

Dutch seaweed

An economic analysis of Dutch seaweed (proteins) in the food and feed industry

Karlijn van der Linden – 900709520100
BEC-80433, MSc Thesis Business Economics, 33 ECTS
January 2014 – October 2014

Supervisors:

Dr. M.P.M. (Miranda) Meuwissen, Business Economics Group, Wageningen UR
Dr. W.A. (Willem) Brandenburg, PRI Agrosystems Research, Wageningen UR

Abstract

There is a growing interest in the use of Dutch seaweeds cultivated at the North Sea. Currently, no clear data is available about the best cultivation design, expected yield, and expected costs, due to the lack of experience. The uncertainty in cost data also results in a lack of experience and knowledge about the market values of Dutch seaweed. The purpose of this report is to give insight in the expected costs for offshore cultivation and to examine the opportunities and market values of Dutch seaweeds in the food and feed industry, by interviewing scientific and business experts. In total, 13 experts are interviewed by using semi-structured questionnaires. Results show that newer cultivation designs are needed to lower the costs. Currently, expected costs of between € 1,019 and € 2,500 per tonne (D.M.) are most likely. Wholesale prices for Dutch seaweed are expected to be between € 30 and € 60 per kg. Fresh seaweeds deliver lower market values, varying between € 10 and € 20 per kg. However, opportunities for Dutch seaweeds in the food industry are the fresh market for human consumption. The feed industry offers potential due to its high volume. The market value of whole seaweeds in the feed industry is related to the soy price and are estimated at € 1 per kg. If Dutch seaweed is refined into its main components, the protein component is expected to be worth approximately € 1 – 1.80, until research turns out that seaweed proteins contain specific properties. In the latter case, seaweed proteins are perceived to be worth up to € 20 per kg. This report provides a contribution to the economic insights of Dutch seaweeds on the Dutch market.

Key words: Dutch seaweed, *Laminaria digitata*, *Palmaria palmata*, *Ulva lactuca*, North Sea, market value, seaweed proteins, food industry, feed industry.

Preface

This master thesis is written in the context of the master Management, Economics and Consumer Studies at the Wageningen University. The subject of seaweed (proteins) gained my attention due to its food aspect in combination with an economic analysis. Seaweeds provide interesting opportunities for offshore food production to meet the increasing world population and consumption levels.

The completion of this thesis has been made possible due to the contribution and support of many individuals. In the first place, I would like to thank my supervisor Miranda Meuwissen for her help and insights during my thesis process. I appreciate her positive attitude and the way she supported and motivated me. Additionally, I would like to thank my other supervisor, Willem Brandenburg, who provided me guiding insights in the initial phase of this thesis.

I am grateful to the willingness of the experts who participated in the interviews. They shared helpful information, expertise and insights for this research.

Last but not least, I would also like to express my thanks to my friends and family for all the support they gave me.

Karlijn van der Linden

Wageningen, October 2014

Table of contents

1. Introduction	1
1.1 General introduction	1
1.2 Research objectives	2
1.3 Outline	2
2. Seaweed species in the North Sea	3
2.1 Species	3
2.2 Cultivation	3
2.3 Chemical composition	4
2.4 Biorefinery concept	6
2.5 Proteins in depth	7
2.6 Applications of seaweed proteins	8
3. Expected costs and potential market values	12
3.1 Expected production costs	12
3.2 Ecopiramid and market values	15
3.3 Market value of carbohydrates	15
3.4 Market value of seaweed (proteins) in the food industry	16
3.5 Market value of seaweed (proteins) in the feed industry	18
3.6 Market value of seaweed proteins in the technical industry	20
3.7 Overview	21
4. Materials and Methods	22
4.1 Questionnaire development	22
4.2 Selection of the experts	25
4.3 Data collection	28
5. Results	30
5.1 Cultivation location, cultivation design, yield and expected costs	30
5.2 Applications and opportunities for Dutch seaweed (proteins)	33
5.3 Market value of seaweed (proteins) in the Dutch market	37
6. Discussion & Conclusion	41
6.1 Discussion	41
6.2 Conclusion	42
6.3 Further research	42
7. References	44

Annex A	Interview format	49
	Scientific expert interview	49
	Business expert interview	59
Annex B	Expert information	66

List of tables

Table 2.1	Overview of the seaweed cultivation variants at the North Sea.	4
Table 2.2	Chemical composition of seaweed species native in the North Sea.	5
Table 2.3	The main polysaccharides in brown, red and green seaweeds.	5
Table 2.4	The amount of essential amino acids in proportion to the total amino acids, specific for the seaweed species native in the North Sea.	8
Table 3.1	The estimated costs for offshore seaweed cultivation with long-lines.	13
Table 3.2	The productivity and expected costs per tonne (D.M.) for seaweed cultivation.	14
Table 3.3	Applications and market value of carbohydrates in Laminaria.	15
Table 3.4	Overview of estimated market values in the food industry.	18
Table 3.5	Overview of estimated market values in the feed industry.	19
Table 3.6	The conversion of amino acids into chemicals and their estimated market value.	20
Table 3.7	Overview of the market values in the food and feed industry, specific for the seaweed species native in the North Sea.	21
Table 4.1	Topic guide and sub questions in the questionnaire.	23
Table 4.2	An overview of the cultivation designs and anchor values used in the questionnaire and their references.	24
Table 4.3	Background of the experts.	26
Table 4.4	Experts' indication of expertise.	29
Table 5.1	Assessment on the possible cultivation location, cultivation design, yield and expected costs.	31
Table 5.2	Assessment on the applications and opportunities for Dutch seaweed (proteins) in the food and feed industry.	34
Table 5.3	Assessment on the market value of seaweed (proteins) in the Dutch food and feed industry, specified for scientific and business experts.	38
Table 6.1	Promising Dutch seaweed species; related market values in literature and results.	41

List of figures

Figure 2.1	Seaweed biorefinery concept	7
Figure 3.1	Ecopyramid of biomass and the market value of the applications per tonne	15

1. Introduction

1.1 General introduction

The increasing world's population and accompanying total food consumption raises the worldwide demand for agricultural produces. This raising demand implies a further increase of pressure on current land usage. It becomes more and more important to search for sustainable alternatives of natural resources (FAO, 2011). Shifting part of the production to sea can be such an alternative, since seas and oceans cover 71% of the planet. Seaweeds provide opportunities and can be an important source of proteins for human and animal consumption. Other applications of seaweeds are in the production of hydrocolloids, as a source of chemicals and medicines, as bioactive molecules and as a potential source of bioenergy (Burg, 2013).

The value of the world seaweed market in 2004 was € 6 billion, in which over 90% was farmed. Seaweed production particularly takes place in Asia where China and Japan are responsible for the vast majority of the production. China's demand even outstripped its own supply, resulting in importing seaweeds from countries such as Korea (Douglas-Westwood, 2005). Worldwide, commercial harvesting occurs in about 35 countries, both in the Northern and Southern hemispheres, under varying water circumstances (cold, temperate, tropical) (McHugh, 2003).

Increasing demand for seaweeds results in a worldwide expansion of seaweed farming. Currently, there is no large-scale commercial seaweed production in the Netherlands. The 'Noordzeeboerderij' (Texel) and 'De Wierderij' are small-scale, near shore pilot trials in the Netherlands to investigate the feasibility of offshore seaweed cultivation under North Sea conditions (Burg, 2013). The focus of these pilots is on species that are native in the North Sea (Reith, 2005). Integrated aquaculture (mussels, fish and seaweed) and the integration of seaweed production with wind parks are also explored, since they are considered as possibilities to enhance the economic feasibility of seaweed production (Florentinus, 2010).

The location, the infrastructure and the optimal production design which can handle the weather conditions of a temperate marine climate are important issues in the implementation of offshore seaweed production (Reith, 2005). Besides these technological issues, several other challenges remain, for instance in the field of politics and economics (Burg, 2013). The uncertainties in the offshore seaweed production also involve uncertainty in the expected investment costs and the potential future revenues. Potential revenues largely depend on the seaweed market, which is quite diverse and include high value and low value products (Burg, 2013). Various usages have different market prospects. For example, human consumption shows high value but a relatively small market in Europe. Therefore, the production of only a certain high value product (such as feed additives, chemicals and alginates) will not match the expected production costs (Burg, 2013).

Several studies have identified the different applications of seaweed produce and their economic value in the market. The use of seaweed as animal feed show low value, ranging from € 0.00 - € 121.90 per tonne (D.M.) for the different species used in the pilots for offshore production in the North Sea. Alginates, agars and carrageenans are hydrocolloids extracted from seaweed, mainly used in food products to influence texture and viscosity (Burg, 2013). The FAO shows that hydrocolloids show an average market value of € 490 per tonne fresh seaweed (McHugh, 2003). Reith et al. (2005) used data of Pérez (1997) and calculated a market value of around € 200 per tonne of fresh seaweed, equal to € 1,626 per tonne (D.M.) for hydrocolloids. Seaweeds can also be used for a range of bulk- and fine chemicals. Citric acid is worth € 606 per tonne (D.M.), where butanol has a value of € 87. Other chemicals, like acetic acid, lactic acid, propylene glycol, show a market value of € 140, € 114, € 133 per tonne (D.M.), respectively (Burg, 2013). The market potential for products with high value content components is not clear yet, but provides interesting opportunities. According to Reith et al. (2005) the market value of for instance colorants is € 2,658 per tonne (D.M.). Besides chemicals, also biofuels can be

produced from seaweeds. In Lenstra et al. (2011) biofuels are found to have a very high market volume with a relatively low price at around € 37 per tonne (D.M.). Still, other opportunities and possible applications from seaweeds should be further analysed.

To enhance the economic feasibility of seaweed production, it is necessary to make multiple products in an efficient way (Burg, 2013). The valuable components and the variety of applications make seaweeds well suited for biorefinery. The concept biorefinery means that multiple components of the biomass are released and processed, in order to use them for different applications. The purpose of seaweed biorefinery is to reach an economic value as high as possible (Barbosa, 2009; Burg, 2013; Hal, 2012; López-Contreras, 2012). The market value of carbohydrates from seaweed have already been reviewed for *Laminaria*, a species which is native in the North Sea (Bozell, 2010) (Reith, 2005). Next to the market value of carbohydrates, it is important to further investigate the market value and applications of the other main component, namely the seaweed proteins. However, the market value of seaweed proteins derived from Dutch seaweed is unclear. Market values for non-Dutch seaweed proteins are also lacking. Proteins are becoming more and more important to meet the future protein demand (Huis, 2013). This emphasizes the importance to examine the applications of Dutch seaweed proteins in different industries and the expected market value of these proteins.

1.2 Research objectives

The objective of this study is to examine the potential applications of Dutch seaweeds and their market values. More specifically, the sub-objectives are:

- To give an overview of the expected costs and cultivation designs of Dutch seaweed.
- To analyse the applications and opportunities for Dutch seaweeds in the Dutch market.
- To analyse the market value of seaweed (proteins) in the Dutch market.

The analysis of this study focuses on seaweeds produced at the North Sea with applications in the food and feed industry. Although the technical industry (i.e. chemicals in this report) is also taken into account in the literature research, this industry is not considered in the interviews. Currently, there is no offshore production of seaweeds at the North Sea. There is some information available on the applications and market values of the native seaweed species cultivated elsewhere. Whether this information can be applied for Dutch seaweeds is depending on the influence of North Sea cultivation circumstances on the composition and availability of Dutch seaweed. Regarding the seaweed volume of Dutch nearshore cultivation projects, no information could be found yet. The total volume of European seaweed production is around 738 tonnes in 2010, an increasing number compared to the years before (Burg, 2013).

1.3 Outline

A literature overview is provided in the first part of this research. Chapter 2 includes background information on the seaweed species in the North Sea (cultivation designs and the chemical composition of the seaweeds). Other topics in this chapter are the concept of biorefinery, seaweed proteins and the applications of these proteins in the food, feed, and technical industry. Chapter 3 deals with the expected cultivation costs and the potential market values of seaweeds. Thereafter, the materials and methods are discussed in chapter 4 and the results of the research in chapter 5. In chapter 6, the discussion and conclusion of the report are presented. Chapter 7 shows an overview of the references. The report concludes with annex A and annex B, which include an interview format and a table with expert information, respectively.

2. Seaweed species in the North Sea

2.1 Species

Seaweeds (also called macroalgae) can be divided into three groups based on pigmentation: brown, red and green. The botanical classification of these seaweed groups is Phaeophyceae, Rhodophyceae and Chlorophyceae, respectively. Brown seaweeds are relatively large, ranging from species of 30 – 60 cm long to giant kelp of 20 m long (McHugh, 2003). In total, the brown seaweeds include around 1,500 – 2,000 different species (Burg, 2013). Red and green seaweeds are usually smaller than brown seaweeds, from a few centimetres up to about a metre in length (McHugh, 2003). There are around 4,000 – 10,000 red algae species and around 7,000 green algae species (Burg, 2013). Native species have already been cultivated elsewhere and are endemic to the North Sea. Besides, cultivation conditions and North Sea circumstances played a role in the selection. Species selected for North Sea cultivation are (Burg, 2013; McHugh, 2003; Reith, 2005):

- *Laminaria digitata* (Finger kelp; brown seaweed)
- *Palmaria palmata* (Dulse; red seaweed)
- *Ulva lactuca* (Sea lettuce; green seaweed)

2.2 Cultivation

When cultivating seaweed in the open sea, several environmental factors could influence the cultivation conditions of the water. These factors include: salinity, temperature, light intensity, depth, flows, predation and epiphytes (Reith, 2005). Therefore, offshore cultivation systems require a different design than onshore or nearshore cultivation systems. However, current used systems are aimed for relatively small scale cultivation and mainly suitable for nearshore locations. Those systems consist of lines or nets, anchored to the soil and/or to floating buoys. Currently, there is no optimal design which is resistant to the North Sea conditions (Reith, 2005).

Cultivation designs

Different large scale cultivation designs, especially for open sea, have been tested in the American Marine Biomass Program. The tests were performed in front of the Californian coast, with systems anchored to the soil and/or to floating buoys and totally floating cultivation systems. It turned out that the dynamic of the system and the attached seaweeds were not compatible, since the seaweeds detached from the lines while the line systems kept intact. In another test, the anchors were lost and the lines became tangled. A floating ring structure (15 m diameter) showed the best performance for open sea cultivation (Chynoweth, 2002). This ring structure (5 m diameter) also proved its stability in tests of van Buck and Buchholz. Besides, the structure can be provided by seaweed material onshore. The disadvantage of this system is that it requires a lot of labour and it cannot be mechanically harvested. Therefore, from an economic perspective, this ring system is less attractive (Buck, 2004a). Floating cultivation systems are not applicable for native seaweed species in the North Sea (Reith, 2005). There are also a number of research projects going on in the Netherlands with nearshore and offshore seaweed cultivation. One of them is the nearshore project of a seafarm, named 'De Wierderij'. The seafarm was officially opened in 2011 and is located at the Schelphoek in the Eastern Scheldt. Cultivation of the native species *Ulva*, *Laminaria* and *Saccharina*, takes place by lines attached to floating rafts. Nutrients from the sea are used in order to cultivate in a sustainable way. The possible effects on the environment are closely monitored (GroenKennisnet, 2011). Another trial location is the 'Noordzeeboerderij' of the 'Stichting Noordzeeboerderij' at Texel, founded by Ecofys, Hortimare and ATO. At this location, different cultivation designs are tested and developed, whether or not in combination with other activities, a concept called multiple spatial use at sea (StichtingNoordzeeboerderij, 2014). Therefore, different cultivation variants exist. These variants are mainly interesting due to the elimination of nutrients by the seaweeds, which can be taken

up by mussel, fish, etc. The other variants are of interest because it may increase the biomass productivity per year or it provides an infrastructure for the seaweed cultivation designs. An overview of the cultivation variants and a more detailed description are outlined in Table 2.1.

Table 2.1 Overview of the seaweed cultivation variants at the North Sea.

Variant	Description
Cultivation of seaweeds in layers	Laminaria, Palmaria and Ulva have different light requirements, which provide opportunities for a ring structure with different layers. The upper layer will be used for the cultivation of Ulva, 1 m lower Palmaria, and from 2 m depth Laminaria can be cultivated. This structure requires a limited surface ¹ .
Combination of seaweed cultivation with mussel cultivation	Seaweed cultivation can be combined with the cultivation of mussels. The first layer of 2 m long lines can be provided with mussels, while the second layer at 2 m depth can be used for cultivation of Laminaria. The mussels eliminate nutrients which can be taken up by algae ² .
Combination of seaweed cultivation with fish cultivation	Fish cultivation results in the emission of nutrients. These nutrients can be used by the cultivation of seaweeds. Especially the combination with Ulva can be interesting, since this type of seaweed can take up nutrients very easily. The productivity should still be tested for practice purposes ² .
Cultivation of seaweed species at different times of the year	Seaweeds can have different optimal growth months, which offers the opportunity to cultivate some seaweeds alternately in the time ² .
Combination of seaweed cultivation with offshore wind farms	The combination of offshore wind farms with seaweed cultivation might be interesting, since the generation of wind energy is also an important part of the government policy. Potential advantages of the integration is the joint maintenance and management, training of personnel to perform both activities and the infrastructure for seaweed cultivation which can be provided by the wind farms ³ .

Sources: ¹(Buck, 2004a), ²(Reith, 2005), ³(Buck, 2004b).

Yield

Depending on the supply of nutrients and the cultivation method (which determines the planting density), the productivity of offshore production at the North Sea can be estimated. Without the supply of nutrients, the productivity will be around 20 tonnes/ha/year. When cultivation takes place in layers and/or with dosed nutrient supply, the productivity may increase to around 50 tonnes/ha/year. According to the assessment study of Reith et al. (2005), the projected cultivation area for seaweed in 2040 will be 5,000 km², integrated with offshore wind parks and other potential aquaculture operations. Taken an estimated yield of 20 tonnes/ha/year and the projected seaweed cultivation area in 2040 of 5,000 km², the total seaweed yield would be 10 million tonnes D.M. per year (Reith, 2005).

2.3 Chemical composition

The chemical composition of seaweed depends on the species, season and the area of production. The moisture content can account for 73 % up to 94 %. Other nutritional components of marine algae are: polysaccharides, proteins, lipids, vitamins and minerals (Holdt, 2011). On average, red and green seaweeds show to have higher protein contents compared to brown seaweeds. Due to the low lipid content and the high dietary fibre content, seaweeds have a relatively low energy content (Burg, 2013). Table 2.2 gives an overview of the chemical composition for the seaweed species native in the North Sea (Holdt, 2011; López-Contreras, 2012).

Table 2.2 Chemical composition of seaweed species native in the North Sea, based on Holdt (2011).

Components	Laminaria Saccharina	Palmaria	Ulva
Dry matter	6 – 27 %	11 – 27 %	20 – 22%
Polysaccharides (on D.M.)	38 – 61 %	38 – 66 %	15 – 65%
Mineral residue (on D.M.)	15 – 45 %	12 – 27 %	11 – 55 %
Proteins (on D.M.)	3 – 21 %	8 – 35 %	4 – 44 %
Lipids (on D.M.)*	0.3 – 9.6 %	0.2 – 8.3 %	0.3 – 2.8 %

* Data for the lipid content is supplemented with the results of López-Contreras et al. (2012).

