

*Unlocking the potential of  
macroalgae for a thriving  
European blue  
bioeconomy*

2025



# Value chain analysis of selected SeaMark products

SEAMARK DELIVERABLE 8.5

Wageningen Economic Research



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# SEAMARK DELIVERABLE 8.5: VALUE CHAIN ANALYSIS OF SELECTED SEAMARK PRODUCTS

## OPEN ACCESS

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## Abstract

SeaMark aims to demonstrate how to scale up innovative seaweed cultivation and processing into price competitive product applications, making the entire supply chain attractive for commercial investments. This deliverable presents the value chain analysis for the SeaMark flagship products: P4 fibre, P5 pig feed supplement and P7 green alginates. The objective of the value chain analysis in SeaMark is to understand the cost of producing and processing seaweed into the flagship products and identify opportunities for cost reduction.

The analysis of the Ocean Rainforest (ORF) value chain showed that the biggest cost reduction can come from increasing processing capacity. This would allow for upscaling of harvesting and taking advantage of the full capacity of the boat and transport container in seaweed cultivation. Additionally, several costs can be reduced by upscaling production and producing to full capacity. This would decrease the costs associated with materials and depreciations of equipment as the throughput increases. The cost of energy is quite significant in the dried seaweed value chain at ORF as drying macroalgae is an energy-intensive process. The high cost of drying can be seen in both fibre (P4) and pig feed supplement (P5). Alternative energy sources and investments in newer drying technology should be explored.

Fibre (P4) is a byproduct of the fucoidan extraction. The product is currently made for pet food application, but human food is also considered. We considered the baseline value chain and a scaled-up value chain, assuming higher volumes, co-location and coordination with the farming process. The analysis demonstrated that upscaling is necessary for an economically viable valorisation of the residue from fucoidan extraction.

The analysis showed that two-thirds of the production costs of the pig feed supplement (P5) are from the acquisition of the materials, which are rapeseed, seaweed, and inoculum. The producers of the pig feed supplement, Fermentation Experts (FEXP), have only limited influence on these cost groups highlighting the importance of reducing cultivation costs which will eventually benefit downstream producers.

The two analyses relating to green alginates (P7) produced by Algaia (ALG) focused respectively on the cost of producing *Saccharina latissima* at Algolesko (ALO) and the expected change in the cost of producing alginates when shifting from current processing to a more environmentally friendly processing, the latter being called green alginates. Production of green alginates improves the market position of ALG and enables it to sell higher priced alginates while realising a reduction in the costs of inputs.

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## LIST OF ABBREVIATIONS

Abbreviation	Description
ALG	Algaia
ALO	Algolesko
FEXP	Fermentationexperts
MACR	Macroalgal Cultivation Rig
OCU	Ocean Cultivation Unit
ORF	Ocean Rainforest
TEA	Techno-Economic Assessment
TRL	Technological Readiness Level
Tmg	Thousand meters of grow line
SJO	Sjókovin
VCA	Value Chain Analysis
WW	Wet Weight
WP	Work Package

# 1. INTRODUCTION

The objective of the SeaMark project is to demonstrate how to scale up innovative seaweed cultivation and processing into price competitive product applications making the entire supply chain attractive for commercial investments. To reach this objective, it is essential to create innovations across the supply chain, and to understand where there is most potential for improvement to reach economic profitability. This deliverable is the fifth report from the work package (WP) titled ‘Conduct Techno-Economic and Socio-Economic Assessments’ and presents the value chain analysis for the flagship products. These are P4: Fibres; P5: Pig feed supplement and P7: Green alginates. The focus is on analysing the activities that contribute to the added value of these products and provide feedback regarding the identification of areas for improvements (Figure 1).

