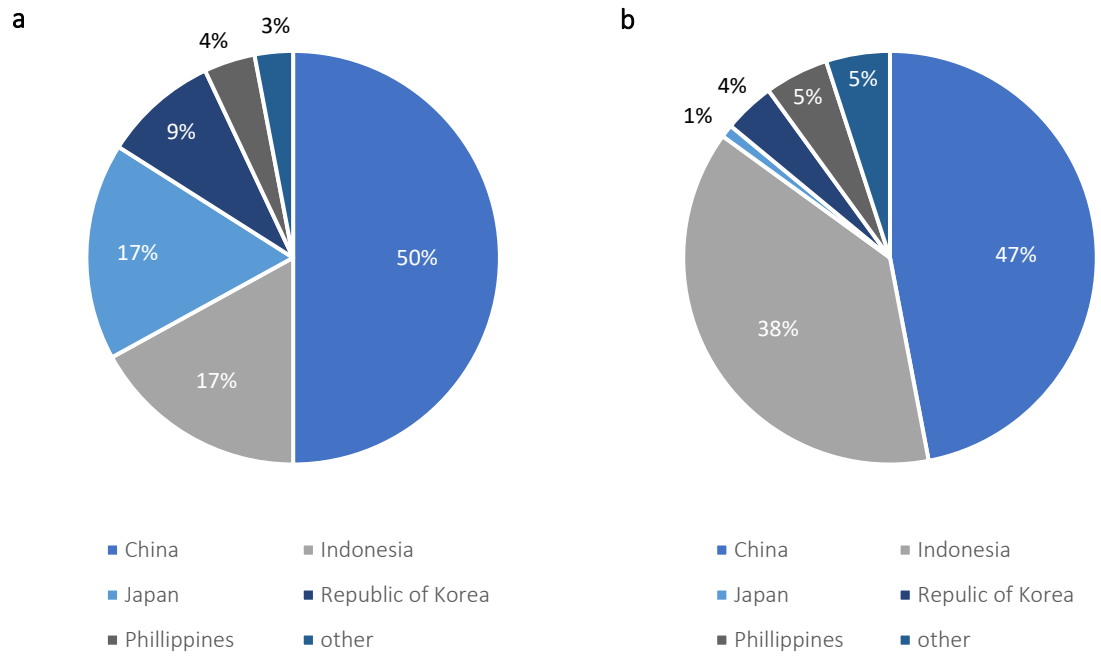
5 The markets for seaweed as food

The following chapter have been focussed to give an insight in the size of the existing seaweed food market in the 2 seas region. In order to do so, first the global and the European seaweed (food)market has been explored in order to place the seaweed food market in the 2 seas region in a larger perspective.

5.1 The global seaweed market

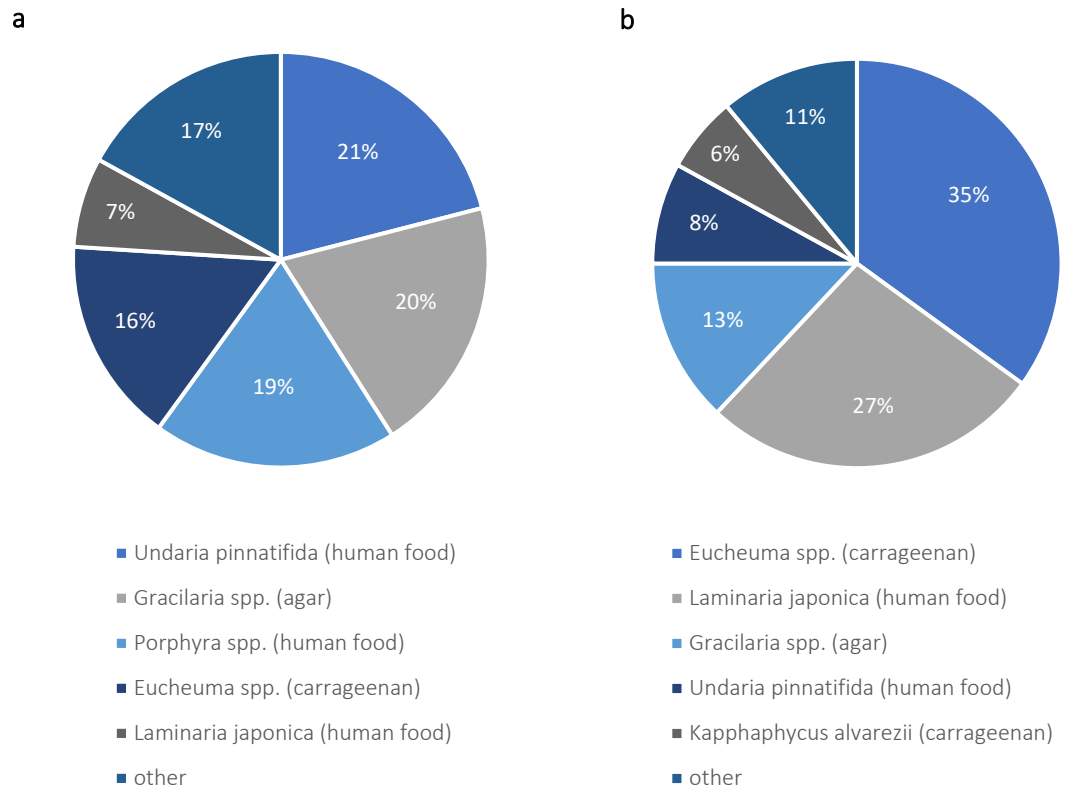
The FAO report about the global status of seaweed production, trade and utilization (2018) estimated that in 2015 the global seaweed production totalled 30.4 million tonnes, of which the vast majority is cultivated and only 1.1 million tonnes was harvested from the wild. In the past decade, the biomass supplied through cultivation has doubled, whereas the biomass supplied through wild harvest remained stable. According to the FAO (2018), seaweed cultivation takes place in about 50 countries, to which countries in East Asia and Southeast Asia contribute the major share in terms of both volume and value. The leading countries for the wild harvest of seaweed in 2015 were Chile, China and Norway (FAO, 2018).

*Figure 8: World cultured seaweed production by country with **a**, value in USD and **b**, weight in tonnes (FAO, 2018).*



According to the FAO (2018), the use of seaweed for human consumption makes up approximately 85% of the total world market. This includes both seaweed food products and the hydrocolloid market in terms of foods. Japanese Wakame (*Undaria pinnatifida*), Nori (*Porphyra sp.*) and Japanese kelp (*Laminaria japonica*) were the most cultivated species for food applications in 2015. For wild harvest, Chilean kelp (*Lessonia nigrescens*) is the most harvested species and accounts for approximately 22% of the harvested total (FAO, 2018).

*Figure 9: World cultured seaweed production by species with **a**, value in USD and **b**, weight in tonnes (FAO, 2018).*



All information on the global seaweed market has been based on publicly available data from the FAO. These FAO statistics include both harvested and cultivated seaweed species, organized by country and production year, and is regularly updated. The FAO statistics are the only available source covering all countries in the world. However, the statistics are updated with a delay of two years and the most recent data publicly available is from 2015. It is therefore questionable whether this data is accurate for the current market, given its fast-growing nature. Furthermore, a few uncertainties of the data have been found when consulting them. It is for example not defined if the production volume of the seaweed is expressed in wet or in dried weight, although it is assumed that the volumes are based on wet weight. Nor is it clear what FAO's definition of 'seaweed for human consumption' is, and whether this includes the entire seaweed hydrocolloid market or not.

5.2 The European seaweed market

Also for the European seaweed market, quantitative data on seaweed production is scarce, and mostly consist of (interpretations of) the FAO statistics and the recently published Phycomorph European Guidelines for a sustainable aquaculture of seaweeds (2019). In this analysis about the European seaweed market, data from all countries from the European Union, countries from the EER (Norway, Iceland, Liechtenstein) and the Russian federation are included.