Polysaccharides

As shown in Table 2.2 seaweeds contain a large amount of polysaccharides, ranging from 15 % up to 66 % (on D.M. weight) (Holdt, 2011). These include structural polysaccharides for the cell wall as well as storage polysaccharides (Kumar, 2008; Murata, 2001). The main polysaccharides are typical for the seaweed type and are shown in Table 2.3 (Mabeau, 1993). The season of the year and the species influence the content and composition of the polysaccharides (Burg, 2013). Large part of the polysaccharides is dietary fibres which are not taken up by the human body. Dietary fibres contribute to a healthy intestinal environment, which in turn positively affects the whole human health (Mouritsen, 2009). The valuable nutrients and substances from dietary fibres resulted in the growing interest in seaweed as meal, functional foods and nutraceuticals (McHugh, 2003). Current commercial applications of polysaccharides in products are as stabilisers, thickeners, emulsifiers, food, feed, beverages, etc. (McHugh, 1987; Tseng, 2001).

Table 2.3 The main polysaccharides in brown, red and green seaweeds, taken from Mabeau (1993).

	Cell wall polysaccharides	Storage polysaccharides
Brown seaweed	Alginate (guluronic acid, mannuronic acid) Fucans (sulfated fucose)	Laminarin (glucose)
Red seaweed	Carrageenans (galactose, sulfate) Agar (galactose) Cellulose Xylan	Floridean starch (glucose)
Green seaweed	Xylan Mannan Glucuronoxylorhamnan (sulfated)	Starch

Proteins

The protein content of the seaweed species have been shown Table 2.2. In general, brown seaweeds contain a smaller protein fraction compared to green and red seaweeds. The protein content in green and red seaweeds can represent up to 44 % and 35 %, respectively. Variation within each species has to do with seasonal influences and the habitat, which also have an effect on the composition of peptides and amino acids present in the seaweed (Arasaki, 1983; Haug, 1954). The brown algae *Laminaria digitata* grow best during September until May, while the red algae *Palmaria palmata* and the green algae *Ulva lactuca* have their growth season presumably at summer (Burg, 2013). Most seaweeds contribute to all the essential amino in the human body and contain a relatively high amount of aspartic acid and glutamic acid (Fleurence, 2004). The protein functions and amino acid composition for the seaweed species native in the North Sea will be further discussed in paragraph 2.4.

Lipids

The seaweed lipid content is low, 0.2 % to 9.6 % depending on the species (Table 2.2), the period of the year and also the environmental conditions (Holdt, 2011; Patarra, 2012). The group of lipids consists of fats, waxes, sterols, fat-soluble vitamins, mono-, di- and triacylglycerols, diglycerides, phospholipids and others. Lipids are a concentrated source of energy and contribute essential fatty acids, vitamins and carotenoids, which are required by the human body. Long chain PUFAs are chains with 20 or more carbons with two or more double bonds from the methyl terminus, which represent a significant part of the marine lipids. Based on their metabolic connections PUFAs can be divided into two families, namely the linoleic acid family (n-6 fatty acid) and the α -linolenic acid family (n-3 fatty acid). Especially EPA (20:5 n-3) and DHA (DHA; 22:6 n-3) are two important fatty acids in marine lipids (Holdt, 2011). It is suggested that the EPA content varies between species up to almost 50 % of the total fatty acids in *Palmaria*. However, seaweed lipids contain a relatively small amount of phospholipids and C18:4 n-3 which is said to influence the immune system (Burg, 2013).

Vitamins

Some seaweed pigments can function as vitamins in humans and animals. The most important of these compounds are β -carotene (carotenoids) with provitamin A activity and tocopherol (tocols), also known as vitamin E (Holdt, 2011). Vitamin A is important in the homeostasis of healthy teeth, bones, soft tissue, mucus membranes and skin. In addition, the vitamin may also be used in breast-feeding and reproduction, and it promotes good vision. Vitamin E acts as an antioxidant, which protects the body from damage by free radicals. Besides, vitamin E plays a role in the immune system by its fight against viruses and bacteria, in the formation of red blood cells, and it helps the body to use vitamin K. In general, vitamins are essential for normal cell function, growth and development (Evert, 2013b). Since seaweeds vary in their vitamin content, the potential for commercial application depends on the type seaweed, but also on the cost of production in comparison with other vitamin sources (Burg, 2013).

Minerals

The mineral content in seaweeds is high, with 11 % to 55 % (on D.M.), see Table 2.2. Like lipids, the mineral composition is influenced by the species, season and environment (Mabeau, 1993). Seaweed mineral content is much higher than found in edible land plants, up to a factor 5 to 10 (Burg, 2013). Iodine content is generally high in seaweed compared to land plants. Other minerals which are relatively high in seaweeds are potassium, sodium, calcium, magnesium, phosphorus and iron (Mabeau, 1993). In addition, minerals such as sulphate and zinc can also represent a significant part of the mineral content (Whittemore, 1975). However, not only the desirable minerals are accumulated in the body, also other metals and bioactives may accumulate and pose negative health effects (Holdt, 2011).

2.4 Biorefinery concept

The separation of seaweeds in its main components can be accomplished by the use of a biorefinery concept. The International Energy Agency (IEA) defined biorefinery as follows: 'Biorefinery is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)' (IEA, 2009). In practice, this means that the production of food, feed, fuel and chemicals will go together. Some parts of the biomass, in this case seaweeds, will be used for human food or animal feed, while other parts are more suitable for the production of fuels and chemicals. A model of a seaweed biorefinery is shown in Figure 2.1.

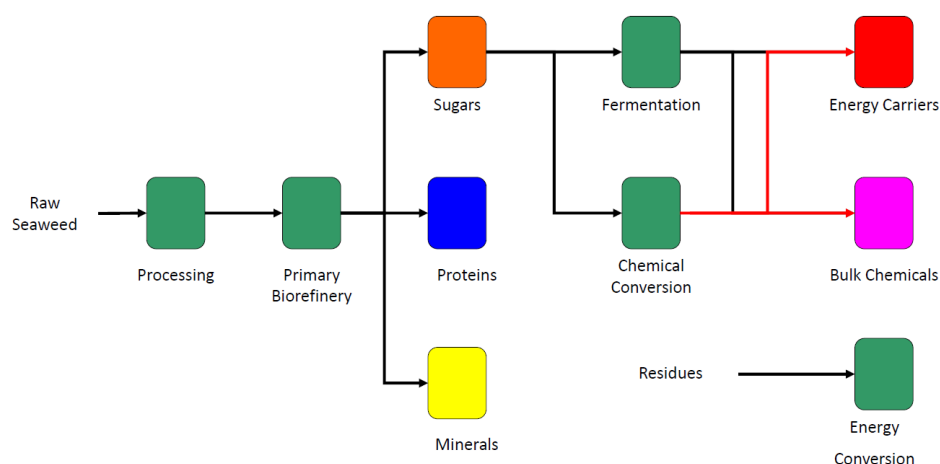


Figure 2.1 Seaweed biorefinery concept, taken from van Hal (2013).

The products derived from seaweed biorefinery all contribute to the economic value of the biomass, so that the final economic value after biorefinery is higher than the initial biomass value (Mulder, 2013).

2.5 Proteins in depth

In the previous paragraph the different seaweed components have been described. Current research is mainly focused on the use of carbohydrates derived from seaweed. These carbohydrates can be used in the food industry as hydrocolloids or in the technical industry as CO₂ neutral bulk chemicals and energy carriers (Bozell, 2010; Reith, 2005). Based on an advised daily intake of 0.75 g proteins per kg bodyweight with an individual mean weight of 70 kg, the total protein demand for mankind will be about 178 million tonnes in 2050 (Brandenburg, 2010). To meet this demand novel protein sources, like insects, algae, duckweed, and rapeseed, are expected to expand in the European feed and food market (Spiegel, 2013). Proteins that cannot be used for feed or food purposes, may be used as feedstock for the technical industry. Seaweeds are of special interest, because they are not in direct competition with the land use of other crops (Poel, 2013).

Functions

Proteins can perform several functions, which can be categorized in enzyme catalysis, defense, transport, support, motion, regulation, and storage proteins (Losos, 2008). According to their shape, proteins may be divided into fibrous and globular proteins (Zimmermann, 2003). Proteins are an essential component in the human and animal diet with an important role in all kind of processes (Friedman, 1996).

Amino acids

Amino acids are organic compounds which form the building blocks of proteins. They are linked together by peptide bonds, and cross-linked between chains by sulfhydryl bonds, hydrogen bonds and van der Waals forces (FAO, 1980). Amino acids can be classified into three groups: essential amino acids, nonessential amino acids and conditional amino acids. Essential amino acids must come from food, because the body cannot synthesize them. In total there are nine essential amino acids: histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. On the other hand, the nonessential amino acids can be produced by the body. The nonessential amino acids in the body are alanine, asparagine, aspartic acid, and glutamic acid. Conditional amino acids mean that they are only essential for the human body in times of illness and stress. Arginine, cysteine, glutamine, tyrosine, glycine, ornithine, proline, and serine can be classified as conditional amino acids (Evert, 2013a).

Most seaweeds contain a high concentration of the essential amino acids and a large fraction of the acidic amino acids, aspartic acid and glutamic acids (Fleurence, 2004). These acidic amino acids can represent

between 22 % and 44 % of the total amino acids in brown seaweeds and between 26 % and 32 % in Ulva species (Munda, 1977) (Fleurence, 1995). Glutamic and aspartic acid levels seem to be lower in red seaweed species, around 14 % to 19 % of the total amino acids (Fujiwara-Arasaki, 1984) (Indegaard, 1991).

Table 2.4 The amount of essential amino acids in proportion to the total amino acids, specific for the seaweed species native in the North Sea, extracted from Holdt (2011).

Essential amino acids (in % of total amino acids)	Laminaria	Palmaria	Ulva
Histidine	2.3 – 2.4 %	1.3 – 2.1 %	1.8 – 4.6 %
Isoleucine	5.5 – 5.8 %	5.3 %	4.8 – 6.1 %
Leucine	8.7 – 9.2 %	7.1 – 7.8 %	5.0 – 9.2 %
Lysine	6.5 – 7.3 %	3.3 – 8.2 %	1.7 – 6.3 %
Methionine	1.9 – 2.2 %	1.9 – 2.7 %	1.6 – 1.8 %
Phenylalanine	5.7 – 6.2 %	5.1 – 5.2 %	3.9 – 6.3 %
Threonine	4.6 – 5.0 %	3.6 – 4.5 %	3.1 – 4.6 %
Tryptophan	–	–	0.3 %
Valine	6.9 %	6.9 – 7.3 %	4.9 – 7.7 %

Brown seaweeds (like Laminaria) are a rich source of the essential amino acids threonine, valine, leucine, lysine and the non-essential amino acids glycine and alanine. The amino acids cysteine, methionine, histidine, tryptophan and tyrosine recorded lower levels (Augier, 1978) (Fujiwara-Arasaki, 1984) (Dawczynski, 2007). In red seaweeds, such as Palmaria, leucine, lysine and valine are well presented in the essential amino acid fraction (Holdt, 2011). According to Fleurence et al. (2004), methione represents a high fraction of the amino acids as well. The main essential amino acids present in Ulva are leucine, lysine and valine (Holdt, 2011).

2.6 Applications of seaweed proteins

In Table 2.2 it is shown that the protein content can represent up to 21 %, 35 % and 44 % of D.M. in Laminaria, Palmaria and Ulva, respectively. The protein levels of Palmaria and Ulva are comparable with those found in high-protein vegetables, such as soybeans, which have a protein content of about 40 % (Murata, 2001). Soybeans are converted to different soy protein products for the use in food, feed and also non-food applications. There are different forms in which soy proteins are available, such as soy flour, soy concentrate and soy isolate, all with a different protein content and commercial value (Mulder, 2010). In chapter 3 the value of seaweed proteins applied in the food and feed industry will also be estimated based on soy protein market values. In this paragraph the applications of seaweeds and its proteins in the food, feed and technical industry will be addressed.

Food industry

Seaweed is a versatile product which can be used as food in direct human consumption. It is rich in dietary fibers, minerals and vitamins and therefore a good source of healthy food (Ito, 1989). In some countries, particularly China, Japan and Korea, seaweeds have been used in the human diet for several centuries, mainly red and brown algae (FAO, 2003; Kılınc, 2013).

Red seaweeds

Red seaweeds are an interesting source for applications in human food due to its high protein level and the amino acid composition. In addition, red seaweeds can also be used as food dye (Fleurence, 1999). The presence of original pigments such as phycoerythrin enables the development of functional ingredients in the food industry (Fleurence, 2012). In a study of Galland-Irmouli phycoerythrin was extracted from Palmaria palmata. Phycoerythrin is a phycobiliprotein with a major light-harvesting pigment present in red algae and

cyanobacteria. It is widely used as a fluorescent probe and have many applications in high-technology areas. The results of the study showed that the phycoerythrin content was 12.2 % of the total protein content (Galland-Irmouli, 2000).

Brown seaweeds

Large part of the brown seaweeds, especially *Laminaria* species, are currently used for alginate production. *Undaria pinnatifida* and *Laminaria digitata japonica* are two brown seaweeds which are still well known to be consumed in the daily diet by Japanese people (Kolb, 2004).

Green seaweeds

Some green algae belonging to the genus *Ulva* are also edible and only a few of these *Ulva* species have been studied for applications in the food industry, among others *Ulva lactuca* (Tabarsa, 2012). Besides, seaweed species belonging to the order *Ulvales* are also used as supplement to flavour food in Southeast Asian countries and in North and South America. These supplements can be used, for example, in salads, soups, cookies and meals (Rodríguez, 2011; Tabarsa, 2012).

Food supplements

In recent years, the interest in seaweeds is growing and expanding in the West (Tabarsa, 2012). Seaweed salads (*Undaria pinnatifida* - Wakame) can already be found on the shelves in the Dutch supermarkets (Zeewierwijzer, 2011). The development of novel foods offers opportunities for protein-rich species, like the red and green seaweed species. The native species in the North Sea, *Laminaria*, *Palmaria* and *Ulva*, have not been tested for their use as food supplement yet. In a study of Kolb et al. (2004) the edible brown marine algae *Undaria pinnatifida* and *Laminaria digitata japonica* were evaluated for their use as food supplements. The results have shown that the values of the essential amino acids exceed the ratios of reference proteins suggested by FAO/WHO/UNU. Only tryptophan, the first limiting amino acid in both algae, did not meet this reference intake. The good protein quality is complementary with proteins in other vegetables, such as grains and legumes. The analysed algae also contributes to the recommended daily doses of vitamins and can compensate for the low content of minerals in food plants grown on soils, due to its rich source of most minerals. Therefore, food supplements from these algae can improve the nutritive value of diets (Kolb, 2004). This study may stimulate further research to evaluate other (native) seaweed species and their potential as food supplements. However, less information is available about the protein digestibility *in vivo*, which may influence the actual uptake of the essential amino acids (Fleurence, 1999). In addition, if isolated proteins are from a 'new' protein source, current legislation can restrict the use in human food (Burg, 2013). In contrary to seaweeds, microalgae supplements are already available in some Dutch shops (DeTuinen, 2014; Gezond&Wel, 2014).

Feed industry

In several coastal regions, seaweed was already commonly used in animal diets, used to feed cattle, horses, and poultry (Chapman, 1970). The feed market is a large industry which makes it interesting for seaweed as animal feed ingredient or additive (Burg, 2013). At the moment, seaweeds are used as feed because of their high mineral content and polysaccharides, but are rarely promoted because of their proteins (Fleurence, 1999).

Seaweed as protein source

In recent years, *Palmaria palmata* gained awareness as a new protein source in animal feed due to its relatively high protein content. The protein content can even be increased when integrated with aquaculture or in co-cultivation with abalone (Langdon, 2004). *Ulva lactuca* is also regarded as interesting biomass source for food and feed purposes (Bolton, 2009; Lahaye, 1993; Taboada, 2010). A study of Ergün et al. (2009) showed that fish fed with a 5 % *Ulva* meal showed an increased growth performance compared with fish without *Ulva* supplementation. The supplementation also improved the protein efficiency ratio. In Poel et al. (2013) seaweed is mentioned as a promising potential protein source to increase the EU feed protein production. Seaweeds can be used in animal diets in different forms: complete, as a residue of bioprocessing, and as a source bioactive components (Burg, 2013). The nutritional value for monogastric animals have only been studied in a few

experiments. The results showed that seaweed in the present form is not suitable for poultry. The nutritional value of extracted seaweed protein concentrates has not been studied yet, but the high content of amino acids (and minerals) in seaweed provide opportunities for its use as a supplement in animal feeding (Poel, 2013). Seaweeds can also be used as a source of feed for fish farming, which additionally fulfils the needs of the industry to replace part of the animal meal by plant meal in fish feed (Fleurence, 1999).

Effect of seaweed proteins in animals

However, at this moment there is little evidence that proteins and peptides in seaweed contribute to beneficial bioactive effects in farm animal nutrition above the amino acid supply of the animals. The number of studies is limited and more research is needed to better evaluate the protein value of seaweed (products). The variation in chemical composition within and between seaweeds is high, which makes the current application in animal diets difficult. To implement *Laminaria*, *Palmaria* and *Ulva* as a feed ingredient, it is important to determine the nutritional value, functional value and digestibility. Besides, research is needed to determine the composition and nutritive value of seaweed residues from a biorefinery. The use of functional feed, so after biorefinery, is mentioned as a potential to increase the economic feasibility of seaweed production. Burg et al. (2013) also concluded that seaweeds have a low contribution to the energy requirements of animals. An increase in energy and protein digestibility will improve the economic value of seaweeds in animal diets. In the future, the use of seaweed ingredients may be most interesting in fish feed (Burg, 2013). Other aspects that should not be forgotten are feed safety and legislation when using new protein sources (Poel, 2013).

Technical industry

Amino acids present in the proteins are a rich source of organic nitrogen. Therefore, proteins can be an attractive feedstock for the production of nitrogen containing bulk chemicals (Scott, 2007). In order to use certain protein sources for production, several factors have to be taken into account. The production of nitrogen containing chemicals requires a source with preferably a large amount of proteins. The composition of the amino acids is also important to explore which amino acids are present in a significant amount to produce certain chemicals. Amino acids which are present in a significantly higher amount than others have more potential to be used as starting material. Glutamic and aspartic acid are well presented in seaweeds, especially in brown and green species, and have a higher potential to be used as feedstock for chemicals. These amino acids are nonessential, which also means that the residue of the source will not lose its value as animal feed. Finally, the available amount of the protein source is also very important in the case of large scale production of chemicals (Lammens, 2011).

Protein applications

The use of proteins is not new to the technical industry. Soy protein demonstrated its potential use in plastics and adhesives already in the early 1900s and Henry Ford applied soy protein in technologies of automobile components. Thereafter, proteins were used in the paper industry as binders, adhesives and glues. In the 1960s, proteins were replaced by synthetic polymers, which had a lower price and a better performance. Due to the relatively high price of proteins in technical applications, little research has been done on the possibilities within this field (Burg, 2013).

New protein sources

Currently, the main outlet for proteins is the food sector (Mulder, 2010). The technical industry can be of special interest for proteins which may not be used in the food industry. This is especially the case for new protein sources, in which legislation prevents application in the food industry. At this moment, the total number of proteins used in technical applications is hard to estimate and will be around 175 kilo tonnes. However, not all data is included in this estimation, which suggests that the total amount will be higher (Mulder, 2013). There is an increasing demand from the consumers and industries to use polymers of renewable resources instead of synthetic polymers. It is expected that within a couple of years several biomass, such as seaweed, will be used in the chemical industry as starting material for the production of polymers (Mulder, 2010). Research regarding the use of amino acids is still in its infancy, so more research is needed.

Especially, the isolation of amino acids and pathways for large scale production from amino acids are essential in the development of technical applications (Mulder, 2013). In the future, seaweed proteins may be derived from biorefinery processes, a concept which will be explained in the next paragraph (Mulder, 2010).