The analysis is based on the innovations and input from WPs 2 – 5. The report serves as the foundation for assessing SeaMark innovations on market potential (WP7), techno-economic and business analyses (WP8), life cycle assessments (WP9) and policy recommendations (WP10). The report is organised as follows: the next part outlines the methods applied in analysis and the general approach for the data collection. The subsequent part focuses on the specific flagship products, where the value chain analysis will be presented, and

Since the best estimate of the value created in the value chain is the cost associated with production, the value chain analysis in SeaMark will not do a full comprehensive value chain analysis, but focus on getting an understanding of the cost of producing and processing seaweed into the flagship products in relation to expected sales prices.

The analysed products in the SeaMark project are on very different Technological Readiness Levels (TRL). Some of the products are on a comparatively low TRL and the value chains

recommendations will be provided as to the potential for improvement. The final part brings together the analyses with discussion and concluding remarks.

# 2. METHODOLOGY

The term value chain analysis (VCA) captures a variety of approaches that aim to understand how a company or set of companies create value through processing inputs into end-products. Between activities, business units and firms there are links that need to be coordinated. The processes are strongly influenced by several external factors such as competitors, institutions, and the general business environment (AquaVitae D7.2). VCA can expose strategic and operational misalignments within chains, and the consequential misallocation of resources, and hence opportunities for improvements which create value and economic sustainability (Fearne et al, 2012).

The objective of the value chain analysis in SeaMark is to get an understanding of the cost of producing and processing seaweed into the flagship products, to determine the financial consequences of the innovation and identify areas for improvement. All the products are based on innovations developed in the SeaMark project and have European cultivated seaweed as an input.

must be considered immature as several innovations are needed to optimize the production processes. The approach taken allows the value chain analyses to feed into the techno-economic analyses in such a way that various cost-saving technological options can be analysed in a focused and meaningful manner. A more comprehensive description of the methodologies used to analyse each value chain is presented under the value chain sections.

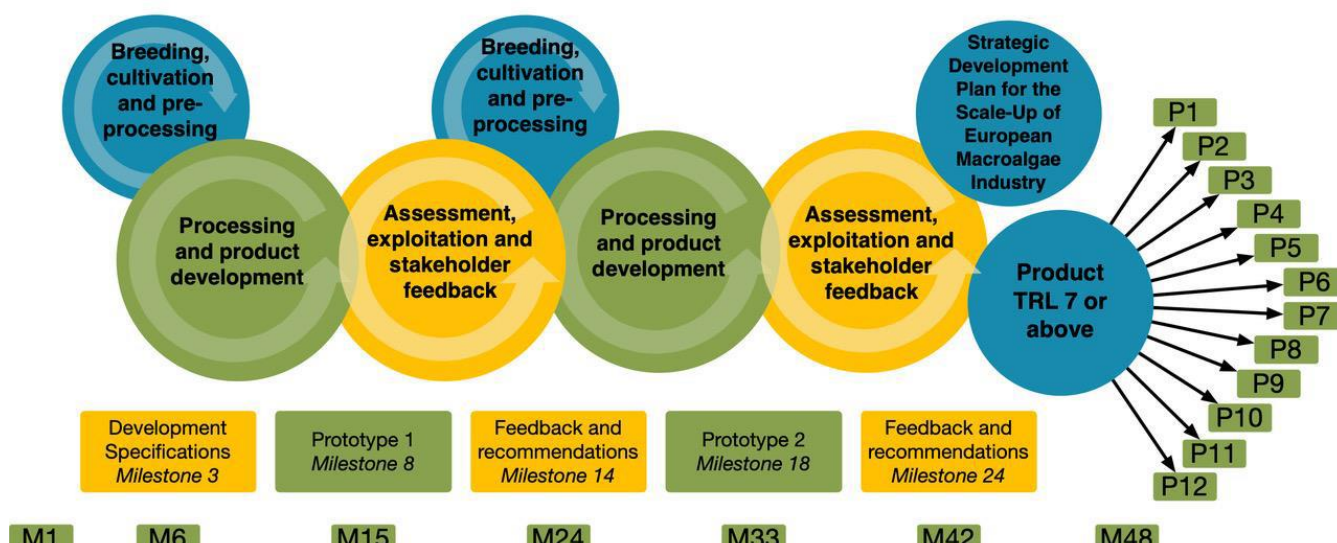


Figure 1: The SeaMark feedback loop model.