According to Camia et al. (2018), European algae production accounted for approximately 1% of the global biomass supply between 2006 and 2015. Camia et al. (2018) estimated the European production of seaweed in 2015 at approximately 230,000 tonnes (of presumably wet weight). The total annual value of the European algae biomass (microalgae and seaweeds) industry in 2015 was estimated by Probst et al. (2015) at EUR 6.3 billon, 4.9 billion of which was accounted for by the European seaweed industry. Hereof, food products for human consumption made up the largest market share with an estimated EUR 4.6 billion (Probst, Frideres, Pedersen, & Amato, 2015).

According to Barbier et al. (2019), this market for seaweed food products is annually growing with an estimated 7-10%.

The dominant production method in Europe is the harvesting of wild stocks. According to Mac Monagail et al. (2017) more than 99% of the seaweed in Europe is harvested from the wild. Camia et al. (2018) claim that in the period from 2006 to 2015 Norway, France, Ireland, Iceland and the Russian Federation were the main algae producers at European level, accounting for 98% of the total algae production in Europe. As is displayed in figure 10 below, in the period 2006-2015, Denmark was the only country with the algae (both seaweed an microalgae) production sector exclusively based on cultivation. However, in the Netalgae report (2012), it is claimed that the current local production dependent on wild harvest is not fully satisfying the European demand and seaweed food producers and processors also import dried seaweed when local supplies are out of season or not sufficient. Also the FAO statistics (2018) show that the import of seaweed in Europe is more than triple the export. As is stated in the Netalgae report (2012), for this reason seaweeds cultivation in Europe will increase in the future to meet the growing demand.
Both the literature and interviews show that seaweed cultivation in Europe has indeed been developing in the last years. From the interviews, it turned out that commercial seaweed cultivation can now be found to a limited extend in Denmark, France, Spain, Ireland, Iceland, Norway, the United Kingdom and the Netherlands. Figure 11 shows the evolution of the cultivation of algae over the period from 2001 to 2015 in both number of countries and volume, where a clear increase of both is visible. Also the FAO (2018) claims that the European seaweed market is characterized by the research and development of industrial cultivation, harvesting and processing technologies.

Figure 10: Total algae production (sum over the period 2006-2015) of the top 10 producers at the European level, by production method. Adapted from Camia, et al. (2018).

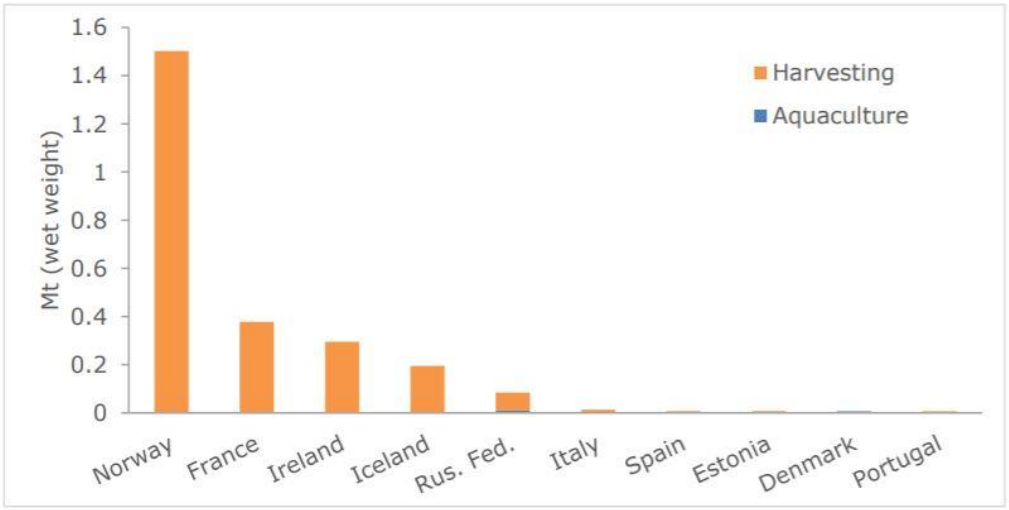
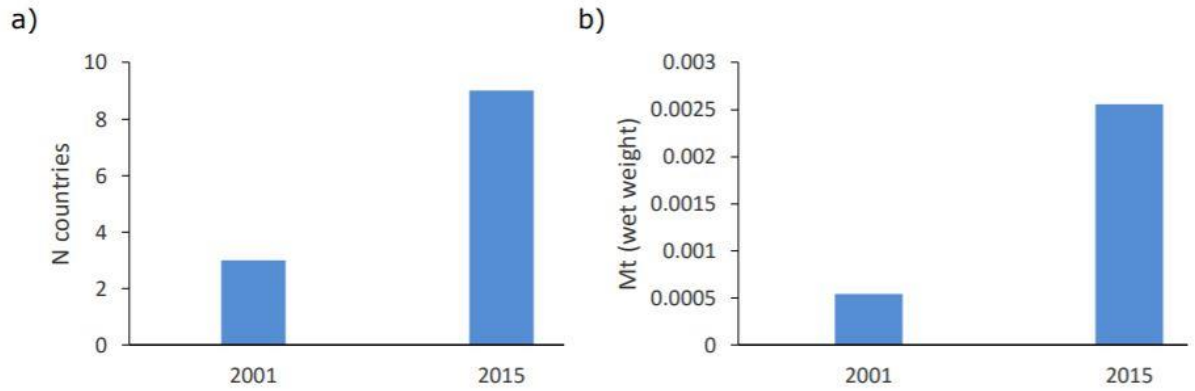


Figure 11: Temporal evolution of algae cultivation in Europe considering the number of countries with cultivation facilities (a) and the total amount of biomass supplied by this production method (b). Adapted from Camia, et al. (2018).



Like the world market, also for the European market the availability of data is limited. The total volume of the European production today is still uncertain as in some cases, monitoring processes are not yet in place in some countries where activity is underway. Furthermore, data from seaweeds and microalgae are often combined making it difficult to get a picture exclusively of the seaweed market. Moreover, it is not always clear which countries are included when the European market is described and what the considerations were.
Despite the limited availability and varying quality of sources, all sources seemed to be unanimous about the relatively small size of the European market compared to the world market, the heavy reliance on wild stocks in Europe and the growing demand for locally cultivated seaweeds.

5.3 Seaweed production in the 2 seas region

By combining the stakeholder interviews and the literature review, an overview could be made of the seaweed production in the 2 seas region. It should be noted that only a very limited amount of official data is available for this region. Therefore, it was sometimes necessary to make an estimation based on the available resources.

5.3.1 France

Main parameters of French seaweed production:

- In France, approximately 70,000 tons of wet seaweeds is produced annually, only 50 tons hereof are cultivated; the rest comes from wild harvest (Mesnildrey, Jacob, Frangoudes, Reunavot, & Lesueur, 2012)
- Brittany is the main area of production, containing 85% of production locations. However, this area falls outside of the 2 seas region. (Netalgae, 2012) (Mesnildrey, Jacob, Frangoudes, Reunavot, & Lesueur, 2012)
- Only 1% of the produced seaweed is intended for the food market. 75% goes to the food processing industry, chemistry and microbiology (production of alginates, agar-agar and carrageenan) (Netalgae, 2012)
- The main species for cultivation are *Undaria pinnatifida* and *Saccharina latissima* (Mesnildrey, Jacob, Frangoudes, Reunavot, & Lesueur, 2012)
- There are approximately 5-10 companies which cultivate seaweeds in France (Annuaire des producteurs et transformateurs, n.d.)