Although there is information available regarding the use of seaweed in other countries, much of the exact possibilities with Dutch seaweeds in the food and feed industry are unknown. In these industries, it is very important to consider the influence of North Sea circumstances on the seaweed and its composition. The history of human consumption of comparable species in other countries, especially Asian countries, offers opportunities for Dutch seaweeds to be used in the diet. In the feed industry, more research is needed on the digestibility of Dutch seaweeds in animals. The use of seaweeds in food supplements is a relatively new area in which research is going on (Kolb, 2004).

3. Expected costs and potential market values

The first part of this chapter will provide an overview of the expected productions costs for different cultivation designs, including an approach for the expected costs for offshore seaweed cultivation in the North Sea. The second part covers the potential market values for seaweed (protein) applications in the food, feed and technical industry.

3.1 Expected production costs

Seaweed cultivation could take place onshore, nearshore and offshore. In this paragraph, only the expected production costs for nearshore and offshore cultivation will be discussed, since these locations are not in direct competition with the land use of other crops.

Offshore

Two different designs will be discussed: the ring structure and long-lines. These designs have been discussed in paragraph 2.2.

Ring structure

As mentioned in paragraph 2.2, the floating ring structure showed the best performance for open sea cultivation so far (Chynoweth, 2002). From an economic viewpoint, the design is less attractive compared to the long-lines. The harvesting requires a lot of labour, which raises the operational costs. In the study of Buck (2004) the investment costs are € 1,000 per fully mounted ring (5 m diameter), with a lifespan of 10 years. These costs are without any labour and ship costs. Given a yield of 0.040 tonnes (D.M.) the costs per tonne are € 2,500 (Buck, 2004a).

Long-lines

In the US Marine Biomass Program the expected costs for offshore line cultivation of *Gracillaria* and *Laminaria* are estimated at \$ 409 (€ 296) for a productivity of 14 tonnes/ha/year (D.M.) and \$ 112 (€ 81) for a productivity of 59 tonnes/ha/year (D.M.) (prices are adapted to the exchange rate of 3-4-2014 (€ 1.00 = \$ 1.37 derived from www.exchangerates.org.uk) (Chynoweth, 2002; Reith, 2005).

Burg et al. (2013) used cost data based on experiences of the Dutch nearshore project 'De Wierderij' (see paragraph 2.2). In this project the estimated total investment costs are in the order of € 25,000 to € 75,000 per ha. Included in these costs are 10 km of long-lines (€ 1/m), buoys, mooring and employment. The investments have an expected lifespan of 10 years. Since these costs are for nearshore cultivation, Burg et al. (2013) doubled the investment costs for offshore application, which results in a 'low' scenario with investment costs of € 50,000 per ha and a 'high' scenario with investment costs of € 150,000 per ha. Given a lifespan of 10 years and a yield of 20 tonnes of D.M./ha/year the expected investment costs per tonne (D.M.) are € 250 and € 750 for the 'low' and 'high' scenario, respectively. Still, costs for new seedlings each year, labour, and harvesting costs have to be added. New ropes with seaweed seedlings are set on € 1/m (1 m rope + 1 seedling). Labour costs for a 10,000 ha sea farm are expected to be € 2,923,200, based on a wage of € 35 per hour and 83,520 hours per year. The labour costs converted per ha are € 300 and are used for operation and maintenance (requires mechanisation in the production process and online monitoring. Data from Lenstra et al. (2011) was used for the harvesting costs (€ 104 per tonne of D.M.). Costs for transport are excluded in the estimated costs (Burg, 2013). An overview of the two scenarios ('low' and 'high' are presented in Table 3.1).

Table 3.1 The estimated costs for offshore seaweed cultivation with long-lines, adapted from Burg et al. (2013).

	Per ha	Lifespan (year)	Costs (per tonne (D.M.))*
Scenario 1 ('low')			
Investment costs	€ 50,000	10	€ 250
1 m rope + 1 seedling	€ 13,000	1	€ 650
Labour	€ 300	1	€ 15
Harvesting			€ 104
Total			€ 1,019
Scenario 2 ('high')			
Investment costs	€ 150,000	10	€ 750
1 m rope + 1 seedling	€ 13,000	1	€ 650
Labour	€ 300	1	€ 15
Harvesting			€ 104
Total			€ 1,519

* Based on a yield of 20 tonnes (D.M.) per year.

In Burg et al. (2013) also the results of Lenstra et al. (2011) are used to calculate the cost price per tonne (D.M.). With a 100 ha scale, the operation and maintenance costs are estimated to be € 75,000 per year, harvesting costs € 104 per tonne (D.M.) and the required total investment is € 25,000 per ha. Given an estimated yield of 50 tonnes/ha/year (D.M.), the indicated cost price is € 669 per tonne (D.M.). There is no information available about the lifespan of the investment (Burg, 2013; Lenstra, 2011).

The complete overview of the expected production costs is shown in Table 3.2.

Nearshore

Nearshore cultivation could also take place by the ring structure and long-lines. Additionally, a design in which plants are attached to rocks will be discussed.

Ring structure

In Florentinus et al. (2008) several promising sets of cultivation designs were investigated for their technical potentials. Besides, the socio-economic aspects of the different designs were estimated. The costs are shown as price estimation ranges, since there is a lack of practical experiences for most designs. Table 3.2 includes two design sets of Florentinus et al. (2008). The nearshore ring structure is designed for seaweed cultivation in rougher seas. The yield is equal to the first set (30 tonnes/ha/year (D.M.)), while costs ranging from around € 380 to € 990 per tonne (D.M.) (Florentinus, 2008).

Long-lines

The highest costs for the production per tonne (D.M.) originates from a study of Petrell et al. in 1993. In this study the costs can be up to € 10,448 per tonne (D.M.). This cost price includes the costs for transport, labour and storage. An important cost factor is the initial investment in 60x20 m farm, which comes down on around € 45,615 (including cost for boats, shed and dryers). Operational costs are estimated to be € 12,155 per year. The study of Petrell et al. (1993) is the most detailed study to describe the estimated production costs (Burg, 2013; Petrell, 1993).

Other

The lowest costs are indicated for nearshore cultivation with *Macrocystis* attached to bags of rocks. The location in this study was a prototype farm design of 2670 hectares in California, with water depths between 8 to 18 m. Costs per tonne (D.M.) were ranging from € 18 to € 29, see Table 3.2 (prices are adapted to the exchange rate of 3-4-2014, € 1.00 = \$ 1.37 derived from www.exchangerates.org.uk) (Chynoweth, 2002;

Reith, 2005).

Overall, the major cost drivers for seaweed cultivation and harvesting are the investment and operational costs. Another important note clearly shown in Table 3.2 is the influence of the biomass productivity on the production costs per tonne seaweed (Reith, 2005).

Table 3.2 The productivity and expected costs per tonne (D.M.) for seaweed cultivation.

Design	Location	Seaweed species	Productivity (tonnes (D.M.)/ha/year)	Costs (per tonne (D.M.))*
Offshore				
Ring structure ¹	North Sea	Laminaria	20	€ 2,500
Long-lines ²	United States	Gracillaria, Laminaria	14	€ 296
			59	€ 81
Long-lines ³	North Sea	Laminaria, Ulva, Palmaria, Undaria	20 (scenario 1)**	€ 1,019
			20 (scenario 2)**	€ 1,519
Long-lines ⁴	Ocean	Not known	50	€ 669
Nearshore				
Ring system ⁵	Not known	Not known	30	± € 380 – 990
Long-lines (seaweed farm) ⁶	Canadian coast	Not known	1.6	€ 10,448
Cultivation (plants attached to bags of rocks) ²	United States	Macrocystis	57	€ 29
			83	€ 18

Sources: ¹(Buck, 2004a), ²(Chynoweth, 2002; Reith, 2005), ³(Burg, 2013), ⁴(Burg, 2013; Lenstra, 2011), ⁵(Florentinus, 2008), ⁶(Burg, 2013; Petrell, 1993).

*Prices in ²(Chynoweth, 2002; Reith, 2005) are adapted to the exchange rate of 3-4-2014 (€ 1.00 = \$ 1.37 derived from www.exchangerates.org.uk).

** For the difference in the scenarios, see Table 3.1.

3.2 Ecopyramid and market values

Figure 3.1 shows a cascade of seaweed applications from high value to low value, which can be accomplished by a biorefinery. This pyramid includes a global overview of the different seaweed applications and does not deal with the main seaweed components (carbohydrates, proteins, etc.) separately. The market value of carbohydrates and proteins will be elaborated in paragraph 3.3 and 3.4 – 3.6, respectively. The top of the pyramid consists of pharmaceuticals and cosmetics with the highest economic value. One layer downward, some food ingredients can be valued at € 5 – 20,000 per tonne. Feed has already a lower value between € 500 and € 800 per tonne. Fuels are represented even lower in the pyramid with a value of € 100 to € 300 (Sanders, 2011).

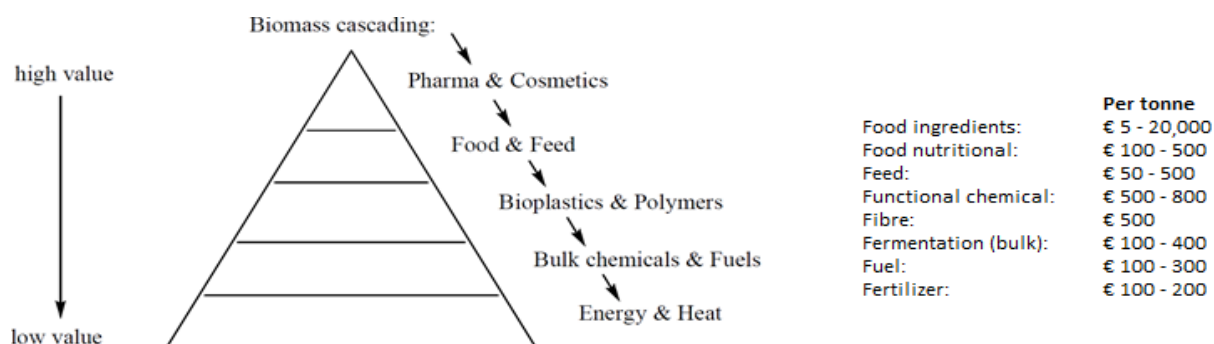


Figure 3.1 Ecopyramid of biomass and the market value of the applications per tonne, taken from Sanders (2011).

3.3 Market value of carbohydrates

As mentioned in paragraph 2.4, the potential of carbohydrates (sugars) derived from seaweed as source for energy carriers and bulk chemicals has been extensively reviewed (Bozell, 2010; Reith, 2005). An overview of the extraction and fermentation products and their market values is given in Table 3.3.

Table 3.3 Applications and market value of carbohydrates in Laminaria. Based on Reith et al. (2005).

Component	Application	Kg per tonne (D.M.)	Per tonne (D.M.)*
Potential extraction products (80 % extraction efficiency)¹	Alginic acid	230	€ 799
	Fucoidan	50	€ 174
	Mannitol	120	€ 417
Platform fermentation products (60 % of weight is polysaccharides and 90 % sugar use)²	Ethanol	255	€ 61
	Acetic acid	247	€ 130
	Butyraldehyde	123	€ 85
	Adipic acid	370	€ 384
	Butanol	123	€ 80
	Lactic acid	486	€ 106
	Succinic acid	429	€ 240
	Propylene glycol	133	€ 123
	Glycerol	247	€ 228
	Citric acid	429	€ 561
	Propanoic acid	227	€ 148
	Butanediol	163	€ 234

¹Reith et al. (2005) used data of Chynoweth (2002).

²Reith et al. (2005) used data of Wooley (1999).

*Prices are adapted to the exchange rate of 3-4-2014 (€ 1.00 = \$ 1.37 derived from www.exchangerates.org.uk).

Reith et al. (2005) used data from Chynoweth to establish an overview of the potential extraction products from *Laminaria*. In order to complement the data with platform fermentation products, Reith et al. used data from the presentation of Wooley, commissioned by the National Renewable Energy Laboratory (Chynoweth, 2002; Wooley, 1999). The market value of extraction products ranges from € 174 to € 799 and different combinations of products are possible. However, the potential market volume for these products are unknown. Platform fermentation products offer large potential with an average product value per ton seaweed of ca. € 200. Further development of technology for fractionation/hydrolysis and fermentation systems for seaweed sugars is required (Reith, 2009). Since the expected production costs for offshore seaweed cultivation is in the range of € 1,019 to € 1,519 per tonne (D.M.), the results show that the use of seaweed for their carbohydrates only, is not economically feasible (Burg, 2013). This emphasizes the importance of the other seaweed components as well (Reith, 2005). In general, plant proteins are very nutritious to humans and animals and have a generally higher economic value than that of carbohydrates (Lammens, 2011).

3.4 Market value of seaweed (proteins) in the food industry

In literature, some market values are shown for the native seaweed species. These market values are discussed for each species separately in the paragraphs below.

Laminaria digitata

In Ireland, good quality, dried and packed *Laminaria* was wholesaling for bulk quantities for prices between € 10 and € 16 per kg. Retail prices vary from € 60 to € 120 per kg. Wet seaweed is only worth € 1 per kg when the end product is for human consumption (Walsh, 2013). Nowadays, seaweed salads are also available in the Netherlands. The price paid for a (brown) seaweed salad of 125 g (70 % *Undaria pinnatifida* - Wakame) in a Dutch supermarket is € 2.49, equivalent to € 19.92 per kg (Zeewierwijzer, 2011). On average, brown seaweed species contain relatively less proteins (Table 2.4). This probably explains the limited amount of literature available on the use of proteins derived from *Laminaria digitata*.

Palmaria palmata

In the UK, the estimated value of *Palmaria palmata* (wet) for consumption purposes is € 0.50 to € 1.20 per kg. Packaged and dried *Palmaria palmata* can have a consumer price of around € 37 per kg (Hart, 2011). However, research on the market analysis of seaweed aquaculture in Ireland revealed wholesaling prices of € 16 to € 19 per kg for dried and packed *Palmaria* in bulk quantities and retail prices of € 57 to € 106 per kg (Walsh, 2013). As described in paragraph 2.5, *Palmaria* contains original pigments such as phycoerythrin which can be used for functional ingredients in the food industry (Fleurence, 2012). The selling price for this specific protein (purified) is approximately € 3,630 per g (Radmer, 1996). Higher values are also indicated, dependent on the quality of the phycoerythrin extracted. The market is divided in food grade R-phycoerythrin extract which has a value of € 176 per L, pure R-PE (€ 126,000 per g), SMCC Activated R-E (€ 140,000 per g) and anti-phycoerythrin anticorps (€ 352,560 per L) (Dumay, 2011).

Ulva lactuca

Ulva lactuca is attractive for commercial exploitation to produce functional or health promoting food, due to its interesting chemical composition (Rodríguez, 2011) (Satpati, 2011). No information is available about the potential market values of *Ulva* as functional food. Consumer prices of *Ulva lactuca* vary between € 45 and € 90 per kg. The value of a kg wet seaweed is estimated to be between € 0.30 and € 0.50 (Hart, 2011).

Food proteins and supplements

Nowadays, seaweed supplements are not available for sale. Microalgae on the other hand are available in some Dutch shops. Although microalgae have higher protein contents and require other processing technologies, it is assumed in this study that the market value of the supplements from microalgae proteins would be in the same range as for macroalgae proteins. Retail prices on these websites of De Tuinen and Gezond&Wel vary from € 104 to € 299 per kg for different *Spirulina* and *Chlorella* products (DeTuinen, 2014)

(Gezond&Wel, 2014). In Kasteren et al. (2012) it is suggested that the food supplements in the current algae market can be worth € 50 per kg. The market value for algae proteins for human consumption decreases to € 5 per kg when produced in bulk amounts (Wijffels, 2010). An important note regarding these algae supplements is that the beneficial health effects are not due solely to the proteins, but also because of the specific substances, such as β -carotene and omega-3 fatty acids, which are present in the algae (Kasteren, 2012). As described in paragraph 2.5, some seaweed species have a comparable protein content with soy products (Murata, 2001). Soy flour with a 40 % protein content has a value of € 0.80 per kg for commercial purposes (Mulder, 2013). The proteins in this biomass are the most valuable components. Therefore, the economic value will increase when these proteins are isolated. The prices paid for a tonne of soy proteins is in the range of € 2,000 when concentrated and € 3,000 for isolated proteins (Mulder, 2010). Based on the information that *Palmaria* and *Ulva* are comparable with soybeans regarding their protein levels, it can be assumed that these seaweeds have more or less the same economic value as soybeans when used as food proteins. It is not mentioned whether these economic values of proteins are for food or feed purposes. In a document of the valorisation of protein-rich waste and residue streams, the value of food proteins are indicated. Protein bulk fillers are valued at € 2 to € 4 per kg, technical functional proteins at € 4 to € 10 per kg and specific functional between € 10 and € 20 per kg. The potential to develop these markets can be time consuming due to its long and costly procedures. The opportunities mentioned for food proteins are in meat substitutes, milk products, bakery products and food supplements (Engelen, 2013). An overview of the market values is shown in Table 3.4.

Table 3.4 Overview of estimated market values in the food industry.

Application	Laminaria digitata	Palmaria palmata	Ulva lactuca
Whole seaweed (/kg)			
Wet	€ 1 ¹	€ 0.50 – 1.20 ²	€ 0.30 – 0.50 ²
Wholesale (bulk, dried, packaged)	€ 10 – 16 ¹	€ 16 – 19 ¹	
Retail prices	€ 60 – 120 ¹	€ 57 – 106 ¹	€ 45 – 90 ²
Functional ingredient (/g)			
(e.g. colourant)			
Pure phycoerythrin		€ 3,630 ³	
Other phycoerythrin forms		> € 3,630 ⁴	
Non-specific			
Seaweed proteins (/kg)			
<u>Based on possibly comparable sources</u>			
Waste residues			
- Protein bulk fillers		€ 2 – 4 ⁵	
- Technical functional proteins		€ 4 – 10 ⁵	
- Specific functional proteins		€ 10 – 20 ⁵	
Microalgae			
- Food supplement		€ 50 ⁶	
- Food supplement (bulk)		€ 5 ⁷	
- Retail websites		€ 104 – 299 ⁸	
Soy proteins			
- Soy flour (40% protein)		€ 0.80 ⁹	
- Concentrated		€ 2 ¹⁰	
- Isolated		€ 3 ¹⁰	

Sources: ¹(Walsh, 2013), ²(Hart, 2011), ³(Radmer, 1996), ⁴(Dumay, 2011), ⁵(Engelen, 2013), ⁶(Kasteren, 2012), ⁷(Wijffels, 2010), ⁸(DeTuinen, 2014; Gezond&Wel, 2014), ⁹(Mulder, 2013), ¹⁰(Mulder, 2010).

3.5 Market value of seaweed (proteins) in the feed industry

Although more research is needed regarding the effect of both whole seaweeds and seaweed proteins in animal diets, it is possible to estimate the potential economic values. In this study, it is assumed that microalgae and soy are comparable sources to the seaweeds *Palmaria* and *Ulva*. Therefore, the market value of seaweed (proteins) in the feed industry will be based on literature, retail websites and complemented with economic information of microalgae and soy sources.