## 2.2 Fibre – Ocean rainforest and Oceanium (P4)

Data used in the value chain analysis of ORF was collected by Sjókovin (SJO) during two interviews in the preliminary VCA and one additional interview for the VCA in the second loop. SJO travelled to ORF facilities and carried out an informal interview with the key personnel at ORF on the 25<sup>th</sup> of September 2023. SJO collected exhaustive data on the costs associated with each step of the value chain. SJO carried out a draft analysis of the value chain and identified data gaps. During the second interview on the 4<sup>th</sup> of October 2023, SJO travelled to ORF facilities and presented the results of the draft analysis. ORF provided extensive feedback on the analysis and additional information regarding the data gaps and current ongoing strategies that can have the potential to reduce the costs of *Saccharina latissima* production. In addition to the two physical interviews, SJO kept an open dialogue with ORF and supplemented the analysis with additional data and feedback throughout the process.

The preliminary analysis and discussions with ORF highlighted areas where data collection in the company could be improved. ORF has since implemented changes to their timekeeping system which enables a better division of the labour hours and a more exact cost allocation to the various value chain activities. This has significantly improved the accuracy of the cost structure calculations as labour is a substantial cost in all three stages of macroalgae production. Thus, the VCA in the second loop benefits from even better data than the preliminary VCA.

The data for the second loop was collected during an online meeting with ORF on 5 May 2025. Following the meeting, ORF received a spreadsheet containing the preliminary VCA source data, which they could update with new information. Subsequently, SJO and ORF maintained an open dialogue to refine and validate the findings.

All calculations for the ORF part of the value chain have been performed using real numbers, however, to respect data confidentiality they have been indexed and expressed as percentages. A separate report showing the real numbers and costs in EUR/kg Wet Weight (WW) has been delivered separately to ORF for internal use.

The data for biorefinery stage of OCE was collected by Nofima with the help of a questionnaire that was completed by OCE. Missing parameters and values were obtained from the academic literature, reports, online databases, SeaMark partners' own experts and informants and external companies (such as equipment manufacturers). OCE could not disclose or did not yet have information on some of the key values such as the location of scaled-up demonstrator facility inputs specification and quantities and investment cost, due to the early stages of the project, which makes the results uncertain. For the second loop, several meetings were held with OCE representatives online, and the preliminary model was corrected and updated. There has been a change of the

flagship product from P1 Beta-glucan to P4 Fibre. The biorefinery model has also changed, where only 2 products are now made from *S. latissima*. Fucoidan is the main product, while fibre is a byproduct. This, however, did not affect the model significantly. In the second loop, we considered a baseline value chain and a scaled-up value chain with assumptions made on the effects of increased volumes, co-location and coordination with the farming process. Assumptions are discussed with OCE to design realistic scenarios.

## 2.3 Pig feed supplement – Ocean Rainforest and FEXP (P5)

Data collection for ORF is described above. Data used in the value chain analysis of FEXP was collected by SJO during an informal online interview. SJO sent out a request for data through an email two weeks before the interview, and during the online interview on 27 October 2023 discussed the strategy for the analysis and received requested data points. SJO carried out the preliminary analysis and presented it to FEXP during a second meeting on 1 November 2023. The value chain analysis has been a confidential process with only SJO having access to the raw data from ORF and FEXP, the results presented in this report have been carefully reviewed and approved by the two companies before being included in the report.

## 2.4 Green alginates – Algaia and Algolesko (P7)

For P7 Green Alginate, two partners needed to provide data: Algaia (ALG) and Algolesko (ALO). Between 6 and 9 September 2023 the team from Wageningen Social and Economic Research visited the partners from ALG in Saint-Lo, France. During this meeting, an informal interview was conducted and data collected. After the visit, a template for data collection was created and sent on 26 September 2023 to ALG. With ALO, a Teams meeting/interview was conducted on 26 September 2023 and a data template was sent.