5.3.2 Netherlands & Belgium

Main parameters of the Dutch seaweed production (all information is derived from interviews):

- In the Netherlands, seaweed is both wild harvested and cultivated on a small scale
- Wild harvesting occurs by hand, requiring a permit
- The total production quantity is estimated at 15 tons wet weight per year
- Seaweed cultivation is starting-up, mainly onshore and in sheltered areas
- There are approximately 5 companies which cultivate seaweeds in the Netherlands
- The main species for cultivation are *Ulva sp.* and *Saccharina latissima*
- The vast majority of Dutch seaweed production is intended for the food market

Main parameters of the Belgian seaweed production (information is derived from interviews):

- The Belgian seaweed market is at a very small scale at this stage and mainly consist of pilot projects (Seaconomy, Value@Sea, Wier&Wind) on offshore cultivation and IMTA projects.

5.3.3 United Kingdom

Main parameters of United Kingdom seaweed production:

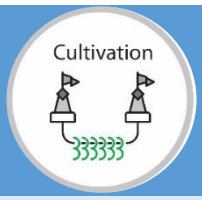
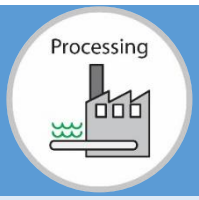
- The UK seaweed production is estimated at 20,000 to 30,000 tonnes wet weight per year (Cefas, 2016)
- By far the most seaweed is collected in the Outer Hebrides. This area falls outside of the 2 seas region. (Netalgae, 2012) (Cefas, 2016)
- The vast majority of the seaweed is wild harvested (Cefas, 2016) (Netalgae, 2012)
- There is limited cultivation of seaweed, pilot seaweed farms are currently in development (Netalgae, 2012)
- Most seaweed businesses work within the food sector (Netalgae, 2012)

The main production areas in France (Brittany) and the United Kingdom (Outer Hebrides) fall outside of the 2 seas region. As a result, the seaweed production in the 2 seas region is very limited. Accordingly, in terms of seaweed production, there is still much to be gained in this region.

5.4 Main stakeholders in the European seaweed food market

Through desk research and interviews, ten different types of stakeholder categories could be identified, based on the seaweed value chain (Figure 12). Hereof, six are commercially active stakeholders (seaweed breeder, seaweed producer, seaweed processor, seaweed food producer, seaweed food trader, retail & foodservice), which are related to a specific position in the value chain. Furthermore, there are several other stakeholder categories which are involved in the topic of seaweed for food, thereby affecting the whole value chain. These can include science and research institutes, governments and branch organisations and so on.

Figure 12: Seaweed for food value chain with different corresponding stakeholder categories (Stichting Noordzeeboerderij, 2019).

				
Seaweed value chain position	Seeding, hatchery & breeding	Cultivation & production	Processing and refinery	End products, trading & sales
Description	The production and supply of seaweed starting material	The wild harvest and cultivation of seaweed	The processing of raw materials into (ingredients for) food products	The distribution of seaweed food products to end-users
Stakeholder categories	Seaweed breeder	Seaweed producer	Seaweed processor, seaweed food producer	Seaweed food trader, retail & foodservice
	Science & research, branch organisation, government, other			

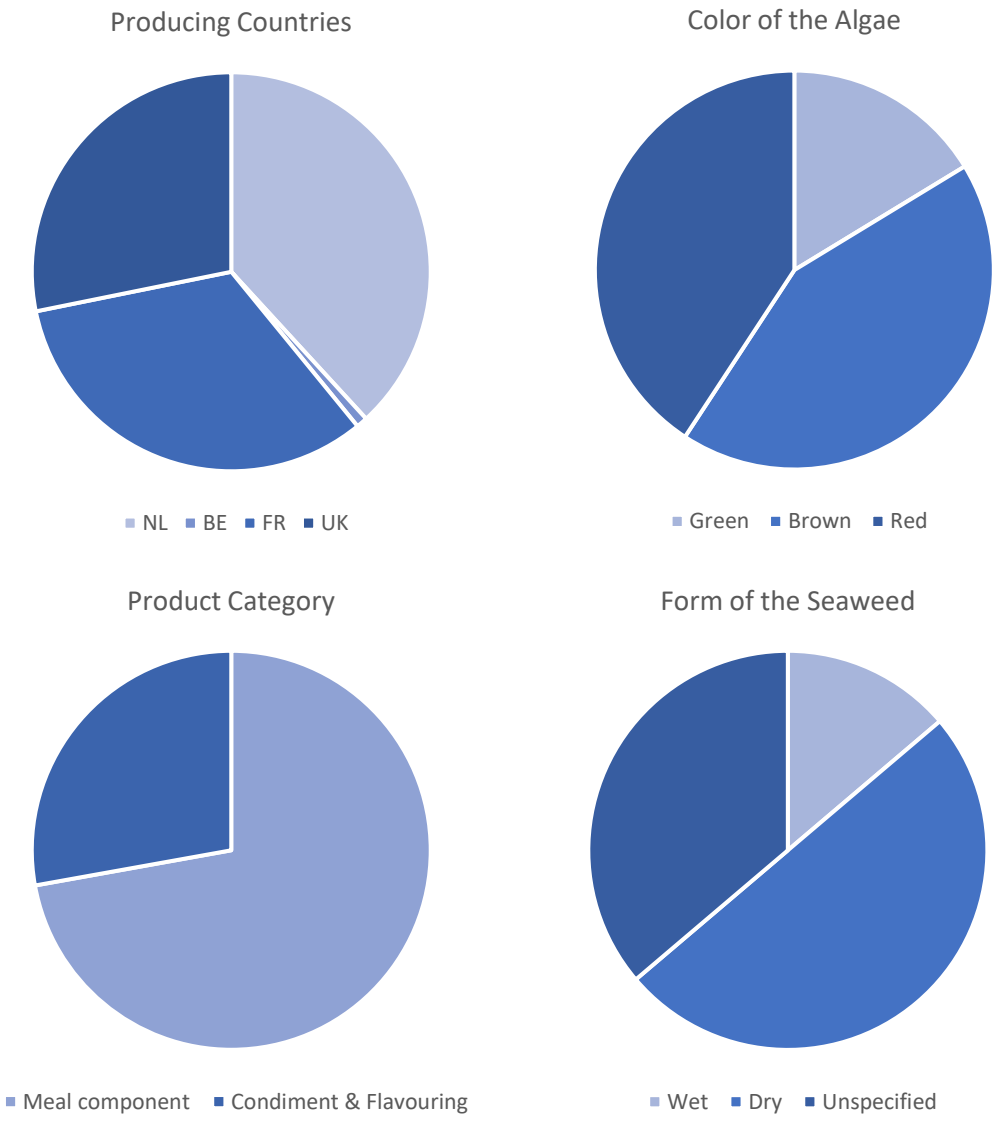
The interviewed stakeholders of the seaweed food market in the 2 seas region have been classified in the different stakeholder categories. This overview can be found in annex 4.
By analysing this overview and the information acquired through the interviews, it can be concluded that seaweed producers and seaweed food producers are well represented. Furthermore, breeders and seaweed food processors are stakeholder categories which might be slightly underrepresented. During interviews, stakeholders highlight that there is not much choice in seeding material, because it all originates from the same few seaweed breeders. In addition, several seaweed producers mentioned that they have inhouse processing facilities for the washing and drying of the seaweed. Although they would like to outsource these processing steps, they claimed that there are few companies which specialize in this, forcing them to do it themselves. Moreover, retail and foodservice are also underrepresented in the stakeholder interviews. It is unclear if this is because of a sample gap, or if they are actually missing in the seaweed supply chain.