Literature and retail websites

Brown seaweed produced in Norway can be used as an additive to animal feed. It is collected, dried and milled, before it is sold on the market. In total 10,000 tonnes of seaweed meals are produced, with a total value of \$ 5 million. This comes down to approximately € 365 per tonne of seaweed meal (price is adapted to the exchange rate of 3-4-2014 (€ 1.00 = \$ 1.37 derived from www.exchangerates.org.uk) (FAO, 2003). In this study it is assumed that also red and green seaweeds, such as *Palmaria* and *Ulva*, have a comparable value. According to Burg et al. (2013), these market values for the seaweeds native in the North Sea are too optimistic. Based on a feed optimisation program, the value of *Laminaria digitata* as animal feed per tonne turned out to be € 0. *Ulva lactuca* scored higher with € 49 per tonne and *Palmaria palmata* has the highest economic value of € 122 per tonne. Several assumptions were made regarding the digestibility and amino acid composition, which may influence the outcome of the results. The valuation of seaweeds used as feed additives was not included due to

the lack of exact information (Burg, 2013). The value of feed proteins has been indicated in the document of the valorisation of protein-rich waste and residue streams, and comes down on € 1 to € 2 per kg. This market is regarded as the most important market with a trend to more speciality applications. Besides, it is important in biorefinery, in which the protein fraction can be used for feed after extraction of the other components (Engelen, 2013). Retail prices of seaweed in animal diets are considerably higher. A seaweed meal ordered on the internet can be € 4 up to € 13 per kg (BeaufortAnimalSupplies, 2013; BetterPlants, 2014; Bio-Ron, 2014; Dierendrogist, 2014). However, several factors like the ordered quantity, quality, country of origin, and the seaweed species influence the price per kg.

Microalgae

Since the application of seaweed as feed is quite new, little literature is available about market values. On the other hand, markets for algae in the feed industry do already exist. The price of a litre fish feed derived from algae is estimated to be € 70. The market value for bulk applications of algae is considerably lower, namely € 0.75 per kg for animal feed proteins (Kasteren, 2012; Wijffels, 2010).

Soy sources

Soybeans are the most important protein source used to feed farm animals (OilWorld, 2010). To illustrate, in 2010 the total soy imported for animal feed equalled 2,765,000 tonnes (PDV, 2014). Soy cake and soy grains are worth € 300 and € 410 per tonne, respectively, for their use in animal feed. The different forms of soy proteins and their protein content influence the price. As already shown in Table 3.4, the prices paid for a tonne of concentrated soy proteins is € 2,000 and for isolated proteins € 3,000. These concentrated and isolated proteins are not exclusively used for animal feed. Denatured proteins, like maize, gluten and potato protein in general have a lower economic value than the proteins that are not being denatured in the isolation process, such as soy protein and pea protein (Mulder, 2010). An overview of the market values will be shown in Table 3.5.

Table 3.5 Overview of estimated market values in the feed industry.

Application (per tonne)			
	Laminaria digitata	Palmaria palmata	Ulva lactuca
Whole seaweed			
Dried	€ 0 ¹	€ 122 ¹	€ 49 ¹
Non-specific			
Whole seaweed			
Seaweed meal*		€ 365 ²	
Retail (websites)		€ 4,000 – € 13,000 ³	
<u>Based on possibly comparable sources</u>			
Soy		€ 300 – € 410 ⁴	
Seaweed proteins			
<u>Based on possibly comparable sources</u>			
Based on waste residues		€ 1,000 – € 2,000 ⁵	
Based on microalgae		€ 750 ⁶	
Based on soy proteins			
- Concentrated		€ 2,000 ⁴	
- Isolated		€ 3,000 ⁴	

Sources: ¹(Burg, 2013), ²(FAO, 2003), ³(BeaufortAnimalSupplies, 2013; BetterPlants, 2014; Bio-Ron, 2014; Dierendrogist, 2014), ⁴(Mulder, 2010), ⁵(Engelen, 2013), ⁶(Kasteren, 2012; Wijffels, 2010).

*Price is adapted to the exchange rate of 3-4-2014 (€ 1.00 = \$ 1.37 derived from www.exchangerates.org.uk).

3.6 Market value of seaweed proteins in the technical industry

Industrial produced proteins were restricted to high value market applications like bioplastics, glues, coatings and surfactants. It is important to study the possibilities of intact functionalities of the protein after isolation processes. Not only the polymer properties of the whole protein can be used in the technical industry, amino acids can also be converted to several chemicals which are valuable components in, for example, surfactants. The surfactant market is quite big and diverse and surfactants based on protein fragments have already been used in cosmetic products (Mulder, 2013). The chemical reactions in which amino acid are involved are diverse. Especially the conversion of lysine and phenylalanine into ϵ -caprolactam and styrene, respectively, can be of great importance since they are produced on a bulk scale.

Table 3.6 The conversion of amino acids into chemicals (data from Mulder (2010)) and their estimated market value.

Amino acid	Chemical	Market value (per tonne) *
Alanine	Ethylamine	€ 1,000 ¹
Asparagine/Aspartic acid	2-amino-1,4-butanediol,	€ 1,600 ²
	Amine tetrahydrofuran	€ 1,661 – 1,877 ³ € 1,444 – 2,166 ³
Glutamic acid	<i>N</i> -methylpyrrolidon	€ 1,800 ¹
		€ 3,070 ⁴
Glycine	Nitric acid	€ 274 – 325 ³
	Oxalic acid	€ 505 – 722 ³
Leucine	Isoprene	€ 1,200 – 1,800 ⁵
		€ 722 – 1,083 ³
Lysine	ϵ -caprolactam	€ 1,500 ⁶
		€ 1,213 – 1,300 ³
Phenylalanine	Cinnamic acid	€ 361 – 3,610 ³
	Styrene	€ 903 – 1,119 ³
		€ 1,173 – 1,187 ⁷
Proline	Pyrrolidone	€ 1,733 – 2,166 ³
Serine	Ethanolamine	€ 1,227 – 1,444 ³
Threonine	Isopropanol amine	€ 1,083 – 1,444 ³
Tryptophan	Catechol	€ 722 – 2,166 ³
	Muconic acid	€ 722 – 1,444 ³
Tyrosine	p-hydroxy-cinnamic acid	€ 433 – 3,610 ³
Valine	Isobutyraldehyde	€ 722 – 14,440 ³

Sources: ¹(Mulder, 2013), ²(Jenkins, 2013), ³(Alibaba.com, 2014), ⁴(ICIS, 2014), ⁵(Zuidema, 2010), ⁶(NWO, 2013), ⁷(Orbichem, 2013).

*Prices from Alibaba.com are adapted to the exchange rate of 3-4-2014 (€ 1.00 = \$ 1.37 derived from www.exchangerates.org.uk).

Table 3.6 gives an overview of the chemicals that can be derived from amino acids (Mulder, 2010). The market values for the different chemicals were hard to find. Most data originates from a website which offers the different chemicals for sale (Alibaba.com, 2014). The form, purity and quality of the specific chemical greatly influences the price, therefore the prices given in the table are the averages found on the website. In addition, the date and country in which the chemical is sold, also influence the price.

The market value of seaweed as chemicals can also be derived from microalgae. The use of microalgae as feedstock for chemicals gives approximately between € 1,000 and € 5,000 per tonne. However, it is not mentioned whether this concerns amino acids or sugars as basis for the chemicals (Diels, 2009).

3.7 Overview

As shown in Table 3.2, the expected costs for offshore cultivation at the North Sea are ranging from € 1,019 to € 2,500. These costs are based on estimations and/or small scale experiments and are only focused on the cultivation costs. In practice, the seaweeds have to be transported, packaged and sometimes processed as well in order to be traded and sold on the market. The seaweed market value has to compensate for these costs. Literature research shows that only few data is available about the market values for the specific Dutch seaweed species. The information found is summarized in Table 3.7.

Table 3.7 Overview of the market values in the food and feed industry, specific for the seaweed species native in the North Sea.

Whole seaweeds	<i>Laminaria digitata</i>	<i>Palmaria palmata</i>	<i>Ulva lactuca</i>
Food industry (/kg)			
Wet	€ 1 ¹	€ 0.50 – 1.20 ²	€ 0.30 – 0.50 ²
Wholesale (bulk, dried, packaged)	€ 10 – 16 ¹	€ 16 – 19 ¹	
Retail prices	€ 60 – 120 ¹	€ 57 – 106 ¹	€ 45 – 90 ²
Feed industry (/tonne)			
Dried	€ 0 ³	€ 122 ³	€ 49 ³

Sources: ¹(Walsh, 2013), ²(Hart, 2011), ³(Burg, 2013).

Food industry

The market values for the native Dutch seaweed species in the food industry involve much uncertainty since they are based on only a few literature sources, mainly specified to the (native) seaweed species traded and sold in a foreign market. Information on seaweed proteins was lacking and therefore also based on comparable protein sources in the literature research. The main information gaps in the food industry are the exact opportunities of native Dutch seaweeds and their market values in the Dutch market.

Feed industry

In the feed industry, seaweeds turned out to be a potential sustainable alternative for soy. Research is going on to determine the digestibility of raw and processed seaweeds in animals. Only one literature source indicated an expected market value for the dried native seaweed species. Since seaweeds are mentioned to be a soy replacer, the market value is also based on soy prices in the literature research. However, in practice, it is still unknown if the seaweed market value of Dutch seaweeds is the same as for soy. This can be considered as a knowledge gap. Another knowledge gap is the form in which seaweeds can be best applied in the feed industry, either as a whole product or as feed additive.

Technical industry

No information was found on the amino acid market values derived from native Dutch seaweed species. The opportunities of seaweeds in the technical industry is not further explored in this report. The industry could be of interest in the future, for example, if part of the seaweed proteins will be used for technical applications and the remaining part for feed.

4. Materials and Methods

The method part consists of interviews with scientific experts and business experts by using semi-structured questionnaires. In-depth questions are conducted in order to assess the expert's view on the current seaweed market, the opportunities of Dutch seaweed (proteins), the market value of seaweed (proteins) and a prognosis for the Dutch seaweed market.

4.1 Questionnaire development

The questionnaires are established based on information and anchor values found in literature. The interviews are used to provide support for exploratory research, which means it is the initial research into a hypothetical or theoretical idea (Vaus, 2001). This research deals with the current and future applications of whole seaweeds cultivated at the North Sea, its proteins and their market values in the Dutch market, which can be considered as a relatively new topic in the research field. Although there are some market values of whole seaweeds (wet and dried) given in literature, the information for the native Dutch seaweed species is very limited. The semi-structured nature of the questionnaires is well suited for new topics and the different ideas and perspectives of the experts. The topics addressed in the questionnaire are outlined in Table 4.1. The anchor values chosen in topics with closed-ended questions are presented in Table 4.2. The interviews are first held with the scientific experts. The information gathered from these experts is used to adjust the questionnaire for the business expert interviews. The adjustment in anchor value can be found in Table 4.2.

Topics

The questionnaire consists of 3 main topics divided in different sub questions (Table 4.1). The semi-structured nature of the interview contains closed-ended and open-ended questions, in which the open ended-questions led to in-depth information about certain topics. The main topics discussed in both interviews are the possible cultivation designs and the expected costs for offshore cultivation (main topic 1), the applications and opportunities of Dutch seaweed (proteins) (main topic 2) and the market value of seaweed (proteins) in the Dutch market (main topic 3). In main topic 1 the different cultivation designs appropriate at the North sea, the expected yield and the expected costs of the different cultivation designs are discussed. The current use of seaweeds, the development of the market and the opportunities for seaweed (proteins) in the food and feed industry are discussed in main topic 2. In the last main topic, the market value for whole seaweeds and seaweed proteins applied in the food and feed industry are discussed. The questionnaires were provided to the experts in advance. Since the experts had different scientific and business perspectives, they had the possibility to select topics to discuss. The complete questionnaire can be found in Annex A.

Anchor values

Anchor values were used in order to formulate closed-ended questions in both the scientific expert and business expert interviews (Table 4.2). The data found in literature formed the basis for the anchor values in the questionnaire. The market values for seaweed (proteins) were divided into three market value categories, so that the interviewee could choose the market value category which fits the best according to him/her. The anchor value constitutes the middle price category, with the other two market value categories being either lower or higher than this anchor value. Market values of seaweed proteins are not available. Therefore, the anchor values for seaweed proteins are based on the market values of possibly comparable protein sources (soy, waste residues and microalgae).

Table 4.1 Topic guide and sub questions in the questionnaire.

Main topics	Sub questions	Open-/Closed-ended question
1. Possible cultivation locations, cultivation designs, yield and expected costs.	➤ Location of seaweed cultivation ➤ Cultivation designs ➤ Offshore seaweed cultivation ➤ Offshore yield ➤ Expected costs for different cultivation designs	Closed Open/Closed¹ Open/Closed Open/Closed² Closed³
2. The applications and opportunities for Dutch seaweed (proteins).	➤ Current use of seaweeds ➤ Development of the market ➤ Opportunities seaweed (proteins) in the food and feed industry	Closed Closed Open
3. The market value of seaweed (proteins) in the Dutch market.	➤ Market value of whole seaweeds ➤ Market value of seaweed proteins ➤ The role of biorefinery	Open/Closed Open/Closed⁴ Open

Note (more information on note 1 to 4 can be found in Table 4.2):

¹ Cultivation designs included are based on literature research.

² Anchor values used in this question, to estimate the offshore yield, are based on findings in literature. The question is also open ended to leave space for additional comments.

³ Anchor values used in this closed-ended question are based on findings in literature. Each cultivation design is discussed separately due to the different anchor values for each design.

⁴ Anchor values used in this closed-ended question are based on findings in literature. The market value of seaweed proteins is not shown in literature and will therefore be based on possibly comparable protein sources. The protein sources considered in this research are waste residues, microalgae, and soy. The market value of whole seaweeds and seaweed proteins are divided into three categories. The interviewee can indicate in which category the market value will most likely be.

Table 4.2 An overview of the cultivation designs and anchor values used in the questionnaire and their references.

	Designs and anchor values	Literature research	Reference
1. Cultivation designs	➤ Ring structure	Paragraph 2.2	(Chynoweth, 2002); (Buck, 2004a)
	➤ Long-lines	Paragraph 2.2	(Reith, 2005)
2. Offshore yield	➤ 20 tonnes/ha/year ¹	Paragraph 2.2	(Reith, 2005)
	➤ 50 tonnes/ha/year ²	Paragraph 2.2	(Reith, 2005)
3. Expected costs	➤ Ring structure: € 2,500	Paragraph 3.1	(Buck, 2004a)
	➤ Long-lines		
	- Scenario 1: € 1,019 per tonne (D.M.)	Paragraph 3.1	(Burg, 2013)
	- Scenario 2: € 1,519 per tonne (D.M.)	Paragraph 3.1	(Burg, 2013)
4. Market value	➤ Whole seaweeds in the food industry		
	- Scientific expert interview*	Table 3.4	(Walsh, 2013), (Hart, 2011)
	- Business expert interview: € 40 – 60	Table 3.4	(Walsh, 2013), (Hart, 2011), scientific expert interviews
	➤ Seaweed proteins in the food industry		
	- Scientific expert interview: € 2 – 6	Table 3.4	(Engelen, 2013), (Wijffels, 2010), (Mulder, 2010), (Mulder, 2013)
	- Business expert interview: € 4 – 8**	Table 3.4	(Engelen, 2013), (Wijffels, 2010), (Mulder, 2010), (Mulder, 2013), scientific expert interviews
	➤ Whole seaweeds in the feed industry		
	- Scientific expert interview*	Table 3.5	(Burg, 2013), (FAO, 2003), (Mulder, 2010), (BeaufortAnimalSupplies, 2013; BetterPlants, 2014; Bio-Ron, 2014; Dierendrogist, 2014)
	- Business expert interview: € 2 – 4	Table 3.5	(Burg, 2013), (FAO, 2003), (Mulder, 2010), scientific expert interviews
	➤ Seaweed proteins in the feed industry		
	- Scientific expert interview: € 0.50 – 1.50	Table 3.5	(Mulder, 2010), (Engelen, 2013), (Kasteren, 2012; Wijffels, 2010)
	- Business expert interview: € 0.50 – 1.50	Table 3.5	(Mulder, 2010), (Engelen, 2013), (Kasteren, 2012; Wijffels, 2010), scientific expert interviews

¹ Cultivation without supply of nutrients.

² Cultivation in layers and/or with dosed nutrient supply.

* Anchor values on whole seaweeds in the food and feed industry were not given in the scientific questionnaires.

** The anchor value on seaweed proteins in the food industry was adjusted to the information given by the scientific experts.

4.2 Selection of the experts

The participants in this research consist of scientific experts and business experts. In total 13 experts were interviewed, of which 7 with a scientific background and 6 with a business background. Table 4.3 gives an overview with the background of the experts. Selection took place in two steps: the first step was the selection of scientific experts and the second step the selection of the business experts.

Scientific experts

These participants from the scientific perspective were selected through purposive sampling. Initially, Dutch authors of articles which contributed to the literature overview were approached to participate in the research. Participants from the LEI and Wageningen UR were selected due to their contributions to the article 'A Triple P review of the feasibility of sustainable offshore seaweed production in the North Sea'. ECN was selected because of their extensive research in the possibilities of offshore seaweed cultivation at the North Sea for energy purposes and other products. The Netherlands Seaweed Science Centre (NSSC, also known as Seaweed Centre) located at NIOZ is another important supplier of scientific knowledge about seaweed. The goal of the Seaweed Centre is to perform fundamental and applied research on seaweeds. The Protein Competence Centre is an organisation which has recently been started as an initiative of the Wageningen UR. The aim of the organisation is to pool knowledge and research on the protein field together with seven food and feed companies and six knowledge institute in the Netherlands.

Business experts

The selection of the business experts took place by snow-ball sampling. This is a sampling method which can be described as gathering research subjects by an initial subject who provides the names of other subjects (Atkinson, 2004). In this research, particularly the experts of the Wageningen UR and LEI provided their web of contact and inquiry. The experts gave the names and email addresses of some other business experts which are operating in the food and/or feed industry with interests in (Dutch) seaweed.

An overview of the expert names can be found in Annex B.

Table 4.3 Background of the experts.

Experts (n=13), of which:	Description of the group
Scientific (n=7)	➤ Wageningen UR (n=3): Experts of the Wageningen University have their background in different chair groups: Animal Sciences Group (ASG) (n=1) and Food and Biobased Research (FBR) (n=2). ASG covers a lot of research areas concerning animal health and welfare. One of the current research topics is the search for alternative protein sources in animal feed (next to soy). FBR performs applied research for sustainable innovations in healthy food, fresh food chains and biobased products. One of their current research domains is seaweed biorefinery. ➤ Energy Centre of the Netherlands (ECN) (n=1): ECN is the largest energy research institute in the Netherlands. Currently their research is focussing on solar power, wind energy, biomass, energy efficiency, environment & energy engineering, and policy studies. ECN is involved in research and projects concerning seaweed cultivation at the North Sea. ➤ Protein Competence Center (PCC) (n=1): This center bundles protein research and protein knowledge through collaboration of food and feed companies and knowledge partners. The aim is to strive towards a healthy and sustainable society. Seaweed is one of the protein sources considered within PCC. ➤ Landbouw Economisch Instituut (LEI) (n=1): LEI is a part of the Wageningen University, however, it acts as an independent and internationally leading socio-economic research institute. Their models and knowledge is used to offer clients insights and integral advice for policy and decision-making processes in an innovative way. LEI is also examining the economic perspectives of seaweed cultivation. ➤ Koninklijk Nederlands Instituut voor Onderzoek der Zee (NIOZ) (n=1): The Netherlands Seaweed Science Centre (NSSC, also Seaweed Centre) is located at NIOZ Texel. The goal of this Seaweed Center is to perform fundamental and applied research on seaweed. Examples of research topics are the ecophysiology of seaweeds and the selection of the most suitable seaweed species for cultivation at the North Sea.
Business (n=6)	➤ CONO Kaasmakers (n=1): CONO Kaasmakers is a cheese producer. Its vision is to have tasty and fair products for their conscious clients and consumers. The company wants to be leading in their corporate social responsibility. Recently, the company got involved in a project to use local seaweeds as part of the feed meal for their cows. ➤ Hortimare (n=1): Hortimare is a company founded by Job Schipper in 2008. The company cultivates seaweed juveniles in order to sell them to future seaweed growers. The company's concept consists of a 'Seaweed Genetics and Hatchery' in which they develop and sell seaweed juveniles. The 'Integrated Aquaculture Service' supplies the service to produce seaweed in the direct neighbourhood of salmon farms and with the 'Seaweed Bio-Refinery Plant' they process and refine the seaweed and produce high quality protein for feed and food applications. ➤ Cargill (n=1): Cargill provides food, agriculture, financial and industrial products and services to the world. One of their domains is the offering of a broad range of hydrocolloids (including alginates, carrageenans, etc.), which are extracted from plants and seaweed (or

produced by microbial synthesis). Currently, the company is importing seaweed, but also looking for alternatives such as local cultivated seaweeds.