From both partners, we received the requested data (for ALO; costs on 5-year basis in total output. For ALG: the changes in percentage for the new production). Additional clarification was needed from ALG per step. The draft analysis was sent separately on 1 November 2023 to the partners. Based on the provided data a cost analysis was done, followed by four possible scenario analyses.

In 2025, both companies were contacted to review the data provided. Two meetings were set up with ALG to review the data and clarify how recent insights impact the value chain analysis (1 April 2025 and 19 May 2025). This was followed by follow-up emails leading to the completion of the analysis.

The results presented in this report have been carefully reviewed and approved by the two companies before being included in the report.

The analyses of the cost structure in the different value chains, and the different companies' part of the value chains, have in

each case been adapted to the specifics of the value chain and the availability of data.

The results of the value chain analysis allow identification of the areas of possible optimisation. Typically, operations with largest cost share will be of the primary interest for optimization. However, the industry partners have also identified development initiatives that they prioritise. These initiatives will be investigated in the subsequent work in WP8.

### 2.5 Data accessibility and limitations

The variations in data collection did not allow for the same level of detail across the value chain analyses of all products. It is worth noting that the value chain analysis performed for ORF is a data-rich case allowing for a comprehensive analysis of the costs, however, the analysis does not include administration costs, this can be seen as a limitation as the real costs of producing the macroalgae at ORF may be higher.

The aggregated data received from FEXP did not allow for separating the costs between various value chain steps therefore limiting the ability to analyse the separate steps of the production process.

Analysis of the OCE's biorefinery part of the value chain for P4 is largely based on assumptions, as most of the details of production process are considered sensitive. However, the assumptions were discussed with OCE to produce realistic models.

In the analysis for ALO, due to reasons of confidentiality, the absolute numbers are not presented. Without presenting the absolute numbers of on cost of production, it is impossible to conduct a full value chain analysis for *S. latissima* produced by ALO and used by ALG to process green alginates (P7).

For the cost analysis for ALG we were not able to obtain data regarding the maintenance costs of new equipment required for the green transition. Consequently, the analysis does not include maintenance costs, difference between current equipment and the required equipment. Also, we did not incorporate the financial costs of the upfront investment in the analysis.

## 3. SACCHARINA LATISSIMA PRODUCTION IN THE FAROE ISLANDS: INPUT INTO FIBRES (P4) AND PIG FEED SUPPLEMENT (P5)

The value chains for the two products (P4) and (P5) begin with macroalgae cultivation in Faroe Islands at ORF's facilities. The two products share the same production steps including the hatchery, seeding, ocean cultivation unit (OCU) deployment, grow line deployment, and OCU and grow line maintenance, harvesting, and pre-processing, and only diverge at the point of product-specific processing. Therefore, the work presented in this section will describe in detail and analyse the part of the shared value chains steps and will subsequently connect with the part of value chains that are located at OCE (P4) and FEXP (P5). Firstly, concessive overviews of the two value chains are presented outlining the value chain steps and linkages between the companies and markets. Throughout the analysis, comparisons between the cost structure of dried macroalgae in (P4) and fermented macroalgae in (P5) will be made.

### 3.1 The Value Chain of Ocean Rainforest

The Faroese company ORF produces *S. latissima* in offshore and nearshore exposed conditions (Bak et al. 2020). The technology to cultivate kelp under exposed conditions in the Faroe Islands was designed, developed, and improved for over a decade and the structure was referred to as a Macroalgal Cultivation Rig (MACR). The company recently expanded the design of the cultivation rig, the new rig type is referred to as Ocean Cultivation Unit (OCU). Since 2016, the company has been implementing the multiple partial harvest method. This method allows for re-growth of the *S. latissima* from the same holdfast, avoiding the need for re-seeding after each harvest (Bak et al, 2018). ORF had a production capacity of 600 tonnes WW in 2022. ORF currently has licences on two fjords in the Faroe Islands, Funningsfjørður and Gøtuvík. In this section, the cultivation process of ORF will first be outlined before emphasis is placed on the processing.