5.5 Seaweed food products on the European market

The seaweed food market is growing at a fast pace and increasingly this market is being researched to compile information on the type and specifications of seaweed products. Research by Barbier et al. (2019) found that food and drink products containing seaweed or seaweed flavours increased with almost 150%. Through desk research and interviews, a list has been compiled containing only seaweed food products currently produced by companies situated in the Netherlands, France, United Kingdom and Belgium. Herein, the distinction, as mentioned earlier, is applied: Seaweed as meal component and seaweed as condiment or flavouring. The more detailed overview can be found in annex 5.
Due to rapidly changing seaweed and food market, it should be kept in mind that this overview does not present a complete overview, but rather an indication on important parameters for seaweed as food. This list does not represent the offer of seaweed food products solely in the 2 seas region, as some of the products contained by this list might be produced in areas in France, the Netherlands and the United Kingdom that fall outside of the 2 seas region.

Below, this data has been illustrated. As becomes clear from figure 13, the production of seaweed food products is fairly similar among three countries (UK, NL and FR). Only Belgium has little to no products that contain seaweed. The majority of seaweed originates from red and brown algae and is used as meal component (>70%). A smaller fragment of the products is used as condiment or flavouring agent. 50% of the found products contained dry seaweeds, whereas only 14% contains wet seaweed. A large share of the products (36%) did not indicate whether the seaweed contained by the products was wet or dry. Therefore, these numbers should not be regarded as final numbers but more as an indication.

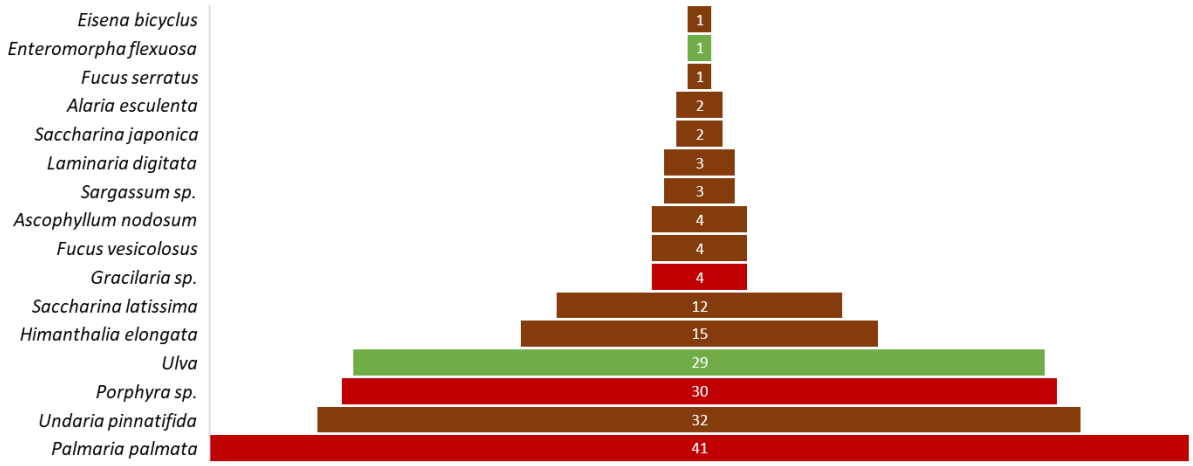
Figure 13: Snapshot of current seaweed products produced in the Netherlands, France, the United Kingdom and Belgium (Stichting Noordzeeboerderij, 2019).



In figure 14, more details are illustrated on the exact species used. Clearly the most commonly used species in these products is *Palmaria palmata*, followed by *Undaria pinnatifida.* An almost equal amount of products contain red or brown algae; 41% and 43% respectively. However, a key difference which can be observed is that over ten different brown seaweed species are used in the compiled list, whereas only 3 three red seaweed species are purposed. This indicates that a wide variety of brown

seaweed species are used in products, whilst only a few red seaweed species are being used by seaweed food producers. A similar note can be made for green seaweed species, of which only 2 species are used for the compiled product list. However, it must be noted that only 16% of all products contain green seaweed species.

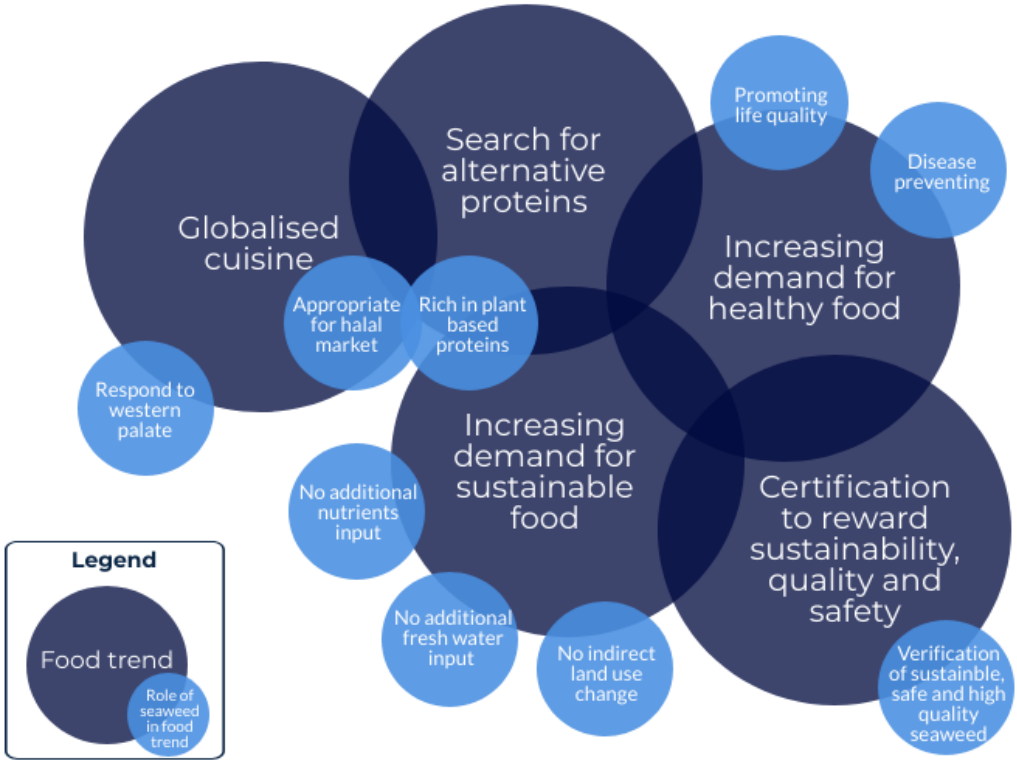
Figure 14: Snapshot of current seaweed species used in seaweed food products produced in France, The United Kingdom, The Netherlands and Belgium (Stichting Noordzeeboerderij, 2019).



6 Market trends and developments

The current food landscape is subject to several trends and developments. In this chapter, we will highlight a few of these trends and developments which are of importance for the European seaweed sector.

Figure 15: Overview of global food trends and how seaweed fits into it (Stichting Noordzeeboerderij, 2019).



6.1 Globalised cuisine

The modern consumer is increasingly exposed to different food cultures and products from foreign countries. Not only do we travel more, the offer in our local supermarket also changes. A study of Maxwell and Desoucey (2016) have found significant percentages of foreign cultural influences in both French and UK supermarkets which they link to trends of globalizing consumer markets and gastronomic cosmopolitanism. The study found that East Asian products are overwhelmingly present in both French and UK supermarkets. During the interviews, stakeholders mentioned that they regularly come across Asian seaweed products such as sushi or wakame salad.

6.1.1 Western palatability

Although a globalised cuisine seems to create awareness for seaweed as food, Hotchkiss (2010) claims: *"Despite an increased awareness of and exposure to different food cultures and ingredients, the "western" palate is still generally not accepting of many of the tastes and textures associated with Asian products, derived from seaweed, that are increasingly found in our markets".* By investigating the offer of seaweed products produced within the 2 seas region, it was remarkable that most products are not necessarily inspired on Asian seaweed products, but rather respond to meet the requirements and wishes of the European consumer. However, to better respond to the "Western" palate and preferences, further research to characterise the sensory profile of individual seaweed species is required. Likewise, creating a vocabulary describing the different flavours of seaweeds to the consumers would help increase public awareness seaweed as food (Barbier, et al., 2019).