- FeyeCon (n=1): FeyeCon is an engineering company, involved in the development and manufacture of pressurised CO₂ technologies for a range of industrial applications. They offer tailor-made process designs and equipment at bench, pilot and production scales. They have been involved in an project with the purpose to investigate the role of seaweed in water purification and as plant growth stimulator.
- Your Well (n=1): Your Well is a company specialized in the marketing and sales of products (organic food, natural health and bodycare) based on seaweed. The company's mission is to contribute to the health of people. Your Well distributes seaweed products in Belgium, the Netherlands, and Luxembourg, to health stores, fish and specialty stores, restaurants and industry.
- Menken van den Assem (n=1): Menken van den Assem delivers high-quality fresh and frozen foods to the culinary market (retail and industry). The company is monitoring the developments in the demand for food to be leading in unique fresh and chilled products in retail packaging. Their assortment offers products like glasswort and seaweed salad.

4.3 Data collection

Data collection took place by interviews. Each interview took approximately 1 – 1.5 hour. The location of the interview was different for each interview. Interviews with the scientific experts of the Wageningen University, the PCC and the LEI took place at the university. The business expert interviews took mainly place at the company's location (CONO Kaasmakers, FeyeCon and Menken van den Assem) or at a location elsewhere (Your Well). Interviews with ECN (scientific), NIOZ (scientific), Hortimare (business) and Cargill (business) took place by phone. The data collected was different for each expert, in which scientific experts were mainly focused on main topic 1 and 2, while the business experts elaborated more on main topic 2 and 3 (see Table 4.1 for the main topics discussed).

Expert information on research topics

Since most of the experts selected a few topics to discuss during the interview, it was not possible to discuss every topic in the questionnaire with each expert. Therefore, Table 4.4 presents an overview of the expert's expertise (based on own indication).

Table 4.4 Experts' indication of expertise.

	Scientific experts							Business experts						n=*
Main topics	1	2	3	4	5	6	7	1	2	3	4	5	6	
1. The possible cultivation designs, locations, and expected costs.														
- Location of seaweed cultivation	x		x		x			x		x	x	x	x	8
- Cultivation designs	x		x		x			x						4
- Yield	x		x		x			x						4
- Expected costs	x							x						2
2. The applications and opportunities for Dutch seaweed (proteins).														
- Background of the Dutch seaweed market	x	x	x	x	x	x	x	x	x	x	x	x	x	13
- Main opportunities in the food industry	x	x			x	x	x	x	x	x	x	x	x	11
- Main opportunities in the feed industry	x	x		x	x	x	x	x	x	x	x	x		11
3. The market value of seaweed (proteins) in the Dutch market.														
- Market value of whole seaweeds in the food industry	x					x		x	x	x	x	x	x	8
- Market value of whole seaweeds in the feed industry	x			x		x		x		x	x	x		7
- Market value of seaweed proteins in the food industry		x				x		x		x				4
- Market value of seaweed proteins in the feed industry				x				x		x				4

* This number will not automatically be the same as the numbers in the results (Table 5.1 t/m 5.3), since the experts could not answer every question under a certain main topic.

5. Results

The results are shown for each main topic separately. The distribution of answers given by scientific (S) or business (B) experts is given between brackets.

5.1 Cultivation location, cultivation design, yield and expected costs

An overview of the questions and are presented in Table 5.1. The explanation on the answers is divided into the following paragraphs: cultivation location, cultivation design, yield, and expected costs.

Cultivation location

The answers given about the most potential seaweed cultivation location are varying. Two of the three scientific experts choose for offshore cultivation as the most potential location in the long term, only when some main obstacles can be overcome. The business experts were more reluctant towards offshore cultivation at the North Sea. Costs are mentioned as the main issue. Besides, the technical challenges (implementation at sea) play a role. Reasons for the business experts to choose for onshore or nearshore cultivation are the easiness to implement and the lower costs. The experts added that if costs for offshore cultivation will become lower, it will be more attractive to cultivate offshore (also from a marketing point of view). According to most scientific and business experts, *Ulva* seems less appropriate to cultivate at the North Sea and *Laminaria* is mentioned to be the most suitable species.

Cultivation design

Both the scientific and business experts were consistent about the most optimal design for offshore cultivation, namely the long-lines. The ring structure is too complex and more expensive than long-lines. Still, the optimal design for offshore cultivation is not constructed yet and requires further research. The costs as well as the ability to resist North Sea circumstances are important for the new design. One of the new ongoing experiments is a cultivation design consisting of a special type of textile, in cooperation with a textile manufacturer.

Yield

Only three scientific experts could answer this question. The question was not addressed to business experts, however, one business expert gave additional information based on own experiences with seaweed cultivation. Two scientific experts suggested that 20 tonnes/ha/year is a real number. The experts admitted that the number is not well evidenced. Therefore, it is usable for some basic calculations, but only huge research projects can accept or reject this number. Besides, there are so many parameters of influence and therefore every situation is different when it comes to yield. One scientific expert and the business expert were more sceptical towards the number of 20 tonnes (D.M.) yield/ha/year. Especially on the short term, this yield is too optimistic due to the lack of information of influencing parameters. The business expert mentioned that the net yield of nearshore cultivation in Norway turned out to be 12 tonnes (D.M.)/ha/year, based on the assumption that the hectare is fully covered with seaweed and waterways are not taken into account. Therefore, the actual yield will be lower. In the current situation, the amount of seaweed per 1 m line is 8 kg, which comes down on 1.2 kg D.M. per m². This amount will raise due to improvements in cultivation designs and crop breeding which leads to an improvement in quality. In the long-term (10 – 15 years), the net yield will be around 20 tonnes (D.M.)/ha/year according to the business experts. However, new solutions in cultivation techniques are necessary to reach this number. Besides, seasonality of the seaweeds is an important issue when determining the yield.

Table 5.1 Assessment on the possible cultivation location, cultivation design, yield, and expected costs.

Questions	Answers			Other
Cultivation location				
Location with the highest potential for seaweed cultivation in the Netherlands? (n=8)	<u>Onshore</u> 2 (B)	<u>Nearshore</u> 3 (1S,2B)	<u>Offshore</u> 3 (2S,1B)	
Which seaweed type is most suitable to cultivate at the North Sea (more answers possible)? (n=7)	<u>Laminaria</u> 4 (3S,1B)	<u>Palmaria</u> 1 (S)	<u>Ulva</u> 0	2 (1S,1B) ¹
What are the main obstacles in offshore seaweed cultivation (more answers possible)?	Short waves, storms, turbulent water; restricting regulations; relatively high costs; technical uncertainty; lacking infrastructure for attachment; uncertain impact on environment and risks; crop breeding required.			
Cultivation design				
Which cultivation design is most suitable for offshore cultivation? (n=4)	<u>Long-lines</u> 4 (3S,1B)	<u>Ring structure</u> 0	<u>Other</u> 0	
Yield				
The productivity of offshore production at the North Sea (tonnes/ha/year) in case of <u>no</u> supply of nutrients and <u>no</u> layers: (n=4)	<u>≤ 20</u> 2 (1S,1B)	<u>20</u> 2 (S)	<u>> 20</u> 0	
What are the main factors influencing this yield (more answers possible)?	Presence of nutrients; seasonality; selection of seaweed species; risks and diseases.			
Expected costs				
Ring structure (North Sea), based on 20 tonnes (D.M.)/ha/year (including investment costs, without operational costs, capital costs, labour costs) in € per tonne (D.M.). (n=1)	<u>≤ 2,500</u> 0	<u>2,500</u> 1 (S)	<u>> 2,500</u> 0	
Long-lines (North Sea), based on 20 tonnes (D.M.)/ha/year and investment costs of 150,000 per ha (including investment costs with lifespan of 10 years, labour costs and harvesting costs) in € per tonne (D.M.). (n=2)	<u>≤ 1,519</u> 0	<u>1,519</u> 1 (S)	<u>> 1,519</u> 0	1 (B) ²

¹ Preferred seaweed species: *Laminaria Saccharina*.

² Current cost price € 5.000 – 10.000 per tonne (D.M.) for small scale cultivation (ha unknown). Future cost price (2018): € 1.000 per tonne (D.M.) based on large scale cultivation (>100 ha).

Expected costs

Only one scientific expert indicated an expected cost price category, however, this expert was involved in the research of expected costs data. One business expert gave additional information based on own experiences with long-lines. The current cost price for the expert's company is € 5 – 10 per kg (D.M.). In the business plan the company adapted a calculated cost price of € 6.50 per kg (D.M.). This is based on small scale cultivation. The company expect to reach a cost price of € 1 per kg (D.M) in 2018 for large scale cultivation, which means for at least 100 ha. The cultivation takes place nearshore. The costs savings can be attained in the areas of cultivation systems, scaling-up, crop breeding and labour. In the current cost price, labour represents about 25 % of the total costs. In the new situation, labour remains its proportion (25 %), while the total costs for labour are saved. In what extent these cost prices can be applied for offshore cultivation is unknown.

5.2 Applications and opportunities for Dutch seaweed (proteins)

Table 5.2 shows an overview of the questions and answers given on the applications and opportunities for Dutch seaweed (proteins) in the Dutch market. The topic is divided into seaweeds in the Dutch industry and seaweed types, the opportunities in the food industry and the opportunities in the feed industry.

Background of the Dutch seaweed market

According to the experts, seaweeds are mostly used in the food industry, also on a worldwide scale. Currently, there is a lot of research going on to examine the possibilities in the feed and technical industry since these industries offer a lot of potential. The technical industry is not further considered in this research, but is expected to increase due to the rise of cheaper protein sources other than used in this industry. These proteins are used as chemical building blocks. The volume of seaweeds used in the Dutch industry is relatively small. Some experts who indicated food as the main industry, argued that in the future feed will have much more potential. Next to the food, feed, and technical industry, two experts mentioned that seaweed (proteins) could also become important in the pharmaceutical industry. The pharmaceutical industry concerns only very specific protein fragments with an extremely high functionality and high values.

Seaweed species

The use of brown seaweeds in the different industries is popular, due to their high content of alginates. Red seaweeds are high in agars and carrageenans and therefore also popular. Although it is not exactly known yet which of the Dutch seaweed species will be suitable for food and feed purposes in the future, the seaweeds that have already been used in the feed industry are *Laminaria*, *Ulva*, and *Saccharina*. In the question in which seaweed type business is most interested, the answers of the business experts were divided among the brown and green seaweed species. Two of them already use brown seaweeds for food or feed purposes. This concerns the *Saccharina latissima* for one of them, used as fishmeal. The brown seaweeds are relatively high in polysaccharides, which makes them very interesting for commercial applications in the food industry. Two other business experts showed more interest in green seaweeds, especially for the application in the fresh market. In their perspective, brown seaweeds are less attractive for commercial purposes due to the brown colour. One expert mentioned that red seaweeds could be interesting as well, but the cultivation requires more tropical circumstances (therefore not included in Table 5.2).

Development of the seaweed market

Both the scientific as the business experts agreed upon the prediction of the seaweed market. They regard the seaweed market as growing, in the short term (3 years) as well as in the long term (10 years). However, some experts argue that seaweed cannot compete with soy within three years and others complemented that it can take even more than 10 years until the seaweed market is a more matured market. The first three years are really needed to refine the seaweed and to promote and brand it in the market, before it will be used as food. Besides, seaweed is not the only protein rich crop which has been considered in research. Concerning isolated seaweed proteins, it can take at least 10 years to enter the market, if the proteins have no history in human consumption. The role of seaweed biorefinery in the future have also been discussed with six scientific experts. The experts were consistent and emphasized the importance of biorefinery. The successive phases seaweed biorefinery must pass are the establishment of the process, the model, and afterwards the costs. Most of the experts ensure that the development of the technique will be a matter of time.

Opportunities in the food industry

The use of seaweeds in the food industry can be divided into traditional consumption, the fresh seaweed market as an alternative for lettuce), or non-traditional, for its proteins, polysaccharides or other byproducts.

Whole seaweeds

While the question was intended to figure out the opportunities for isolated proteins in the food industry, most experts argued that seaweeds should be first used for direct consumption of fresh seaweed. In this way the

Table 5.2 Assessment on the applications and opportunities for Dutch seaweed (proteins) in the food and feed industry.

Questions	Answers			Other
Seaweeds in the Dutch industry				
• The main industry in which seaweeds are used (in the Netherlands). (n=11)	<u>Food</u> 8 (4S,4B)	<u>Feed</u> 3 (1S,2B)	<u>Technical</u> 1 (S)	
• The seaweed types used in these industries are mainly: (n=11)*	<u>Brown</u> 9 (6S, 3B)	<u>Red</u> 3 (2S,1B)	<u>Green</u> 2 (1S,1B)	
• In which type of seaweed is business most interested? (n=5)*	<u>Brown</u> 4 (B)	<u>Red</u> 0	<u>Green</u> 3 (B)	
• Development of the seaweed market. (n=13)	<u>Growing</u> 13 (7S,6B)	<u>Declining</u> 0	<u>Steady</u> 0	
Opportunities in the food industry				
• Food industry: What are the main opportunities for seaweed? (n=11)	Fresh seaweed; dried and as addition to products; as functional ingredient; as supplements; in a totally ‘new’ concept.			
• And which seaweed species show the greatest potential (more answers possible)? (n=8)	<u>Laminaria</u> 1 (S)	<u>Palmaria</u> 1 (S)	<u>Ulva</u> 3 (1S,2B)	3 (B) ¹
Opportunities in the feed industry				
• Feed industry: What are the main opportunities for seaweed? (n=11)	Fish feed; dried seaweed; proteins as feed additive; wet seaweed (if digestible).			
• And which seaweed species show the greatest potential (more answers possible)? (n=6)	<u>Laminaria</u> 2 (1S,1B)	<u>Palmaria</u> 1 (S)	<u>Ulva</u> 2 (1S,1B)	1 (B) ²

¹ Greatest potential for green seaweeds (species not mentioned).

² Greatest potential for *Saccharina latissima*, especially in fish feed.

* Some experts gave more than one answer.

seaweed can be regarded as meat replacer, especially due to its relatively high protein content. The food industry is a very big market and the potential is high, especially when healthy food becomes more and more important. Next to fresh seaweed, also the frozen and dried form are possible to add to other products. Seaweeds can also be considered as potential salt replacer. One problem with the fresh market is the expire date, which is very short for fresh seaweed. Besides, the experts mention it is very important to brand the Dutch seaweed, otherwise only a few people will eat fresh seaweed. The current sales channels are mainly the catering industry, bakeries, fish retailers, supermarkets, and bulk consumption. In the future, also health and grocery stores offers marketing prospect. Although the interest for seaweeds is increasing, big market players are currently missing. So there is a market, especially in the Netherlands, England and Germany for local meat replacers, but there should be a party to start a big initiative (which involves a lot of costs). A rather important thing to reach the market with high volumes is marketing, otherwise it would be very small scale. The question remains, who is going to pay for this? Will the supermarket contribute or does it has to come from somewhere else in the chain? Another important issue is that further research is needed to examine the properties of Dutch seaweed for food purposes.

Proteins

Regarding the seaweed proteins, only a few proteins are sold in isolated form. Proteins which has been used in food are mainly soy preparations. These proteins are used for specific purposes in the food sector, such as for foam, their absorbency ability and emulsifying properties. Proteins with such properties do deliver more value due to its functionality, which is in relation with their costs. This market is relatively small.

Although most business experts focused on the consumption of whole seaweeds, another expert mentioned that it will be very difficult to let all people eat whole seaweeds. Therefore, this expert expects that the market for purified proteins from seaweed will become more important, especially if it concerns high-end proteins in high volumes. The applications of these proteins will be in meat replacers, soluble protein products, or something completely new which have to be discovered yet. The latter is the most likely scenario and will concern a new product which will deliver more value.

Important to note is that, when it comes to (Dutch) seaweed proteins without a history in human consumption, it is not allowed to use it for food and feed purposes directly. First a dossier has to be established in order to prove the protein is non-allergenic and not harmful to humans. In order to build such a dossier, the end consumer has to be defined before investors will finance the project.

Seaweed species

Although brown seaweeds are mentioned to be used most in the food industry, Ulva (green) is mentioned to be the most promising species. The main reason is the cultivation and the high protein content of Ulva.

Opportunities in the feed industry

Some experts indicated that the first target market for seaweed will be the feed industry. This concerns the isolated proteins derived from seaweed, especially in the fish feed industry since this industry delivers the highest market value. After the fish feed market, other feed markets will be targeted (this trajectory will take about 5 – 8 years). There are also experiments going on with seaweed components in feed for other animals. Some experts mentioned that it will be too expensive to add isolated proteins to animal feed, even when the digestibility potential for isolated proteins is higher than whole seaweeds.

Soy

Most of the proteins are going to feed, this is like a factor 10 difference with the amount of proteins destined to the food sector. Seaweed is mentioned to be a potential protein replacer for soy, which is the main protein component of feed. It is expected that if the seaweed proteins can be isolated, than its protein profile will be very close to soy protein. In the feed industry, always the cheapest raw materials will be used. Since soy is very cheap compared to other protein sources, the experts expect that soy will never be replaced totally.

Feed industry

Currently, research has shown that pigs and chicken experience problems with the digestion of intact seaweed (wet), due to the carbohydrates in which they are embedded. The nitrogen digestibility (20-30%) is much lower compared with a good protein source (above 75%). This means that the whole seaweeds are not suitable for these animals. The digestibility can be improved by isolating the proteins. Research showed that these proteins are better digestible, which offers opportunities for the isolated proteins as feed additive. However, the isolation of proteins is a very expensive process. Both the amino acid profile and the digestibility of the proteins in different animals is very important when applying in the feed industry.

If seaweed (proteins) are implemented in feed, it is very important to use this as a marketing tool according to the experts.

Fish feed

Some experts indicate seaweed is very suitable as fish feed. The Dutch market is too small and it is better to expand the scope to North-West Europe as well. One expert claimed that the purified proteins from brown seaweeds will be used first for the feed market and then for the food market. The isolated proteins can be added to feed. In fish feed, this means that soy and fishmeal can be replaced by seaweed proteins. In this way, the proteins can be regarded as marine proteins, which have a factor 4 higher market value than other proteins. One of the prerequisites is that the purity of the protein is 60 %. These marine proteins can be used for fish farming, especially salmon. Brown seaweeds are expected to be the first with applications in the feed and food industry, especially *Saccharina Latissima*.

Although some companies are already familiar with the use of seaweed as feed, the market is still in its infancy. Experts mention that there are opportunities on the long term for seaweed supplements, dried seaweed, seaweed proteins and even maybe for wet seaweed (which is the cheapest form). First, more research is needed about the exact amino acid profile, the beneficial health effects, and the digestibility of seaweed (proteins) in different forms and in different animals.