### 3.2 Overview of the value chains for P4 and P5

The work carried out in D8.1 mapped out the supply chain that is the product flow and key processes carried out at ORF. The value chain analysis builds upon the supply chain mapping by analysing the cost structure associated with each step. Figure 2 illustrates the value chains of the two flagship products fibres (P4) and pig feed supplement (P5).

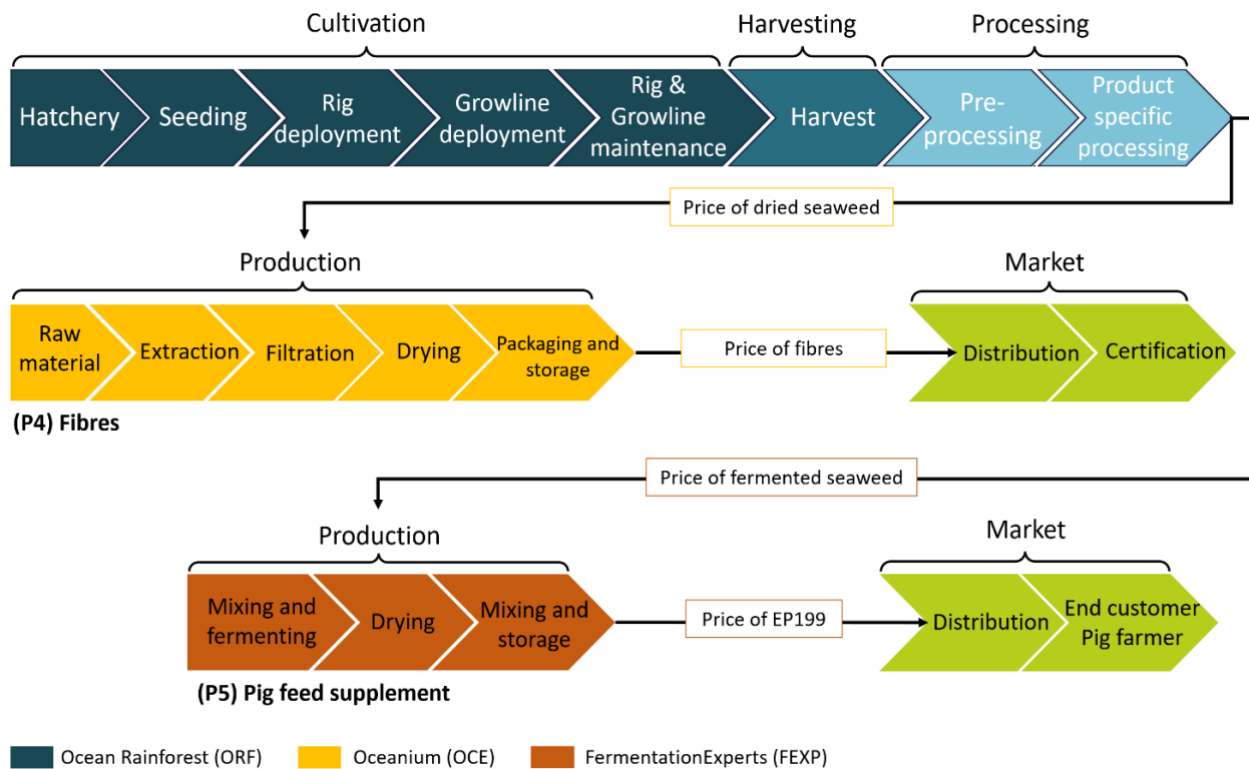


Figure 2: Overview of the value chain for fibres (P4) and pig feed supplement (P5) – Ocean Rainforest connection to Oceanium and Fermentationexperts.

The ORF value chain is presented in three stages: (1) Cultivation, which includes hatchery, seeding, cultivation unit deployment, grow line deployment, as well as grow line and OCU maintenance, (2) Harvesting, and (3) Processing, which includes pre-processing and product specific processing (Figure 2). Dividing the value chain into three sections (cultivation, harvest, and processing) provides us with an opportunity for potential future cost comparisons of the cultivated and wild-harvested macroalgae.