6.2 Food for health

Although the "western" palate has an important role in the European seaweed product development, additional parameters such as nutritional value and 'food for health' are also considered (Buschmann, et al., 2017). According to Santeramo et al. (2018), consumer demand for health-enhancing food products, such as functional foods, has grown rapidly. Santeramo et al. (2018): *"The term "functional food" is generally used to communicate either that the food may provide health benefits beyond those delivered by traditional nutrients, or that the food has potential in preventing disease or in promoting a better life quality".* Seaweeds are rich in polysaccharides, minerals, vitamins and bioactive substances such as proteins and lipids which gives seaweed great potential as a supplement in functional food or for compound extraction (Holdt & Kraan, 2011).

6.3 Alternative protein sources

The search for essential minerals and nutrients for health benefits have stimulated the interest in proteins contained by seaweed. Globally, the search for a sound alternative for animal protein sources is motivated through both cultural and environmental drivers. An increasing interest for seaweed as a source of plant-based protein comes from the halal market, mainly for its gelling and thickening characteristics. The expanding Muslim population and their increasing purchasing powers will result higher demand for halal products (Noor, Noor, Weliyadi, & Salleh, 2018). The lack of any animal (in particular pig) components makes seaweed and seaweed-derivatives highly suitable for halal products. Noor et al. (2018) suggest that promoting the halal values in seaweed production can enhance the value proposition of the products.
A further important push for the search for alternative protein sources comes from the increasing environmental burdens of food production. The search for alternative proteins is stimulated by governmental policies, as the importance of seaweed is often emphasized in policies. The Dutch government wants the Netherlands to lead the way for innovative, healthy and sustainable products with more vegetables and plant-based proteins (Rijksoverheid, 2016). Furthermore, the European commission recognized that algae (seaweeds and microalgae) were such a promising option for food security that by 2054 algal collective cultivation could reach the production of 56 million metric tonnes of protein, which would constitute 18% of the global alternative protein market. (Buschmann, et al., 2017). Additionally, consumers show more interest in alternative protein sources. A clear trend within consumption patterns in the 2 seas region includes the switch to plant-based proteins. In the Netherlands, the consumption of meat substitutes increased by 51% since 2017. Furthermore, the consumption of meat (beef, pig and game) decreased with 9% over the same period (NOS, 2019). In addition, also commercial companies seem to respond to the trend of sustainable, plant-based foods. For example, WWF in collaboration with Knorr has published the Future 50 Foods, with seaweed on both number one and two (Knorr, n.d.). Similarly, in the Lidl future goods week, a seaweed food product is included (StartLife, 2019). Increasingly expressed interest and high innovation characterise the European seaweed food market, which resulted in Europe coming in second place for seaweed product innovation rate (FAO, 2018).

6.4 Sustainability

The many environmental benefits offered by seaweed (cultivation), in comparison the land-based agricultural systems (Bikker, et al., 2016; Duarte, Wu, Xiao, Bruhn, & Krause-Jensen, 2017) propose seaweed as a sustainable source of plant-based proteins. Benefits include little to no input of freshwater or nutrients and the absence of indirect land use change (van Hal, Huijgen, & López-Contreras, 2014).This has spurred interest in cultivation in several European countries. Currently, in the United Kingdom, the Netherlands and France seaweed cultivation is practiced on a small to

medium scale and shows an experimental character (van Oirschot, et al., 2017) in which the research and development of industrial cultivation, harvesting and processing technologies are rapidly developing (FAO, 2018). Furthermore, research interest in optimising and examining cultivation technologies have resulted in a fivefold influx of publications surrounding the topic of seaweed cultivation (Buschmann, et al., 2017). An increasing interest in cultivation is also expressed during the interviews with the relevant stakeholders. The majority of the (commercial) stakeholders cultivate seaweed themselves or process cultivated seaweed into their food products. Interviewees suggested that benefits of seaweed cultivation in comparison to conventional agricultural and the opportunities it offers for expanding the sector sustainably, will augment the developments of seaweed as food.

Figure 16: Trends & development important for the European seaweed food market (Stichting Noordzeeboerderij, 2019).

6.5 Certification

This increase in demand for sustainable and healthy food products has led to the creation and adoption of standards and certifications which can be used to reward sustainability and safety (FAO, 2018). The same is true for the seaweed market. For example, the ASC-MSC Seaweed Standard has been released in 2017, focussing on minimising the environmental and social impacts of seaweed operations (MSC, 2017). For the future, it would be interesting to consider certification or a standard for seaweeds, encompassing both quality, sustainability, health, origin and food safety. Such an all-encompassing certification or standard could be an paramount driver for the development of a European seaweed market based on local, sustainably produced and high quality seaweeds.

6.5.1 High quality

An important aspect of an all compassing certification scheme is the guarantee that seaweed is of high quality. Through the development of suitable cultivation techniques in the 2 seas region, a stable supply of seaweed in both quantity and quality can be ensured (van den Burg, et al., 2013). Quality is seen as an important driver for the development of the European seaweed market for food, which is confirmed by many of the interviewed stakeholders. An important consideration is between volume versus value. Whereas high quantities of seaweed are produced in South East Asia, the European market may tend to focus more on high quality and can hereby proliferate itself on the seaweed market.

7 Conclusions and recommendations

As part of Work Package 4: 'Valorisation; to support and accelerate the development of a technically and commercially viable seaweed supply chain for food applications', the following question has been addressed in this report: What is the existing market for seaweed food applications?
This report provides an insight into the existing markets for seaweed in both the EU and the 2 seas region. By means of a literature research and interviews, the following has been analysed: 1) the European food trends and developments related to seaweed as food, 2) the current supply of the seaweed food market and 3) the characteristics of the current seaweed food market. Ensuing is a brief summary of the conclusions per subject.

European food trends and developments related to seaweed as food:

- An increasing number of consumers are being introduced to seaweed as food through a more globalising cuisine.
- Seaweed is recognized for its sustainability aspects by both national governments as well as by the European Commission.
- There is a search for alternative proteins and other essential nutrients, many of which can be found in seaweed, that is driven by national and European governmental organisations, commercial parties and consumers.
- Certification schemes that verify the quality, sustainability and safety of products are considered paramount in the food sector. Also, in the seaweed food sector, new certifications and standards are created and adopted.

Current supply of the seaweed food market:

- European production of seaweed currently plays a minor role in the global market, with a market share of approximately 1% of the global seaweed biomass supply in recent years. Production in the 2 seas region represents only a fraction of the entire EU production since the main production areas of France and the United Kingdom fall outside of this region.
- Sourced from literature, it was found that 99% of the European seaweed supply currently originates from wild harvest. Even so, the current European seaweed production is not fully satisfying the demand, seeing as the import of seaweed is more than triple the export. Investing in seaweed cultivation in Europe is seen as a sustainable solution to meet this high demand.
- A growing interest in seaweed cultivation has been distilled from the interviews, due to its benefits in comparison to conventional agricultural and the opportunities it offers for sustainable sector expansion. Although seaweed cultivation in Europe is still in its infancy, it is considered a key development which should be embraced and supported.

Characteristics of the current seaweed food market:

- Seaweed food applications have a substantial role in the seaweed market both globally and within Europe. The use of seaweed for human consumption (including both seaweed as food and as a functional ingredient), makes up approximately 85% of the world market. Additionally, the European market for seaweed food products is growing annually by an estimated 7-10%.
- For this research, seaweed as food has been delimited to seaweed as a meal component, flavouring and condiment. The market for seaweed as a functional ingredient has been excluded since it has proved difficult to discriminate which part of these ingredients was used for food applications. Nevertheless, seaweed as a functional ingredient seems to have a large potential within food applications. For future research, it is therefore recommended to discover the potential of seaweed as functional ingredient.