Seaweed species

According to the experts, *Laminaria* and *Ulva* are the most interesting species, mainly because these species can be cultivated relatively simple.

5.3 Market value of seaweed (proteins) in the Dutch market

Market values in the food industry

Whole seaweeds (scientific experts)

The opinions are divided among the scientific experts whether seaweeds have to be used for consumption as a whole or for its different components separately. Two scientific experts indicated a market value for whole seaweeds. The market value for Dutch seaweeds is estimated at € 2 – 3 per kg, based on the use of peas or soy as meat replacer. Another expert indicated a value of € 4 – 5 per kg for Dutch seaweed (fresh). The expert commented that the price is related to the specific proteins in seaweed, which requires further research.

Whole seaweeds (business experts)

Dutch

According to the business experts, prices for Dutch seaweeds are ranging from € 10 to 60. One expert even mentioned prices above € 60. Another expert claimed that wholesale prices for Dutch seaweed are between € 30 – 40 within the seaweed season and € 40 – 60 out of season. One expert shared information for the specific Dutch seaweed species. Dried seaweed prices are ranging from € 30 – 60, with the highest market value for *Palmaria* (€ 60) and the lowest for *Saccharina* and *Ulva* (€ 30). Fresh seaweed prices have lower values, varying from € 10 to € 20, according to the same expert. In this case, *Ulva* and *Saccharina* probably have the lowest market value (€ 10) and *Palmaria* (€ 10) again the highest value. It is commented that it will be a matter of time until the market values are generally known. Although the market values give some economic information, it does not reveal information on the profit margin.

Non-Dutch

Some experts are currently importing seaweeds. The Taiwanese *Wakame* (frozen) is sold in the supermarket. Price variation is caused by the amount of E-numbers, from ± € 3.34 to € 4.70, for seaweed high in E-numbers and seaweed without E-numbers, respectively (prices are adapted to the exchange rate of 3-4-2014 (€ 1.00 = \$ 1.37 derived from www.exchangerates.org.uk)). Supermarket take about 45 % of the sales margin. Dried *Wakame* from France costs € 23 when it is unpacked. On the other hand, fresh seaweed is sold at the Dutch fishmonger for approximately € 13 per kg. The experts who are currently importing the seaweeds, have an open attitude towards Dutch seaweeds and are willing to use these seaweeds. However, the difference in cost prices prevents them from doing so. The experts emphasize that if they are going to use Dutch seaweed, it will be very important to do a lot of marketing for the positioning of Dutch seaweed. One of the experts expect that it will be possible to ask a maximum of 20 to 30 % higher price for Dutch seaweed.

Most experts claimed that, if the fresh market is saturated, the seaweeds have to be dried or refined into its different main components to optimize the economic value.

Seaweed proteins (scientific experts)

The experts gave different estimations of the market value of seaweed proteins. It is mentioned that seaweed proteins with a specific functionality in the food sector (e.g. applications in foam and as emulsifier) can be worth between € 5 to € 10 per kg. Another expert indicated that plant proteins can be worth about € 2 – 4 per kg. These are preparations consisting of about 90 % proteins. The price is related to the protein content, so if the protein content decreases, the market value will also decrease. Seaweed proteins can be compared with plant proteins and are therefore also worth between € 2 and € 4 per kg, however, only if it has the same specific properties. In the extreme case that seaweed proteins contain very specific amino acid sequences which can be used in special applications, it can also be worth between € 15 and € 20 per kg. If proteins are isolated, it should be considered that the isolation process itself also has influence on the protein properties. So far, the specific properties of seaweed proteins are not known. As long as it is not proved that seaweed

Table 5.3 Assessment on the market value of seaweed (proteins) in the Dutch food and feed industry, specified for scientific and business experts.

• Food industry: What is a realistic price for seaweeds in € per kg?*					
<u>Scientific</u>	Prices (/kg)	n=	<u>Business</u>	Prices (/kg)	n=
Whole seaweeds					
Meat replacer (Dutch)	€ 2 – 3	1	- Wakame frozen (Taiwan)	€ 3.34 – 4.70**	1
Wholesale fresh (Dutch)	€ 4 – 5	1	- Wakame dried (France)	€ 23	1
			- Retail fresh (non-Dutch)	€ 13	1
			- Wholesale dried (Dutch)	> € 60	1
			- Wholesale dried (Dutch)	€ 30 – 40	1
			- Wholesale dried (Dutch)	€ 30 – 60	1
			- Wholesale fresh (Dutch)	€ 10 – 20	1
Seaweed proteins					
Without functionality (Dutch)	€ 1	3	- Isolated form (meat replacer, supplements, something 'new')	€ 1.40 – 1.80	1
With functional (Dutch)	€ 5 – 10	1			
	€ 2 – 4	1	- Isolated (application not known)	€ 4 – 8	1
	€ 15 – 20	1			
• Feed industry: What is a realistic price for seaweeds in € per kg?*					
<u>Scientific</u>	Prices (/kg)	n=	<u>Business</u>	Prices (/kg)	n=
Whole seaweeds					
- Soy	€ 1	3	- Soy	€ 1	1
	€ 1.50 – 2.00	1		€ 0.50 – 1.50	1
			- Without functionality (Dutch)	< € 2	1
			- With functionality (Dutch)	€ 2 – 4	1
			- Retail (species unknown)	€ 13.90	1
Seaweed proteins					
- Grass proteins	€ 1	1	- Isolated form (to replace fishmeal and soy in fish feed)	€ 1.40 – 1.80	1
			- Supplements	> € 4	1

- **Factors influencing the market value**

What are the main factors influencing the market values (more answers possible)? ¹	Availability of alternative proteins; volume; the emergence of new protein markets; protein functionality.
---	--

¹ The experts indicated that the price for seaweed proteins will probably increase within the range of 5 – 10 % (this question was only addressed to the business experts).

* This question was intended to estimate the market value for the different Dutch seaweed species Laminaria, Palmaria, and Ulva. However, it turned out that this was too specific and therefore all the information gathered is listed in the table.

** Prices are adapted to the exchange rate of 3-4-2014 (€ 1.00 = \$ 1.37 derived from www.exchangerates.org.uk).

proteins have properties with high functionality, a more realistic assessment of the market value will be around € 1 per kg or a little bit more, which is mentioned by three scientific experts.

Seaweed proteins (business experts)

Only two business experts indicated a market value for seaweed proteins in the food industry. One of the experts estimated this value based on the value of seaweed proteins in the fish feed market. According to him, the proteins are worth between € 1.40 and € 1.80 and can be used in meat replacers, supplements, and something completely 'new' which has to be discovered yet. Another expert indicated a market value between € 4 and € 8.

Market values in the feed industry

Whole seaweeds (scientific experts)

The experts argue that the price for seaweed is related to the price of soy. Bulk applications in feed, such as soy, have a market value of around € 1 per kg. In ten years, the demand for feed will increase and therefore the price of soy will probably rise to € 1.50 and maybe even € 2. If research turns out that seaweed has additional beneficial effects for animals, it is likely that a small premium price is paid, which is related to the specific functionality. One expert argued that the feed industry is quite conservative, which makes it more difficult to give perspectives for seaweed.

Whole seaweeds (business experts)

The business experts have more or less the same arguments in determining the seaweed prices in feed as the scientific experts. The experts indicated that the price paid for seaweeds will be very closely related to the price for soy, namely € 1. It is expected that the price for soy will rise coming years due to the increased demand for feed. The feed component covers a large part of the total costs in the maintenance of animals, so the industry will keep on looking for the cheapest alternative (especially with the expected rise in demand for feed). One expert added that if seaweed proteins show specific properties, the price of whole seaweeds is expected to be between € 2 and € 4. Another expert argued that if seaweed proteins do not show specific properties, the market value of whole seaweeds is expected to be lower than € 2. An expert who is trading seaweed for feed purposes (species unknown), have a retail price of € 13.90.

Seaweed proteins (business experts)

According to one expert, seaweed proteins could be compared with grass proteins. New projects on grass proteins also assume a protein price of € 1 per kg, since the specific functionalities of the proteins are not known yet.

Seaweed proteins (business experts)

Only two experts indicated a price for purified proteins, of which one expert for purposes specific in fish feed. The price of these proteins in fish feed lies between € 1.40 and € 1.80 per kg. These seaweed proteins could replace the soy and fishmeal component in fish feed. The expected price for seaweed proteins in other feed purposes is not known. One expert indicated that seaweed proteins in the form of supplements could have a market value of > € 4. No additional information was given.

6. Discussion & Conclusion

6.1 Discussion

The focus in this report was on the native species *Laminaria digitata*, *Palmaria palmata*, and *Ulva lactuca*. Since business already exploit *Saccharina latissima* (considered as native species) on a commercial scale (abroad), the focus of the economic analysis of Dutch seaweed should be extended with this species. The food and feed industry were correctly chosen as the industries to focus on. Experts argued that these industries are the first to target with Dutch seaweed. Only if more information is known about the specific properties of seaweed proteins, other markets such as the pharmaceutical and technical industry, become interesting.

Table 6.1 Promising Dutch seaweed species; related market values in literature and results.

	Literature (/kg)	Results (/kg)
Food industry		
Wholesale (dried)		
<i>Laminaria digitata</i>	€ 10 – 16 ¹	
<i>Palmaria palmata</i>	€ 16 – 19 ¹	€ 60
<i>Ulva lactuca</i>		€ 30
Wholesale (fresh)		
<i>Palmaria palmata</i>		€ 20
<i>Ulva lactuca</i>		€ 10
Retail		
<i>Laminaria digitata</i>	€ 60 – 120 ¹	
<i>Palmaria palmata</i>	€ 57 – 106 ¹	
<i>Ulva lactuca</i>	€ 45 – 90 ²	
Proteins		
Species not specified	€ 0.80 - 20 ³	€ 1 – 20
Feed industry		
Dried		
<i>Laminaria digitata</i>	€ 0	
<i>Palmaria palmata</i>	€ 0.12	
<i>Ulva lactuca</i>	€ 0.05	
Species not specified	€ 0.40	€ 0.50 – 4 ⁴
Proteins		
Species not specified	€ 0.75 – 3 ³	€ 1 – 1.80, > € 4 ⁵

¹ These prices are obtained from the Irish Sea Fisheries Bond.

² Market not explicitly mentioned.

³ Based on the possibly comparable sources of waste residues and soy proteins.

⁴ Retail price not included.

⁵ As supplement.

In literature, some market values for seaweed species which are native in the North Sea are revealed. However, these market values are not specific to seaweeds cultivated at the North Sea and not sold on the Dutch market. In this research it turned out that the experts faced difficulties in indicating the market value for the native Dutch seaweeds, they were only able to share general information on the market values (non-specific). Table 6.1 presents an overview of the information found in literature compared with the results on seaweed species native in the North Sea.

The closed character of most questions was not totally appropriate for this exploratory research, since most of the closed questions were too specific and the background of the experts differed too much. In-depth

interviews would be more appropriate since this interview type could adjust to the scope of the expert's expertise and knowledge.

6.2 Conclusions

Currently, there is no optimal design for offshore cultivation of Dutch seaweed. Much scientific research is carried out on the ring structure as most suitable cultivation design. In practice, experts prefer long-lines or other newer designs. An important condition of these new designs are lowered costs. Practical experiences are needed to demonstrate the real expected costs of seaweed cultivation at the North Sea. Until this is achieved, expected costs of between € 1,019 and € 2,500 per tonne (D.M.) are most likely.

According to the experts, the seaweed market is regarded as a growing market in the Netherlands. Both the food and feed industry provide opportunities for different seaweed applications. In general, the food industry is regarded as the industry with the highest market values. The fresh market for human consumption is expected to be the most promising market. If this market becomes saturated, seaweed could be dried and added to other products. *Ulva lactuca* is perceived as the most appropriate species for these purposes, since this species belongs to the green seaweeds. Green seaweeds are regarded as most attractive for human consumption. To sell fresh seaweeds on the Dutch market, it is important to find the right marketing channels and to do a lot of marketing so that the consumer get familiar with fresh seaweeds. Possible marketing channels include the greengrocers, health stores, and supermarkets. Although the main focus is put on the consumption of whole seaweeds, the opportunities for seaweed proteins are expected to be in high-end protein markets with high volumes (such as for foam, in meat replacers or as soluble protein products). The feed industry offers opportunities due to its high volume. The lack of information about the digestibility of whole seaweeds prevents the current application of native seaweeds in the feed industry. The improved digestibility of isolated seaweed proteins offers potential, however, the costs of this isolation process have to be taken into account.

The exact market values of Dutch seaweeds cultivated at the North Sea is not known. Estimations for wholesale prices for bulk quantities of Dutch seaweed (fresh) in the food industry are varying between € 10 – 20 per kg, in which *Ulva* has the lowest value (€ 10) and *Palmaria* the highest (€ 20). Comparable data in literature is not found. Wholesale prices for dried Dutch seaweed are expected to be higher, in the range of € 30 for *Ulva* and € 60 for *Palmaria*. In general, the market value for *Ulva* is perceived as lowest, while this species is expected to offer the most opportunities in the food industry. In the feed industry, whole seaweeds are expected to have a market value of approximately € 1, which is related to the price of soy. Additional benefits from seaweeds can cause a price increase estimated at € 2 to € 4 per kg. In scientific research, much attention is paid to seaweed biorefinery in order to optimize the economic value. The protein component of seaweed will most likely contribute about € 1 – 1.80 per kg, depending on its application. However, if it turns out that seaweed proteins show specific functionalities, the price is expected to increase up to € 20 per kg (in the food industry). Next to the functionality, also volume influences the market value of Dutch seaweeds.

6.3 Further research

The seaweed chain involves a lot of uncertainty in all stages. In the early cultivation stage, much more research is needed to explore the expected costs of offshore seaweed cultivation. Practical experiences are needed to support cost data and to examine the expected yield, which influences the cost price. Opportunities of seaweed proteins in the food industry are related to the specific protein properties. Therefore, more research is needed to examine these properties. The protein functionality is also determining in the seaweed protein market value and the ability to apply seaweed protein in markets other than the food and feed industry. In order to apply seaweeds in the feed industry, it is important to know the digestibility of native Dutch seaweeds in animals. Current research indicates that the digestibility of seaweed proteins are higher compared to whole

seaweeds, however, more research is needed to confirm these findings. Using these findings can contribute to assess the most appropriate form in which seaweeds have to be applied in the feed industry (either as a whole products or only the seaweed proteins).

7. References

- Alibaba.com. (2014). Available at <http://www.alibaba.com/>, accessed on 13-3-2014, Alibaba, Londen, United Kingdom.
- Arasaki, S., Arasaki, T. (1983). Low calorie, high nutrition vegetables from the sea to help you look and feel better. P. 196, Japan Publications, Tokyo.
- Atkinson, R., Flint, J. (2004). Snowball Sampling. Available at <http://srmo.sagepub.com/view/the-sage-encyclopedia-of-social-science-research-methods/n931.xml>, accessed on 13-8-2014.
- Augier, H., Santimone, M. (1978). Contribution à l'étude de la composition en azote total, en protéines et en acides aminés protéiniques des différentes parties du thalle de *Laminaria digitata* (Huds.) Lamour. dans le cadre de son exploitation industrielle et agricole. Bulletin de la société phycologique de France 23, 19-28.
- Barbosa, M., Wijffels, R.H. (2009). Marine Biorefineries. Available at <http://www.biorefinery.nl/fileadmin/biosynergy/user/docs/MarineBiorefinery-Barbosa.pdf>, presentation, 17th June 2009, by Wageningen UR in Wageningen, The Netherlands.
- BeaufortAnimalSupplies. (2013). Seaweed meal 5kg. Available at <http://beaufortanimalsupplies.com.au/product/horse-products/health-horse/seaweed-meal-5kg>, accessed on 7-3-2014, Beaufort Animal Supplies, Beaufort, Australia.
- BetterPlants. (2014). Better Feeds Animal Feed 3Kg. Available at <http://www.betterplants.ie/index.php/produtrang1/seaweed-animal-feed/better-feeds-animal-feed-3kg-detail>, accessed on 7-3-2014, Better Plants, Mullingar, Ireland.
- Bio-Ron. (2014). Available at <http://www.bio-ron.com/producten/voedingssupplementen/noors-zeewier.html>, accessed on 7-3-2014, Bio-Ron, Doornspijk, The Netherlands.
- Bolton, J.J., Robertson-Andersson, D.V., Shuuluka, D., Kandjengo, L. (2009). Growing Ulva (Chlorophyta) in integrated systems as a commercial crop for abalone feed in South Africa: a SWOT analysis. Journal of Applied Phycology 21, 575-583.
- Bozell, J.J., Petersen, G. R. (2010). Technology development for the production of biobased products from biorefinery carbohydrates—the US Department of Energy's "Top 10" revisited. Green Chemistry 12, 539-554.
- Brandenburg, W.A., Wald, J. (2010). Seaweeds for proteins? Available at <http://www.presentations-dlgbenelux.com/Congres/download/a54d393f2a5b039cca341dbf28b2a3e7/06022011125903/559>, presentation, 1st December 2010, by Wageningen UR in Amsterdam, The Netherlands.
- Buck, B.H., Buchholz, C.M. (2004a). The offshore ring: A new system design for the open ocean aquaculture of macroalgae. Journal of Applied Phycology 16, 355-368.
- Buck, B.H., Krause, G., Rosenthal, H. (2004b). Extensive open ocean aquaculture development within wind farms in Germany: the prospect of offshore co-management and legal constraints. Ocean & Coastal Management 47(3-4), 95-122.
- Burg, S.v.d., Stuijver, M., Veenstra, F., Bikker, P., López Contreras, A., Palstra, A., Broeze, J., Jansen, H., Jak, R., Gerritsen, A., Harmsen, P., Kals J., Blanco, A., Brandenburg, W., Krimpen, M. van, Duijn, A.P. van, Mulder, W., Raamsdonk, L. van. (2013). A Triple P review of the feasibility of sustainable offshore seaweed production in the North Sea. Available at <http://edepot.wur.nl/276368>, Wageningen UR.
- Chapman, V.J. (1970). Seaweed and their uses. Methuen and Co. Ltd., London, United Kingdom.
- Chynoweth, D.P. (2002). Review of biomethane from Marine Biomass. Available at http://abe.ufl.edu/chyn/download/Publications_DC/Reports/marinefinal_FT.pdf.
- Dawczynski, C., Schubert, R., Jahreis, G. (2007). Amino acids, fatty acids, and dietary fibre in edible seaweed products. Food Chemistry 103, 891-899.
- DeTuinen. (2014). Spirulina Chlorella Greens. Available at <http://www.detuinen.nl/weerstand/spirulina-chlorella-greens.html>, accessed on 5-3-2014, De Tuinen, Beverwijk, The Netherlands.
- Diels, L. (2009). Bioraffinaderij: een weg naar hernieuwbare brandstoffen en chemicaliën in een duurzaam evenwicht met voedselvoorziening? Available at <http://www.chemmystery.be/archiefchem4/chem4/pdf/Microsoft%20PowerPoint%20-%20Chemmystery-Diels-bis.pdf>, paper presented at the ChemMysteryforum4, 9th February 2009, by VITO (Vlaamse Instelling voor Technologisch Onderzoek) in Antwerp, Belgium.