Cultivated macroalgae is a major cost component in both fibres (P4) and pig feed supplement (P5) value chains. Cost reduction in these value chains will be highly dependent on reducing the cost of macroalgal cultivation at ORF. Therefore, while we analyse and discuss other cost categories such as labour, energy and equipment cost located in P4 and P5 value chains the biggest part of the cost analysis taken place in the ORF value chain, and the cost of macroalgal cultivation travels up the P4 and P5 value chains.

The OCE part of the value chain is divided into five steps. Various cost categories including energy are discussed within the context of the entire value chain. The costs of cultivation and costs of production at biorefinery are presented separately in the OCE biorefinery sections, however, cost and price of the *S. latissima* biomass link the two parts. Similarly, cost and price of the fibres product link the extraction and market part of the value chain.

There are three distinctive steps in the FEXP value chain: mixing and fermenting, drying, and mixing and storage. The data from

FEXP does not allow for an analysis of the individual steps in the value chain since the same labour is involved in all the steps of the production process and there is no detailed data on the individual steps. Nevertheless, the steps have quite distinct inputs, e.g. ‘Mixing fermenting’ step uses rapeseed, macroalgae and inoculum while ‘Drying’ uses almost all the energy input, therefore, the lack of separation does not limit the analysis in any substantial way.

### 3.3 Ocean Cultivation Unit (OCU) as the unit of measurement (ORF)

The value chain analysis will start by analysing the cost structures at ORF, where the analysis is performed using Ocean Cultivation Unit (OCU) as a common unit of measurement between the ORF value chain steps. In this context, we calculate the current output and costs associated with each of the value chain steps needed to produce one OCU of macroalgae.

The following assumptions are made about the OCU:

- An OCU has a capacity of 82,5 thousand meters of grow line (tmg)
- 3 kg WW macroalgae per meter grow line
- 10 % defective and entangled lines annually
- The lifespan of the grow line is three years, during this time multiple harvests take place
- The lifespan of the OCU is six years for mainlines and buoys and ten years for anchors and chains

In the “Current Value Chain” section of the report, we present the costs associated with the current set-up of the value chain, which is a company with five operating OCUs. In addition to the current cost structure, we present the cost structure development as the company expands beyond the five OCUs.

Considering a production capacity of 82.5 tmg the potential harvest is calculated in the following way:

$$82.5 \text{ tmg} \times 3 \text{ meter yield} \times 3 \text{ year grow time} \times 10\% \text{ loss due to defective grow lines} = 223 \text{ tons annually}$$

### 3.4 Cultivation

Costs presented in this section are associated with the cultivation of *S. latissima*.

#### 3.4.1 Hatchery

Hatchery is the first step in the ORF value chain, it involves the spore release and culture. In 2023, ORF expanded the production capacity from 250 thousand meters of grow lines (tmg) to 800 tmg. An increase in the production capacity from 250 to 800 tmg required an additional staff member, currently, there are three full-time staff working at the hatchery. Reaching an actual production of 800 tmg will not require additional staff members, meaning that as the production volumes increase the labour cost from hatchery per kg WW will decrease.

Due to the recent scale-up, ORF incurred an investment which will depreciate over a 10-year period. The investment covers the cost of a new container and equipment including shelves and lamps. Each container uses the same size cooling equipment despite one container being twice the size, the electricity utilisation is 400kWh per day for two containers. The hatchery has substantial fixed costs in the form of buildings, equipment, energy, and basic hatchery staff. These are to a wide degree not related to the level of production and are held constant within the context of a production capacity of 800 tmg meaning that regardless of the production size, there is a large startup and the per unit cost will fall drastically as production increases towards the capacity limit of 800 tmg (**Error! Reference source not found. 4**). Thus, the increased production in the hatchery will contribute greatly to the falling production cost of macroalgae.

In addition to the costs above, there are two types of costs which are scalable in line with the actual production volume. These are the lab equipment (materials) and microbiological analysis (other) costs which will increase according to the production volume.