- The taste of seaweed is an important component of food applications and, as aforementioned, requires more research into how it will or can be made to fit into European palatability.
- More knowledge is required on the nutritional properties of seaweed as well as potentially undesirable compounds in seaweed. In particular, the bioavailability of the various elements in seaweed and their chemical configurations needs to be further researched in order to assess the advantages and disadvantages regarding public health.
- Stakeholders have indicated that essential links in the current seaweed value chain are lacking, forcing especially seaweed producers to fulfil multiple roles in the value chain. In the future, stakeholders should become more specialized and value chain segments such as breeding and processing require more attention in order to in order to improve and optimize the overall value chain.

By means of this report, the first steps have been made towards developing a complete overview of the European and the 2 seas market of seaweed for food. However, the limited availability of quantified and accurate data increases the difficulty of such an assessment. Especially concerning the European and 2 seas region, seaweed market information is uncertain due to the lack of monitoring and reporting processes. In order to improve the availability and accuracy of market data, stakeholders and countries are greatly encouraged to start monitoring and reporting activities in the seaweed market in order to be able to assess the barriers, drivers and overall progress of the sector. This is an essential basis for the further development, growth and professionalisation of the seaweed sector in Europe.

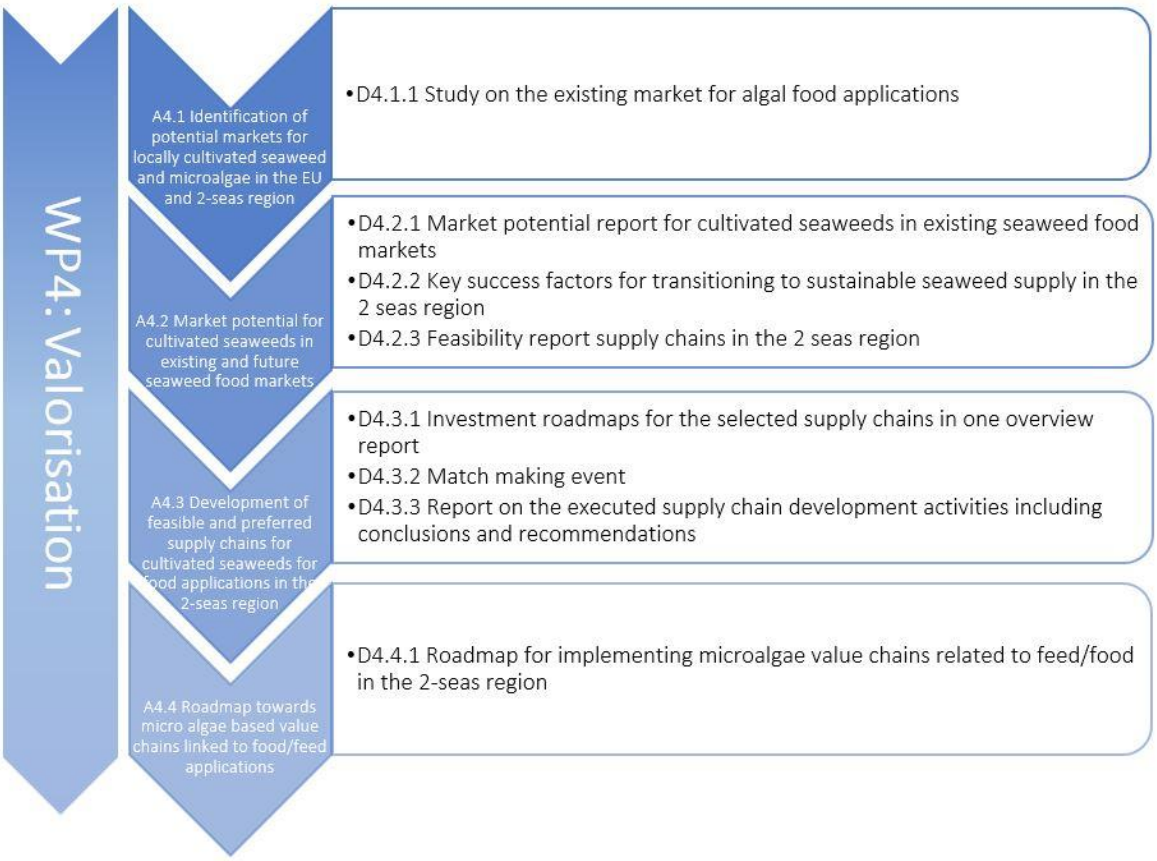
In summary

This study on the existing market for seaweed food applications has given insights into the current market of seaweed for food applications in the EU and 2 seas region. The modest role of locally cultivated seaweeds in this market has been identified. The next step, which will be further elaborated on in deliverable 4.2.1, is to research the market potential for cultivated seaweeds in existing seaweed food markets. Subjects that have remained underexposed in this deliverable, or which need further research, will also be further addressed in deliverable 4.2.1.

Next steps:

- Further research in subjects which are underexposed in this research, such as seaweed as a functional ingredient.
- Work towards improved market information on the current seaweed food market in Europe and the 2 seas regions, by actively collecting new data through interviews and other sources.
- Estimate the growth potential of the identified existing, and possible new, seaweed food markets.
- Research to what extent these seaweed food markets could be supplied with seaweeds, cultivated locally in Europe or the 2 seas region.

Figure 17: Activities and deliverables for Work Package 4: Valorisation (Stichting Noordzeeboerderij, 2019).



8 References

Andersson, M., De Benoist, B., Darnton-Hill, I., & Delange, F. (2007). *Iodine Deficiency in Europe: A continuing public health problem.* World Health Organization.

Annuaire des producteurs et transformateurs. (sd). Opgehaald van Ceva algues: https://www.ceva-algues.com/document/annuaire/

Barbier, M., Charrier, B., Araujo, R., Holdt, S., Jacquemin, B., & Rebours, C. (2019). *PEGASUS - PHYCOMORPH European Guidelines for a Sustainable Aquaculture of Seaweeds.* Roscoff, France: COST Action FA1406.

Bikker, P., van Krimpen, M. M., van Wikselaar, P., Houweling-Tan, B., Scaccia, N., van Hal, J. W., . . . Ana, M. (2016). Biorefinery of the green seaweed Ulva lactuca to produce animal feed, chemicals and biofuels. *Journal of Applied Phycology*, 3511-3525.

Buschmann, A. H., Camus, C., Infante, J., Neori, A., Israel, Á., Hernández-González, M., . . . Critchley, A. (2017). Seaweed production: overview of the global state of exploitation, farming and emerging research activity. *European Journal of Phycology*, 391-406.

Camia, A., Nicolas, R., Jonsson, K., Pilli, R., Condado, S. G., Lozano, R. L., . . . Giuntoli, J. (2018). *Biomass production, supply, uses and flows in the European Union: First results from an integrated assessment.* Publications Office of the European Union.

Cefas. (2016). *Seaweed in the UK and abroad - status, products, limitations, gaps and Cefas role.* Suffolk: Cefas.

CEN/TC 454 Algae and Algae products. (Unpublished). *Specifications for food/feed sector applications.*

Duarte, C. M., Wu, J., Xiao, X., Bruhn, A., & Krause-Jensen, D. (2017). Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? *Frontiers in Marine Science* , 100.

EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA). (2014). *Scientific Opinion on Dietary Reference Values for iodine.* Parma, Italy: European Food Safety Authority (EFSA).