- Dierendrogiest. (2014). Dierendrogiest IJslands Zeewier Navulzak - 5 kg. Available at <http://www.bol.com/nl/p/dierendrogiest-ijslands-zeewier-navulzak-5-kg/9200000010739181/?Referrer=ADVNLKEL0020349200000010739181>, accessed on 7-3-2014.
- Douglas-Westwood. (2005). Marine industries global market analysis. Available at http://www.marine.ie/NR/rdonlyres/B66FBE34-3859-4FA8-9ABF-8C8558CDB15E/0/ForesightSeries1_global_market_analysis.pdf, Marine Foresight Series No. 1., Marine Institute, Oranmore, Ireland.
- Dumay, J., Morancais, M., Munier, M., Fleurence, J. (2011). Feasibility study of the recovery of R-Phycoerythrin from red algae in France. Available at http://www.biotechmar.eu/IMG/pdf/Feasability_study_Recovery_of_pigments_from_Red_Algae.pdf.
- Engelen, E., Westenbroek, A. (2013). Visiedocument: Valorisatie van eiwithoudende reststromen. Available at http://www.dutchbiorefinerycluster.nl/download/302/documenten/Visiedocument_Eiwitten_NL_nov_2013.pdf, The Dutch Biorefinery Cluster, Groningen, The Netherlands.
- Ergn, S., Soyutrk, M., Groy, B., Groy, D., Merrifield, D. (2009). Influence of Ulva meal on growth, feed utilization, and body composition of juvenile Nile tilapia (*Oreochromis niloticus*) at two levels of dietary lipid. *Aquaculture International* 17(4), 355-361.
- Evert, A. (2013a). Amino acids. Available at <http://www.nlm.nih.gov/medlineplus/ency/article/002222.htm>, accessed on 13-3-2014, MedlinePlus, Bethesda, MD, United States.
- Evert, A. (2013b). Vitamins. Available at , accessed on 14-4-2014, MedlinePlus, Bethesda, MD, United States.
- FAO. (1980). Aquaculture development and coordination programme. Fish feed technology. Available at <http://www.fao.org/docrep/x5738e/x5738e00.htm>, accessed on 24-3-2014, FAO (Food and Agriculture Organization), Rome, Italy.
- FAO. (2003). A Guide to the Seaweed Industry. Available at <ftp://ftp.fao.org/docrep/fao/006/y4765e/y4765e00.pdf>, FAO (Food and Agriculture Organization), Rome, Italy.
- FAO. (2011). The state of the world's land and water resources for food and agriculture: managing systems at risk. Available at <http://www.fao.org/docrep/015/i1688e/i1688e00.pdf>, FAO (Food and Agriculture Organization), Rome, Italy.
- Fleurence, J. (1999). Seaweed proteins: biochemical, nutritional aspects and potential uses. *Trends in Food Science & Technology* 10(1), 25-28.
- Fleurence, J. (2004). Seaweed proteins. In: *Proteins in food processing*, R. Y. Yada (Ed.), pp. 197-213. Cambridge: Woodhead Publishing Limited, United Kingdom.
- Fleurence, J., Coeur, C. Le, Mabeau, S., Maurice, M., Landrein, A. . (1995). Comparison of different extractive procedures from the edible seaweeds *Ulva rigida* and *Ulva rotundata*. *Journal of Applied Phycology* 7, 577-582.
- Fleurence, J., Morancais, M., Dumay, J., Decottignies, P., Turpin, V., Munier, M., Garcia-Bueno, N., Jaouen, P. (2012). What are the prospects for using seaweed in human nutrition and for marine animals raised through aquaculture? *Trends in Food Science & Technology* 27, 57-61.
- Florentinus, A. (2010). Realizing macro algae cultivation offshore: Diving into the offshore renewables potential of our oceans. Available at <http://www.presentations-dlgbenelux.com/Congres/download/4301167711fc0258168905ba1ca7266e/11012012044308/563>, Ecofys, Utrecht, The Netherlands.
- Florentinus, A., Hamelinck, C., Lint, S. de, Iersel, S. van. (2008). Worldwide Potential of Aquatic Biomass. Available at <http://waterenenergie.stowa.nl/Upload/Worldwide%20Potential%20of%20aquatic%20biomass.pdf>, Ecofys, Utrecht, The Netherlands.
- Friedman, M. (1996). Nutritional value of proteins from different food sources. A review. *Journal of Agricultural and Food Chemistry* 44, 6-29.
- Fujiwara-Arasaki, T., Mino, N., Kuroda, M. (1984). The protein value in human nutrition of edible marine algae in Japan. *Hydrobiologia* 116-117(1), 513-516.
- Galland-Irmouli, A.V., Pons, L., Luon, M., Villaume, C., Mrabet, N.T., Guant, J.L., Fleurence, J. (2000). One-step purification of R-phycoerythrin from the red macroalga *Palmaria palmata* using preparative polyacrylamide gel electrophoresis. *Journal of Chromatography B: Biomedical Sciences and Applications* 739(1), 117-123.
- Gezond&Wel. (2014). Chlorella/ Available at <http://www.gezondheidswinkel.nl/productcategorie-26.aspx?GroupID=GROUP39600>, accessed on 5-3-2014.

- GroenKennisnet. (2011). Zeeboerderij teelt wier voor de toekomst. Available at http://www.groenkennisnet.nl/Pages/Zeeboerderij_teelt_wier_voor_de_toekomst.aspx, accessed on 15-4-2014.
- Hal, J.W.v. (2012). Seaweed Biorefinery: towards third generation biobased fuels and chemicals. Available at <http://www.ecn.nl/docs/library/report/2012/l12044.pdf>, presented at the European Algae Biomass Conference, 25th-26th April 2012, by ECN (Energy research Centre of the Netherlands) in London, United Kingdom.
- Hart, P.t., Schipper, J. (2011). Zeewieren in gesloten systemen. Available at http://www.koersenvaart.nl/files/zeewieren_in_gesloten_systemen.pdf, InnovatieNetwerk, Utrecht, The Netherlands.
- Haug, A., Jensen, A. . (1954). Seasonal variations in the chemical composition of *Alaria esculenta*, *Laminaria saccharina*, *Laminaria hyperborea* and *Laminaria digitata* from Northern Norway. Report Norwegian Institute of Seaweed Research 4, 1-14. Akademisk Trykningssentral, Blindern, Norway.
- Holdt, S.L., Kraan, S. (2011). Bioactive compounds in seaweed: functional food applications and legislation. *Journal of Applied Phycology* 23(3), 543-579.
- Huis, A.v., Itterbeeck, J. van, Klunder, H., Mertens, E., Halloran, A., Muir, G., Vantomme, P. (2013). Edible insects, Future prospects for food and feed security. Available at www.fao.org/docrep/018/i3253e/i3253e.pdf, FAO (Food and Agriculture Organization), Rome, Italy.
- ICIS. (2014). Available at <http://www.icis.com/chemicals/>, accessed on 13-3-2014, ICIS, Londen, United Kingdom.
- IEA. (2009). IEA Bioenergy Task 42 Biorefinery. Available at http://www.biorefinery.nl/fileadmin/biorefinery/docs/Brochure_Totaal_definitief_HR_opt.pdf, IEA (International Energy Agency), Amsterdam, The Netherlands.
- Indegaard, M., Minsaas, J. (1991). Animal and Human Nutrition. In: *Seaweed Resources in Europe: Uses and Potential*, Guiry, M. D. and Blunden G. (Eds.), pp. 21-64. John Wiley & Sons Ltd., Chichester, United Kingdom.
- Jenkins, S. (2013). Commercial-scale production of bio-based BDO announced. Available at http://www.che.com/only_on_che/latest_news/Commercial-scale-production-of-bio-based-BDO-announced_10221.html, accessed on 8-4-2014, Chemical Engineering, New York, United States.
- Kasteren, H.v., Wentink, C., Konz, W. (2012). Verkenningen toepassing algen als energiebron en grondstof voor de procesindustrie. Available at http://www.telos.nl/Telos/Medewerkers/MKonz/downloads_getfilem.aspx?id=216376, Telos (brabants centrum voor duurzame ontwikkeling), Tilburg, The Netherlands.
- Kılınc, B., Cirik, S., Turan, G., Tekogul, H., Koru, E. (2013). Seaweeds for Food and Industrial Applications. In: *Food Industry*, Chapter 31, Dr. Innocenzo Muzzalupo (Ed.), pp. 735-748.
- Kolb, N., Vallorani, L., Milanovic, N., Stocchi, V. (2004). Evaluation of marine algae *Wakame* (*Undaria pinnatifida*) and *Kombu* (*Laminaria digitata japonica*) as food supplements. *Food Technology and Biotechnology* 42(1), 57-61.
- Kumar, C.S., Ganesan, P., Suresh, P.V., Bhaskar, N. (2008). Seaweeds as a source of nutritionally beneficial compounds—a review. *Journal of Food Science and Technology* 45, 1-13.
- Lahaye, M., Jegou, D. (1993). Chemical and physical-chemical characteristic of dietary fibres from *Ulva lactuca* (L.) Thuret and *Enteromorpha compressa* (L.) Grev. *Journal of Applied Phycology* 5, 195-200.
- Lammens, T.M. (2011). Biobased industrial chemicals from glutamic acid. Available at <http://edepot.wur.nl/186440>, Wageningen UR.
- Langdon, C., Evans, F., Demetropoulos, C. (2004). An environmentally-sustainable, integrated, co-culture system for dulse and abalone production. *Aquaculture Engineering* 32, 43-56.
- Lenstra, W.J., Hal J.W. van, Reith, J.H. (2011). Economic aspects of open ocean seaweed cultivation. Available at <http://www.ecn.nl/docs/library/report/2011/m11100.pdf>, presented at the Alg'n Chem 2011 Conference, 7th-10th November, by ECN (Energy research Centre of the Netherlands) in Montpellier, France.
- López-Contreras, A., Harmsen, P., Blaauw, R., Bakker, R., Hal, J. van, Reith, H., Brandenburg, W., Haveren, J. van (2012). Seaweed biorefinery: production of fuels and chemicals from native North Sea seaweed species. Available at <http://www.presentations-dlgbenelux.com/Congres/download/2c19bc9600d4dea943d4dabad8d7e3cc/01112012140527/738>, presented at the Seagrass: International Sea(Weed) Farming Commodities Conference, 19th September 2012, by Wageningen UR in Zeeland, The Netherlands.

- Losos, J.B., Mason, K.A., Singer, S.R. (2008). Proteins. In: Biology, P. E. Reidy and A. L. Winch (Eds.), pp. 43-53. McGraw Hill Companies, Inc., New York, United States.
- Mabeau, S., Fleurence, J. (1993). Seaweed in food products: Biochemical and nutritional aspects. *Trends in Food Science and Technology* 4, 103-107.
- McHugh, D.J. (1987). Production and utilization of products from commercial seaweeds. FAO Fisheries Technical Paper 288, pp. 1-189, FAO (Food and Agriculture Organization), Rome, Italy.
- McHugh, D.J. (2003). A guide to the seaweed industry. FAO Fisheries Technical Paper 441, FAO (Food and Agriculture Organization), Rome, Italy.
- Mouritsen, O.G. (2009). In: Tang- Grøntsager fra havet, pp. 284 (in Danish). Nyt Nordisk Forlag, Arnold Busck, Copenhagen, Denmark.
- Mulder, W. (2010). Proteins in biomass streams. Available at <http://edepot.wur.nl/158987>, Wageningen UR.
- Mulder, W., Broek, B. van den, Sanders, J., Bruins, M., Scott, E. (2013). Biobased economy: de potentie van eiwitten voor technische toepassingen. Available at <http://edepot.wur.nl/253277>, Wageningen UR.
- Munda, I.M. (1977). Differences in amino acid composition of estuarine and marine fucoids. *Aquatic Botany* 3, 273-280.
- Murata, M., Nakazoe, J. (2001). Production and use of marine algae in Japan. *Japan Agricultural Research Quarterly* 35, 281-290.
- OilWorld. (2010). Major meals, World summary balances. *Oil World Weekly* 55(3), 45.
- Orbichem. (2013). Chemical market insight and foresight – on a single page – Styrene . Available at http://www.orbichem.com/userfiles/CNF%20Samples/sty_13_11.pdf, Orbichem, Londen, United Kingdom.
- Patarra, R.F., Leite, J., Pereira, R., Baptista, J., Neto, A.I. (2012). Fatty acid composition of selected macrophytes. *Natural Product Research: Formerly Natural Product Letters* 27(7), 665-669.
- PDV. (2014). Available at <http://www.pdv.nl/>, accessed on 9-3-2014, PDV (Productschap Diervoeder), Zoetermeer, The Netherlands.
- Pérez, R. (1997). Conception actuelle, rôle dans la biosphère, utilisations, culture. In: *Ces algues qui nous entourent*, Quae (Ed.), Versailles, France.
- Petrell, R.J., Mazhari Tabrizi, K., Harrison, P. J., Druehl, L. D. (1993). Mathematical model of Laminaria production near a British Columbian salmon sea cage farm. *Journal of Applied Phycology* 5(1), 1-14.
- Poel, A.F.B.v.d., Krimpen, M. van, Veldkamp, T., Kwakkel, R.P. (2013). Unconventional protein sources for poultry feeding: opportunities and threats. Available at <http://edepot.wur.nl/274039>, proceedings 19th Symposium on Poultry Nutrition, 26th-29th August 2013, by Wageningen UR in Potsdam, Germany.
- Radmer, R.J. (1996). Algal diversity and commercial algal products. *BioScience* 46, No. 4, Marine Biotechnology, 263-270.
- Reith, J.H., Deurwaarder E.P., Hemmes K., Curvers A.P.W.M., Kamermans P., Brandenburg W., Zeeman, G. (2005). BIO-OFFSHORE Grootschalige teelt van zeewieren in combinatie met offshore windparken in de Noordzee. Available at <http://www.ecn.nl/docs/library/report/2005/c05008.pdf>, ECN (Energy research Centre of the Netherlands), Wageningen UR, Lettinga Associates Foundation.
- Reith, J.H., Huijgen, W.J.J., Hal J.W. van, Lenstra, W.J. (2009). Seaweed potential in the Netherlands. Available at http://www.researchgate.net/profile/Wouter_Huijgen/publication/228957683_Seaweed_potential_in_the_Netherlands/file/504635230230d1d2d0.pdf, presented at the Macroalgae - Bioenergy Research Forum, 2nd June 2009, by ECN (Energy research Centre of the Netherlands) in Plymouth, United Kingdom.
- Rodríguez, A.P., Mawhinney, T.P., Marie, D.R., Cruz-Suárez, L.E.C. (2011). Chemical composition of cultivated seaweed *Ulva clathrata* (Roth) C Agardh. *Food Chemistry* 129, 491-498.
- Sanders, J.P.M., Broeze, J. (2011). Bioraffinage, de brug tussen landbouw en chemie: Valorisation of plant production chains. Available at www.zeeland.nl/digitaalarchief/zeel1200294, presentation, 10th November 2011, by Wageningen UR in Terneuzen, The Netherlands.
- Satpati, G.G., Pal, R. (2011). Biochemical composition and lipid characterization of marine green alga *Ulva rigida* - a nutritional approach. *Journal of Algal Biomass Utilization* 2, 10-13.
- Spiegel, M.v.d., Noordam, M.Y., Fels-Klerx, H.J. van der. (2013). Safety of novel protein sources (insects, microalgae, seaweed, duckweed, and rapeseed) and legislative aspects for their application in food and feed production. *Comprehensive Reviews in Food Science and Food Safety* 12(6), 662-678.
- Stichting Noordzeeboerderij. (2014). Available at <http://www.noordzeeboerderij.nl/>, accessed on 17-4-2014, Stichting Noordzeeboerderij, 't Horntje, The Netherlands.

- Tabarsa, M., Rezaei, M., Ramenzanpour, Z., Waaland, J.R. (2012). Chemical compositions of the marine algae *Gracilaria salicornia* (Rhodophyta) and *Ulva lactuca* (Chlorophyta) as a potential food source. *Journal of the Science of Food and Agriculture* 92, 2500-2506.
- Taboada, C., Millan, R., Miguez, I. (2010). Composition, nutritional aspects and effect on serum parameters of marine algae *Ulva rigida*. *Journal of the Science of Food and Agriculture* 90, 445-449.
- Tseng, C.K. (2001). Algal biotechnology industries and research activities in China. *Journal of Applied Phycology* 13, 375-380.
- Vaus, D.d. (2001). *Research Design in Social Research*. London, Thousand Oaks, New Dehli: Sage Publications.
- Walsh, M., Watson, L. (2013). A market analysis towards the further development of seaweed aquaculture in Ireland. Available at <http://www.bim.ie/media/bim/content/publications/corporate-other-publications/A%20Market%20Analysis%20towards%20the%20Further%20Development%20of%20Sea%20weed%20Aquaculture%20in%20Ireland.pdf>, Bord Iascaigh Mhara, Dublin, Ireland.
- Whittemore, C.T., Percival, J.K. (1975). Seaweed residue unsuitable as a major source of energy or nitrogen for growing pigs. *Journal of the Science of Food and Agriculture* 26(2), 215-217.
- Wijffels, R.H., Barbosa, M.J., Eppink, M.H.M. (2010). Microalgae for production of bulk chemicals and biofuels. *Biofuels, Bioproducts and Biorefining* 4(3), 287-295.
- Wooley, R.J. (1999). Sugar Platform (Bioenergy Initiative Approach). Available at <http://infohouse.p2ric.org/ref/40/39175.pdf>, presentation, 8th-9th December, by NREL (National Renewable Energy Laboratory), Washington, United States.
- Zeewierwijzer. (2011). Albert Heijn zeewiersalade. Available at <http://www.zeewierwijzer.nl/faq---veelgestelde-vragen/albert-heijn-zeewiersalade.html>, accessed on 5-3-2014.
- Zimmermann, K.H. (2003). Proteins. In: *An Introduction to Protein Informatics*, M. Ismail (Ed.), pp. 5-22. Springer-Verlag, LLC, New York, United States.
- Zuidema, T. (2010). Autoband uit biomassa. Available at <http://www.technischweekblad.nl/autoband-uit-biomassa.89629.lynkx>, accessed on 13-3-2014, Technisch weekblad, Den Haag, The Netherlands.

Annex A Interview format

A verification of the available literature on expected production costs and revenues of seaweed (proteins) native in the North Sea

Scientific expert interview

Topic overview

Section		Page
1	General introduction	1
2	Introduction and market background	2
3	Cultivation design and yield	3
4	Expected costs	4
5	Applications of seaweed proteins	5
6	Expected market values	6
7	Market forecast	10

Section 1 General introduction

Thank you for your time to participate in my thesis research.

In my thesis I am looking to offshore seaweed cultivation, the market background, expected production costs, applications of seaweed proteins and the expected revenues. The focus of my research is on seaweed species native in the North Sea: Laminaria, Palmaria, and Ulva.

The purpose of this interview is to gain a deeper understanding of the market developments and revenues of seaweed (proteins) from offshore seaweed cultivation and to verify the data found in literature on market values of seaweed (proteins).

The results from this interview will provide supportive information for the economic evaluation of seaweed (proteins) from offshore cultivation.

This interview will take about 30 to 45 minutes.

Section 2 Introduction and market background

1. Description of the market situation regarding the current use of seaweed.

a) What is the main Dutch industry in which seaweeds are currently used:

☐ Food industry

☐ Feed industry

☐ Technical industry

a) The seaweed types used in these sectors are mainly:

☐ Red seaweeds

☐ Brown seaweeds

☐ Green seaweeds

b) More specifically, which of the following native seaweed species have already been used for purposes in the food, feed and technical industry (more answers possible).