### Hatchery - production costs structure

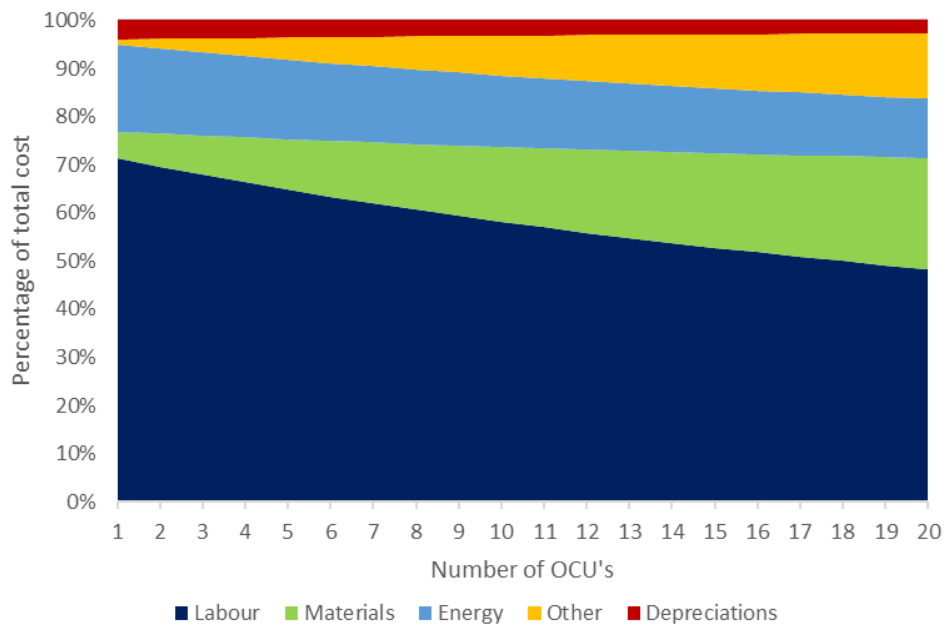


Figure 3: Hatchery - Cost structure and development.

### Hatchery - Production Cost- Index

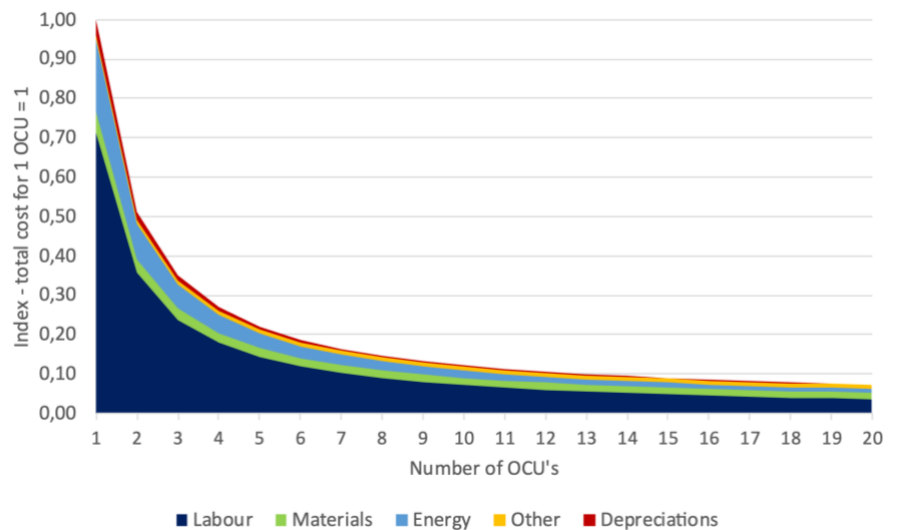


Figure 4: Hatchery production cost - Index (Cost for 1 OCU = 1) - ORF.

The baseline indexed cost of hatchery for one OCU is 1. The production cost per kg WW macroalgae will fall below 10% of the initial cost as production volume increases beyond 13 OCUs.