European Commission. (sd). *Novel Food Catalogue*. Opgehaald van European Commission: https://ec.europa.eu/food/safety/novel_food/catalogue_en

European Union. (2002). *Directive 2002/32/EC of the European Parliament and of the Council on undesirable substances in animal feed - Council statement.*

European Union. (2006). *Commission Regulation (EC) No 1881/2006 setting maximum levels for certain contaminants in foodstuffs (Text with EEA relevance).*

European Union. (2008). *Commission Directive 2008/100/EC amending Council Directive 90/496/EEC on nutrition labelling for foodstuffs as regards recommended daily allowances, energy conversion factors and definitions.*

European Union. (2018). *Commission recommendation (EU) 2018/464 on the monitoring of metals and iodine in seaweed, halophytes and products based on seaweed.*

FAO. (2014). *The state of world fisheries and aquaculture.* Rome.

FAO. (2015). *Consumers' concerns and external drivers in food markets.* Rome, Italy: Fisheries and Aquaculture.

FAO. (2018). *The global status of seaweed production, trade and utilization.* Rome.

Foster, M. S., & Barilotti, D. C. (1990). An approach to determining the ecological effects of seaweed . *Thirteenth International Seaweed Symposium*, 15-16.

Hasselström, L., Visch, W., Gröndahl, F., Nylund, G. M., & Pavia, H. (2018). The impact of seaweed cultivation on ecosystem services-a case study from the west coast of Sweden. *Marine pollution bulletin*, 53-64.

Holdt, S., & Kraan, S. (2011). Bioactive compounds in seaweed: functional food applications and legislation. *Journal of Applied Phycology*, 543-597.

Hotchkiss, S. (2010). *Investigation of the Flavouring and Taste Components of Irish Seaweeds.* Marine Institute.

Ikeda, K. (2002). New Seasonings. *Chemical Senses*, 847-849.

Knorr & WWF. (2019). *Future 50 Foods.*

Knorr. (sd). *Future 50 Foods report*. Opgehaald van Knorr: https://www.knorr.com/uk/future50report.html

Kreischer, L. S. (2016). *Ocean Greens : Explore the World of Edible Seaweed and Sea Vegetables: A Way of Eating for Your Health and the Planet's.* New York: The Experiment.

Mac Monagail, M., Cornish, L., Morrison, L., Araújo, R., & Critchley, A. (2017). Sustainable harvesting of wild seaweed resources. *European Journal of Phycology*, 371-390.

Markets and Markets. (2016). *Commercial Seaweeds Market by Type (Red Seaweeds, Brown Seaweeds, Green Seaweeds), Method of Harvesting (Aquaculture, Wild Harvesting), Form (Liquid, Powder, Flakes), Application (Food, Feed, Agriculture), and Region - Global Forecast to 2021.* Markets and Markets.

Maxwell, R., & DeSoucey, M. (2016). Gastronomic cosmopolitanism: Supermarket products in France and the United Kingdom. *Poetics*, 85-97.

Mesnildrey, L., Jacob, C., Frangoudes, K., Reunavot, M., & Lesueur, M. (2012). *La filière des macro-algues en France.* Netalgae - Interreg.

Michéal Mac Monagail, L. C. (2017). Sustainable harvesting of wild seaweed resources. *European Journal of Phycology*, 371-390.

Michèle Barbier, B. C. (2019). *PEGASUS - PHYCOMORPH European Guidelines for a Sustainable Aquaculture of Seaweeds.* Roscoff, France: COST Action FA1406 .

Mourtisen, O. (2013). *Seaweeds - Edible, Available & sustainable.* Chicago & London: University of Chicago Press.

MSC. (2017, 11 22). *ASC and MSC release joint seaweed standard*. Opgehaald van MSC: https://www.msc.org/uk/media-centre/press-releases/asc-and-msc-release-joint-seaweed-standard

Netalgae. (2012). *Overview of the seaweed industry by country. Ireland, france, norway, portugal, spain, united kingdom.*

Netalgae. (2012). *Seaweed industry in Europe.*

NIOZ, Deltares, Imares, Rijkswaterstaat. (2015). *De staat van de Noordzee.*

Noor, N. M., Noor, S. M., Weliyadi, E., & Salleh, R. (2018). Inculcating Halal Values in Seaweed Production for Competitive Positioning. *International Medical Journal Malaysia*.

Noordzeeloket. (sd). *Waterkwaliteit*. Opgehaald van Noordzeeloket: https://www.noordzeeloket.nl/functies-gebruik/waterkwaliteit/

NOS. (2019, August 14). *Vleesvervangers bezig met snelle opmars, verkoop vlees daalt*. Opgehaald van NOS: https://nos.nl/l/2297492

Ole Mouritsen, P. R.-L. (2018). The rise of seaweed gastronomy: phycogastronomy. *Botanica Marina*, 195-209.

Probst, L., Frideres, L., Pedersen, B., & Amato, F. (2015). *Sustainable, Safe and Nutritious Food - New nutrient sources.* European Union.

Rebours, C., Marinho-Soriano, E., Zertuche-González, J. A., Hayashi, L., Vásquez, J. A., Kradolfer, P., . . . Robledo, D. (2014). Seaweeds: an opportunity for wealth and sustainable livelihood for coastal communities. *Journal of Applied Phycology*, 1939–1951.

Rijksoverheid. (2016, 11 21). *Voedselagenda: Nederland internationaal koploper in gezonde en duurzame voeding*. Opgehaald van Rijksoverheid: https://www.rijksoverheid.nl/actueel/nieuws/2016/11/21/voedselagenda-nederland-internationaal-koploper-in-gezonde-en-duurzame-voeding

Rijksoverheid. (2019). *Inspirerende innovaties kringlooplandbouw: Zeewier brengt Noordzee tot leven*. Opgehaald van Omslag naar kringlooplandbouw: https://www.rijksoverheid.nl/ministeries/ministerie-van-landbouw-natuur-en-voedselkwaliteit/omslag-naar-kringlooplandbouw/inspirerende-innovaties-kringlooplandbouw

Sander van den Burg, A. P. (2016). The economic feasibility of seaweed production in the North Sea. *Aquaculture Economics & Management*, 235-252.

Santeramo, F., Carlucci, D., Devitiis, B. D., Seccia, A., Stasi, A., R.Viscecchia, & Nardone, G. (2018). Emerging trends in European food, diets and food industry. *Food Research International*, 39-47.

Santos, J. E., Freitas, M., Fonseca, C. P., Castilho, P., Carreira, I. M., Rombeau, J. L., & Branco, M. C. (2016). Iodine deficiency a persisting problem: assessment of iodine nutrition and evaluation of thyroid nodular pathology in Portugal. *Journal of Endocrinological Investigation*, 185-191.

StartLife. (2019, 6 18). *Insects, seaweed wraps and socks made from old fishing nets on the shelves at Lidl*. Opgehaald van StartLife: https://start-life.nl/news/insects-seaweed-wraps-and-socks-made-from-old-fishing-nets-on-the-shelves-at-lidl/

Stévant, P., Rebours, C., & Chapman, A. (2017). Seaweed aquaculture in Norway: recent industrial developments and future perspectives. *Aquaculture International*, 1373-1390.

Taelman, S. E., Champenois, J., Edwards, M. D., De Meester, S., & Dewulf, J. (2015). Comparative environmental life cycle assessment of two seaweed cultivation systems in North West Europe with a focus on quantifying sea surface occupation. *Algal research*, 173-183.