☐ Laminaria

☐ Palmaria

☐ Ulva

c) In which form are these seaweeds mainly used in the food and feed industry:

- Food industry:

☐ Raw

☐ Processed

- Feed industry:

☐ Raw

☐ Processed

2. Your view on the seaweed market as: growing, in decline, or remaining steady :

a) In the next 3 years:

☐ Growing

☐ Declining

☐ Steady

b) In the next 10 years:

☐ Growing

☐ Declining

☐ Steady

Additional comments:

Section 3 Cultivation design and yield

3. Location of seaweed cultivation and seaweed species.

a) Which location do you think have the greatest potential for cultivation of good quality seaweed in the Netherlands:

☐ Onshore

☐ Nearshore

☐ Offshore

b) Literature shows there are several cultivation designs possible of which long-lines and the so called ring structure are the most common ones. Which cultivation design is most suitable in case of offshore seaweed cultivation?

☐ Long-lines

☐ Ring structure

☐ Other:

Why do you think so:

c) Which type of seaweed species would be most suitable to cultivate in the North Sea:

☐ Laminaria

☐ Palmaria

☐ Ulva

Why do you think so:

d) What do you consider as the main obstacles in offshore seaweed cultivation?

4. The productivity of offshore production at the North Sea depends on the supply of nutrients and the cultivation method. Without the supply of nutrients the productivity is estimated to be around 20 tonnes/ha/year. Cultivation in layers and or/ with dosed nutrient supply may increase productivity to 50 tonnes a year.

a) What do you think the productivity will be in case of no supply of nutrients and no layers.

☐ < 20 tonnes/ha/year

☐ 20 tonnes/ha/year

☐ > 20 tonnes/ha/year

Why do you think so:

b) What do you think the productivity will be in case there is a supply of nutrients and/or cultivation in layers.

☐ < 50 tonnes/ha/year

☐ 50 tonnes/ha/year

☐ > 50 tonnes/ha/year

Why do you think so:

c) What are the main factors influencing this expected yield:

Section 4 Expected costs

5. In literature, different cultivation designs show different costs per tonne dry mass (D.M.). Based on this literature, the following scenarios are designed (a, b, and c). What do you think will be a good indication of the costs for the following cultivation designs:

a) Ring structure (North Sea), based on 20 tonnes (D.M.)/ha/year:

- Including investment costs
- Without operational costs, capital costs, labour costs

☐ < € 2,500 per tonne (D.M.) ☐ € 2,500 per tonne (D.M.) ☐ > € 2,500 per tonne (D.M.)

b) Long-lines (North Sea), based on 20 tonnes (D.M.)/ha/year:

Scenario 1 (investment costs of € 50,000 per ha, lifespan of 10 years and yield of 20 tonnes (D.M.)):

- Including investment costs (long-lines, buoys, mooring and employment)
- Including labour costs (for a 10 ha sea farm)
- Including harvesting costs

☐ < € 1,019 per tonne (D.M.) ☐ € 1,019 per tonne (D.M.) ☐ > € 1,019 per tonne (D.M.)

Scenario 2 (investment costs of € 150,000 per ha, lifespan of 10 years and yield of 20 tonnes (D.M.)):

- Including investment costs (long-lines, buoys, mooring and employment)
- Including labour costs (for a 10 ha sea farm)
- Including harvesting costs

☐ < € 1,519 per tonne (D.M.) ☐ € 1,519 per tonne (D.M.) ☐ > € 1,519 per tonne (D.M.)

What do you think is a more reliable scenario:

☐ Scenario 1 ☐ Scenario 2

c) Long-lines (ocean), based on 50 tonnes (D.M.)/ha/year:

- In a 100 ha scenario
- Including investment costs
- Including operation and maintenance costs
- Including harvesting costs

☐ < € 669 per tonne (D.M.) ☐ € 669 per tonne (D.M.) ☐ > € 669 per tonne (D.M.)

d) Based on this information, what do you think is a reliable indication of seaweeds per tonne (D.M.)/ha/year for a 10 ha farm with a yield of 20 tonnes/ha/year.

	Costs in € per tonne (D.M.)/ha/year	
	Ring structure	Long-lines
Investment costs	€	€
Labour costs	€	€
Seedlings	€	€
Harvesting costs	€	€

Total	€	€
--------------	----------	----------

Additional comments:

Section 5 Applications of seaweed proteins

6. The protein content can represent up to 21 %, 35 %, 44% of D.M. in Laminaria, Palmaria and Ulva, respectively. Therefore, seaweeds offer potential for their application in the food and feed industry, especially Palmaria and Ulva, due its high protein content.

- a) Based on the nutritional content, do you think seaweed proteins are comparable with soybean proteins?

☐ Yes

☐ No

And if yes, do you think seaweed proteins will replace soy in the near future?

☐ Yes

☐ No

- b) - What do you consider as the main opportunities for seaweed proteins in the food industry (functional ingredient, supplements, meat replacer, etc.)?

- And which seaweed species, Laminaria, Palmaria, or Ulva, show the greatest potential?

(In this question it is assumed that the application of seaweed proteins is approved for its use in food supplements etc.)

- c) Seaweed is already been used in animal diets to feed cattle, horses and poultry. Although more research is needed to investigate the nutritional value of whole seaweeds and seaweed proteins in animals diets, literature suggests that the feed industry is an interesting potential market due to its large size. In literature, seaweed is mentioned as a promising potential protein source to increase the EU feed protein production (Van der Poel, 2013).

- What do you consider as the main opportunities for seaweed proteins in the feed industry (which animals and in which forms)?

- And which seaweed species, Laminaria, Palmaria and Ulva, show the greatest potential?

Additional comments:

Section 6 Expected revenues

7. Market value of seaweed (proteins) in the **food industry**.

- a) In case of the market value of whole seaweeds. Which seaweed species do you expect to deliver the highest market value per tonne (D.M.): Laminaria, Palmaria, or Ulva?

☐ Laminaria

☐ Palmaria

☐ Ulva

- b) In case of the market value of seaweeds proteins. Which seaweed species do you expect to deliver the highest market value per tonne (D.M.): Laminaria, Palmaria, or Ulva?

☐ Laminaria

☐ Palmaria

☐ Ulva

- c) Little literature was available about the market values of seaweed and seaweed proteins. Regarding whole seaweeds I could find the following values in literature (not specifically for the Dutch market):

Market value of whole seaweeds in €/kg.

	Laminaria (€/kg)	Palmaria (€/kg)	Ulva (€/kg)
Wet	1 – 1.15	0.50 – 1.20	0.30 – 1.15
Wholesale (bulk)	10 – 16	16 – 19	–
Retail	60 – 120	57 – 106	45 – 90

Based on this information, what do you think is a good reflection of the market value for seaweed in the Dutch market?

Market value of whole seaweeds in €/kg.

	Laminaria (€/kg)	Palmaria (€/kg)	Ulva (€/kg)
Wet			
Wholesale (bulk)			
Retail			

- d) Now focussing on the seaweed proteins. I could find no data on market values of these proteins. Therefore, I tried to estimate the market values based on comparable protein sources: protein containing waste residues, microalgae, and soy proteins. This resulted in the following data overview:

Market value of protein sources in €/kg.

	Laminaria (€/kg)	Palmaria (€/kg)	Ulva (€/kg)
Waste residues			
Protein bulk fillers	2 – 4	2 – 4	2 – 4
Technical functional proteins	4 – 10	4 – 10	4 – 10
Specific functional proteins	10 – 20	10 – 20	10 – 20
Microalgae			
Food supplement	50	50	50
Food supplement (bulk)	5	5	5
Retail (websites)	104 – 299	104 – 299	104 – 299
Soy proteins*			

Soy flour (40% protein)	–	0.80	0.80
Concentrated	–	2	2
Isolated	–	3	3

* Only Palmaria and Ulva will be compared with soy proteins, since they have more or less the same protein content.

Based on this information and your experiences, what would be a suitable price for seaweed proteins per kg, for Laminaria, Palmaria, and Ulva:

e) Laminaria

On which of the following protein sources can the market value of Laminaria be based best?

☐ Waste residues ☐ Microalgae ☐ Soy proteins

And based on this, what would you expect to be the market value of a kg seaweed proteins (in €):

☐ € 0 – 2 ☐ € 2 – 6 ☐ > € 6

More specifically and why: €, because

f) Palmaria

On which of the following protein sources can the market value of Palmaria be based best?

☐ Waste residues ☐ Microalgae ☐ Soy proteins

And based on this, what would you expect to be the market value of a kg seaweed proteins (in €):

☐ € 0 – 2 ☐ € 2 – 6 ☐ > € 6

More specifically and why: €, because

g) Ulva

On which of the following protein sources can the market value of Ulva be based best?

☐ Waste residues ☐ Microalgae ☐ Soy proteins

And based on this, what would you expect to be the market value of kg seaweed proteins (in €):

☐ € 0 – 2 ☐ € 2 – 6 ☐ > € 6

More specifically and why: €, because

8. Market value of seaweed (proteins) in the **feed industry**.

- a) In case of the market value of whole seaweeds. Which seaweed species do you expect to deliver the highest market value per tonne (D.M.): Laminaria, Palmaria, or Ulva?

☐ Laminaria

☐ Palmaria

☐ Ulva

- b) In case of the market value of seaweeds proteins. Which seaweed species do you expect to deliver the highest market value per tonne (D.M.): Laminaria, Palmaria, or Ulva?

☐ Laminaria

☐ Palmaria

☐ Ulva

- c) Little literature is available about the market values of seaweed and seaweed proteins. Regarding whole seaweeds I could find the following values (not only for the Dutch market):

Market value of whole seaweeds in €/tonne.

	Laminaria (€/tonne)	Palmaria (€/tonne)	Ulva (€/tonne)
Whole	0 – 360	122 – 360	49 – 360
Based on soy prices	–	300 – 410	300 – 410
Retail (websites)	4,000 – 13,000	4,000 – 13,000	4,000 – 13,000

Based on this information, what do you think is a good reflection of the market values for the Dutch market?

Market value of whole seaweeds in €/tonne.

	Laminaria (€/tonne)	Palmaria (€/tonne)	Ulva (€/tonne)
Whole			
Based on soy prices			
Retail (websites)			

- d) Now focussing on the seaweed proteins. I could find no data on market values of these proteins. Therefore, I tried to estimate the market values based on comparable protein sources: protein containing waste residues, microalgae, and soy proteins. This resulted in the following data overview:

Market value of protein sources in €/tonne.

	Laminaria (€/tonne)	Palmaria (€/tonne)	Ulva (€/tonne)
Waste residues	1,000 – 2,000	1,000 – 2,000	1,000 – 2,000
Microalgae	–	750	750
Soy proteins*			
Concentrated	–	2,000	2,000
Isolated	–	3,000	3,000

* Only Palmaria and Ulva will be compared with soy proteins, since they have more or less the same protein content.

Based on this information and your experiences, what would be a suitable price for seaweed proteins per tonne, for Laminaria, Palmaria, and Ulva:

e) Laminaria

On which of the following protein sources can the market value of Laminaria be based best?

- ☐ Waste residues ☐ Microalgae ☐ Soy proteins

And based on this, what would you expect to be the market value per tonne seaweed proteins (in €):

- ☐ € 0 – 500 ☐ € 500 – 1,500 ☐ > € 1,500

More specifically and why: € ..., , because

f) Palmaria

On which of the following protein sources can the market value of Palmaria be based best?

- ☐ Waste residues ☐ Microalgae ☐ Soy proteins

And based on this, what would you expect to be the market value per tonne seaweed proteins (in €):

- ☐ € 0 – 500 ☐ € 500 – 1,500 ☐ > € 1,500

More specifically and why: € ..., , because

g) Ulva

On which of the following protein sources can the market value of Ulva be based best?

- ☐ Waste residues ☐ Microalgae ☐ Soy proteins

And based on this, what would you expect to be the market value per tonne seaweed proteins (in €):

- ☐ € 0 – 500 ☐ € 500 – 1,500 ☐ > € 1,500

More specifically and why: € ..., , because

Additional comments:

Section 7 Market forecast

9. What is your opinion about the role of biorefinery in the future?

10. What are the main factors influencing the role of biorefinery for seaweed (proteins) in the market (technical, financial, etc.)?

11. What kind of companies will be interested in seaweed proteins? Mainly in the food, feed or technical industry?

12. What are the main obstacles to be overcome to use seaweed proteins in the food, feed and technical industry?

Additional comments and tips for further research:

Thank you for your time.

The business perspective of the seaweed (protein) market and the expected revenues

Business expert interview

Topic overview

Section		Page
1	General introduction	1
2	Introduction and market background	2
3	Location of seaweed cultivation	3
4	Applications of seaweed proteins	4
5	Market value and margins	5
6	Market forecast	7

Section 1 General introduction

Thank you for your time to participate in my thesis research.

In my thesis I am looking to offshore seaweed cultivation, the market background, expected production costs, applications of seaweed proteins and the expected revenues. The focus of my research is on seaweed species native in the North Sea: Laminaria, Palmaria, and Ulva.

The purpose of this interview is to gain a deeper understanding of the market developments and revenues of seaweed (proteins) from offshore seaweed cultivation and to verify the data found in literature on market values of seaweed (proteins).

The results from this interview will provide supportive information for the economic evaluation of seaweed (proteins) from offshore cultivation.

This interview will take about 30 to 45 minutes.

Section 2 Introduction and market background

13. Description of the market situation regarding the current use of seaweed.

b) What is the main Dutch industry in which seaweeds are currently used:

- ☐ Food industry ☐ Feed industry ☐ Technical industry

c) The seaweed types used in these sectors are mainly:

- ☐ Red seaweeds ☐ Brown seaweeds ☐ Green seaweeds

14. In which of the following segments is your company active:

- ☐ Food industry ☐ Feed industry ☐ Technical industry

15. Your view on the seaweed market as: growing, in decline, or remaining steady :

c) In the next 3 years:

- ☐ Growing ☐ Declining ☐ Steady

d) In the next 10 years:

- ☐ Growing ☐ Declining ☐ Steady

Additional comments:

Section 3 Location of seaweed cultivation

16. Location of seaweed cultivation and seaweed species.

e) Which location do you think is most suitable for seaweed cultivation destined to your products?

☐ Onshore

☐ Nearshore

☐ Offshore

f) And in which type of seaweed are you most interested?

☐ Brown seaweeds

☐ Red seaweeds

☐ Green seaweeds

g) Do you think is it possible to cultivate the seaweed you need at the North Sea?

☐ Yes

☐ No

Why do you think so:

h) What do you consider as the main problems to use seaweed cultivated offshore on the long term (more answers possible)?

☐ Quality

☐ Costs

☐ Logistics

Other:

Additional comments:

Section 4 Applications of seaweed proteins

17. Which role could seaweed proteins play in your business? And what do you consider as the main opportunities of seaweed proteins in the food and feed market (supplements, functional ingredient, meat replacer, etc.)?

a) Own business:

-
-

This concerns mainly:

☐ Brown seaweeds

☐ Red seaweeds

☐ Green seaweeds

b) Food industry:

-
-

This concerns mainly:

☐ Brown seaweeds

☐ Red seaweeds

☐ Green seaweeds

c) Feed industry:

-
-

This concerns mainly:

☐ Brown seaweeds

☐ Red seaweeds

☐ Green seaweeds

Additional comments:

Section 5 Market value and margins

18. Market value of seaweed (proteins).

- a) In case of the market value of whole seaweeds, which seaweed species do you expect to deliver the highest market value per tonne (D.M.):

Food industry: ☐ Brown seaweeds ☐ Red seaweeds ☐ Green seaweeds
 Feed industry: ☐ Brown seaweeds ☐ Red seaweeds ☐ Green seaweeds

- b) The expected market value for whole seaweeds ready for consumption (per kg):

Brown seaweeds:

Food industry: ☐ < € 40 ☐ € 40 – 60 ☐ > € 60
 Feed industry: ☐ < € 2 ☐ € 2 – 4 ☐ > € 4

More specific:

Food industry: € ..,..
 Feed industry: € ..,..

Red seaweeds:

Food industry: ☐ < € 40 ☐ € 40 – 60 ☐ > € 60
 Feed industry: ☐ < € 2 ☐ € 2 – 4 ☐ > € 4

More specific:

Food industry: € ..,..
 Feed industry: € ..,..

Green seaweeds:

Food industry: ☐ < € 40 ☐ € 40 – 60 ☐ > € 60
 Feed industry: ☐ < € 2 ☐ € 2 – 4 ☐ > € 4

More specific:

Food industry: € ..,..
 Feed industry: € ..,..

- c) In case of the market value of seaweed proteins, which seaweed species do you expect to deliver the highest market value per tonne (D.M.):

Food industry: ☐ Brown seaweeds ☐ Red seaweeds ☐ Green seaweeds
 Feed industry: ☐ Brown seaweeds ☐ Red seaweeds ☐ Green seaweeds

- d) The expected market value for seaweed proteins (ready for use) per kg:

Brown seaweeds:

Food industry: ☐ < € 4 ☐ € 4 – 8 ☐ > € 8
 Feed industry: ☐ < € 0.50 ☐ € 0.50 – 1.50 ☐ > € 1.50

More specific:

Food industry: € ..,..
 Feed industry: € ..,..

Red seaweeds:

Food industry: ☐ < € 4

☐ € 4 – 8

☐ > € 8

Feed industry: ☐ < € 0.50

☐ € 0.50 – 1.50

☐ > € 1.50

More specific:

Food industry: € .., ..

Feed industry: € .., ..

Green seaweeds:

Food industry: ☐ < € 4

☐ € 4 – 8

☐ > € 8

Feed industry: ☐ < € 0.50

☐ € 0.50 – 1.50

☐ > € 1.50

More specific:

Food industry: € .., ..

Feed industry: € .., ..

e) What are the main factors influencing these market values:

-

-

f) How do you think the price of seaweed products and proteins will develop coming years (% increase per year)?

Products: ☐ < 0

☐ 0 – 2

☐ 2 – 4

☐ > 4

Proteins: ☐ < 0

☐ 0 – 2

☐ 2 – 4

☐ > 4

g) Which of your products do deliver the highest margin?

1.

2.

3.

h) Which seaweed products do you think will be most interesting in the next 10 years?

☐ Food

☐ Cosmetics

☐ Supplements

☐ Other

Additional comments:

Section 6 Market forecast

19. The development of the seaweed market.

- a) What is your opinion about the role of biorefinery in the future, so the extraction of multiple components (carbohydrates, proteins, etc.) out of the seaweed?

- b) What will be, according to you, the role of Dutch seaweed in the market according to you?

Additional comments and tips for further research:

Thank you for your time.

Annex B Expert information

Expert name	Background	Institute/company name	Interview date
Sander van den Burg	Scientific	Landbouw Economisch Instituut (LEI)	02-07-'14
Charon Zondervan	Scientific	Protein Competence Center (PCC)	02-07-'14
Jaap van Hal	Scientific	Energy Centre of the Netherlands (ECN) (n=1)	11-07-'14
Marinus van Krimpen	Scientific	Wageningen UR (ASG)	11-07-'14
Klaas Timmermans	Scientific	Koninklijk Nederlands Instituut voor Onderzoek der Zee (NIOZ)	15-07-'14
Wim Mulder	Scientific	Wageningen UR (FBR)	15-07-'14
Ana Lopez Contreras	Scientific	Wageningen UR (FBR)	15-07-'14
Job Schipper	Business	Hortimare	15-07-'14
Dorieke Goodijk	Business	CONO Kaasmakers	05-08-'14
Piet Bogaert	Business	Cargill	12-08-'14
Vincent de Vrind/ Martijn van der Kraan	Business	FeyeCon	13-08-'14
Kees Boender	Business	Your Well	14-08-'14
Ton Menken/ Sandra Rademakers	Business	Menken van den Assem	18-08-'14