Tiwari, B. K., & Troy, D. J. (2015). *Seaweed Sustainability - Food and nonfood applications.* Dublin, Ireland: Department of Food Biosciences, Teagasc Food Research Centre.

van den Burg, S., Stuiver, M., Veenstra, F. A., Bikker, P., Lopez Contreras, A. M., Palstra, A., . . . van Duijn, A. P. (2013). *A Triple P review of the feasibility of sustainable offshore seaweed production in the North Sea.* Wageningen: Wageningen University.

van der Molen, J., Ruardij, P., Mooney, K., Kerrison, P., O'Connor, N. E., Gorman, E., . . . Capuzzo, E. (2018). Modelling potential production of macroalgae farms in UK and Dutch coastal waters. *Biogeosciences*, 1123-1147.

van Hal, J. W., Huijgen, W. J., & López-Contreras, A. M. (2014). van Hal, J. W., Huijgen, W. J. J., & López-Contreras, A. M. (2014). Opportunities and challenges for seaweed in the biobased economy. *Trends in biotechnology*, 231-233.

van Oirschot, R., Thomas, J. B., Gröndahl, F., Fortuin, K. P., Brandenburg, W., & Potting, J. (2017). Explorative environmental life cycle assessment for system design of seaweed cultivation and drying. *Algal Research*, 43-54.

Vásquez, J. A. (1995). Ecological effects of brown seaweed harvesting. *Botanica Marina*, 251-258.

Voedingscentrum. (sd). *Zeewieren en algen*. Opgehaald van Voedingscentrum: https://www.voedingscentrum.nl/encyclopedie/zeewieren-en-algen.aspx

Wageningen University and Research. (sd). *Dossier Seaweed*. Opgehaald van Wageningen University and Research: https://www.wur.nl/en/Dossiers/file/Dossier-Seaweed.htm

9 Appendix

9.1 Information sheet Interreg 2 seas ValgOrize

Algal biomass will play a vital role in feeding the world by 2050. To enhance innovation in the algal sector, ValgOrize will create an open platform for sustainable production of flavoursome, high quality algal foods that meet the requirements of the European market.

Description of the project

ValgOrize is a European Interreg 2 seas project, focusing on the valorisation of algae for a better taste. The project brings together the expertise of twelve diverse European project partners from four different countries and runs from July 2018 to March 2022.
To maintain current consumption trends, the world must produce 50-70% more food by 2050. Algae biomass production can contribute to meet this future demand. Current global algae biomass production is 3M tons annually, of which only 0.1 ton is produced in the EU. Many EU countries allow wild harvesting of seaweed which is an unsustainable practice with low quality yields. Imports of (Asian) algae do not necessarily meet EU food safety standards.
The key challenge of ValgOrize is to facilitate a change to controlled, sustainable production and processing of high quality, stable, safe algal biomass of known composition with important food features and a good total palatability including taste, aroma, colour and texture. Food producers in the EU need a reliable and predictable supply of high-quality biomass and consumers want tasty, safe and high-quality products. ValgOrize will close this gap. The project will focus on increasing and integrating innovations, increasing insights into consumer acceptance of algae products and gaining insights into the investment needed to scale up algae production to commercial scale.

Objectives

The goal of the ValgOrize project is to increase the capacity of members of the 2-Seas region to produce reliable, consistent streams of high-quality algal biomass and to process it for food and facilitate emergence and growth of a new sector within the food industry that produces food products sustainably from algae. The main outputs of the project will be:

- Specific tools and analytical methods from the Analytical Platform to support the sector to assess the safety and quality of products, profile taste (taste, texture, colour, aroma) and upskill operatives.
- An interdisciplinary knowledge-based, open-source platform to support sustainable cultivation and harvest of algal biomass and algae-based foods that meet consumer requirements
- An investor roadmap which will describe the investment needed to scale up production from pre-commercial to the commercial stage.

Role of the North Sea Farm Foundation

The North Sea Farm Foundation is a non-profit organisation aimed at realising a sustainable seaweed industry in the Netherlands and surrounding EU countries. The North Sea Farm Foundation is leading the study on valorisation in the ValgOrize project to support and accelerate the development of a technically and commercially viable seaweed supply chain for food applications. The goal is to develop a roadmap towards sustainable production of algae for food applications. To achieve this, the existing market, the market potential and the key success factors of the algae food market will be studied and identified, and a feasibility report will be composed.
Since market acceptance is a primary focus, stakeholders will be involved throughout the project. By involving relevant stakeholders, North Sea Farm Foundation aspires to encourage investment and enhance the development of a European algal value chain.

Contact: Marlies Draisma

9.2 Overview of the interviewed parties

Here an overview of the interview parties is provided. Almost all (observing) partners have been interviewed. Furthermore, interviews have been conducted that fall outside of the ValgOrize scope. These have been summarized in the figure 19.

Figure 18: Summary of the (observing) partners that have been interviewed

Company	Country	ValgOrize Partner (P) or Observing Partner (O)
Aquimer	FR	O
De Blauwe Cluster	BE	O
European Biogas Association	BE	O
Flanders' Food	BE	O
HZ University of Applied Sciences	NL	P
ILVO	BE	P
Koninklijke Euroma	NL	O
MBA	UK	P
Nausicaa	FR	P
NIOZ	NL	P
North Sea Farm Foundation	NL	P
POM West Flanders	BE	O
Provincie Noord Holland	NL	O
Provincie Zeeland	NL	O
Rijkswaterstaat	NL	O
Texel Saline	NL	P
University of Greenwich	UK	P
VITO	BE	P
WWF	DE	O

In addition to interviewing the (observing) partners of the project, stakeholders from different value chain positions have been interviewed.

Figure 19: Summary of interviewed parties outside of the ValgOrize scope

Value chain position	Count	Countries
Seaweed breeder	1	NL
Seaweed cultivator	4	NL, UK, IE
Seaweed food producer	3	NL

9.3 Interview Protocol

Several interview protocols have been made to ensure that the questions were suitable for the interviewees, something which is common within semi-structured interviews. Whereas the questions per interview protocol may differ, the categories have remained the same throughout the interviews. The following categories have been discussed:

1. *Introduction and goal of the interview*
2. *Practical announcements*
3. *General introduction of interviewee and organisation*
4. *Seaweed production and distribution:*
    a. *Regions*
    b. *Production method*
    c. *Production location*
    d. *Volume*
    e. *Distribution*
5. *Seaweed:*
    a. *Species*
    b. *Form*
6. *Current & future market*
    a. *Perspective of current market*
    b. *Potential of seaweed for food*
    c. *Biggest challenges*
    d. *Future needs*
7. *Closing statements or remarks*
8. *Final remarks by interviewer*

9.4 Interviewed stakeholders of the seaweed food market in the 2 seas region

Figure 20: Overview of Interviewees and the associated stakeholder position

Stakeholder category	# of interviews conducted
Seaweed breeder	1
Seaweed producer	4
Seaweed processor	1
Seaweed food producer	5
Seaweed food trader	1
Retail & foodservice	0
Science & research	5
Branch organisation	4
Government	4
Other	2
Total	**27**

9.5 Seaweed food products produced by companies situated in France, the United Kingdom, the Netherlands and Belgium

One should take in consideration that the seaweed food market in Europe is developing at a fast pace, making the overview possible out of date or incomplete. The tables below contain information on the amount of products for the categories of product category, form of the seaweed, producing country and colour of the algae.

The total count of products compiled is 121. In the product list, not all products have been categorised due to a lack of information contained by the product description. This applies to all the categories summarised below. Furthermore, the count of colour of algae is higher than the total number of products contained in the data base. This is due to the fact that products can contain multiple seaweed species.

Figure 21: Product categories for the seaweed food products produced France, the United Kingdom, the Netherlands and Belgium.

Product category	
Meal Component	Condiment & Flavouring
83	33

Figure 22: Form of the seaweed for the seaweed food products produced in France, the United Kingdom, the Netherlands and Belgium.

Producing country		
Wet	Dry	Unspecified
16	58	41

Figure 23: Count per colour of algae for the seaweed food products produced in France, the United Kingdom, the Netherlands and Belgium.

Colour of the Algae		
Red	Brown	Green
74	79	30

Figure 24: The count of seaweed food products produced per country in France, the United Kingdom, the Netherlands and Belgium.

Producing Country			
France	United Kingdom	Netherlands	Belgium
36	31	42	1