The cost structure in the hatchery will change as production increases (Figure 3). Labour costs are from the offset around 70% of total costs, however, they will fall below 50% as production increases. We can expect that the costs of lab equipment (materials) and microbiological analysis (other) will become significant as production increases indicating potential areas of focus in the future for cost reduction.

### 3.4.2 Seeding

The seeding is partially mechanised with a seeding machine (The SeaSeeder) and requires a degree of manual labour. The SeaSeeder seeds the ropes with a mixture of gametophytes/ sporophytes and glue, the rope is pre-cut into 11m pieces. The final cutting of the rope happens on board the boat.

The baseline indexed cost of seeding one OCU is 1. The current cost of seeding is around 64% of the baseline seeding cost. The SeaSeeder cost is approximately 20% of the total seeding cost at a production level of 5 OCUs and will be depreciated over 6 years. Due to the high initial investment cost the cost of the machine makes a small production of grow lines uneconomical. As the production of grow lines increases, the per kilo cost of the SeaSeeder will fall substantially.

The cost of ropes is currently the largest cost contributor in the seeding accounting for 82% of the total seeding cost (Figure 6) One can assume that the cost of ropes will decrease over time as the company's production volume increases. A 40% decrease in material costs is estimated to take place after ORF reaches a production volume of 10 OCUs – 2000 tons WW. The results of this analysis are presented in the section on cost-reducing initiatives.

consumption, and insurance cost. Both boat costs and labour are depreciated over 6 years. Material cost is by far the biggest contribution to the OCU deployment cost, accounting for 91% of the total cost.

The cost of grow line deployment is calculated based on labour hours and boat hours. The cost of material (rope and glue) is allocated to the seeding part of the value chain. The costs of labour and boat for grow line deployment are depreciated over 3 years.

### 3.4.4 OCU and grow line maintenance

Maintenance of one OCU requires approximately 94 labour hours and 15 boat hours per year. It is worth noting that the maintenance cost of the grow lines and OCU is almost as high as the annual cost of grow line deployment per kg WW. Combining all costs of the OCU and grow line deployment and maintenance, it is clear that material cost is by far the biggest share of the costs (77%) indicating a focus area for potential cost-reducing strategies (Figure 5).

Seeding - Growline Production Cost Index

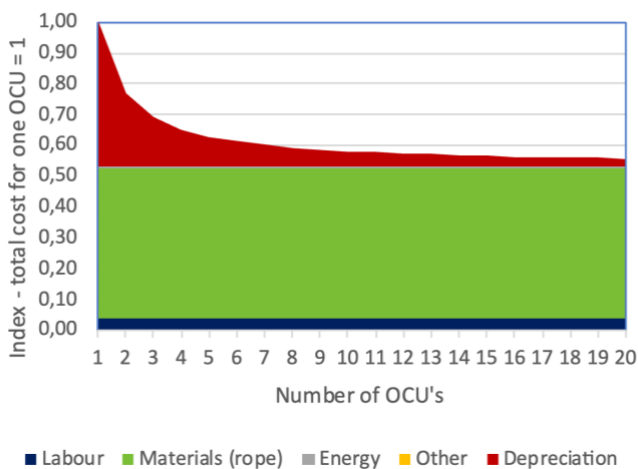


Figure 6: Seeding - Production Cost - Index (Cost for 1 OCU = 1) - ORF.

### 3.4.3 Ocean Cultivation Unit and grow line deployment

The cost of OCU deployment is calculated based on one Ocean Cultivation Unit (OCU). An OCU has 11 main lines of 750 meters each, it can hold up to 82.5 thousand meters of grow line (tmg). The OCU includes anchors, chains, mainlines, and buoys. The cost of anchors and chains is depreciated over 10 years, whereas the cost of mainlines and buoys is depreciated over 6 years.

The cultivation unit deployment involves manual labour both on land and at sea, approximately 70% of the work is carried out on land. The boat cost per hour is calculated based on the depreciation cost, maintenance cost, fuel costs and

Cost Structure: OCU and growline deployment and maintenance

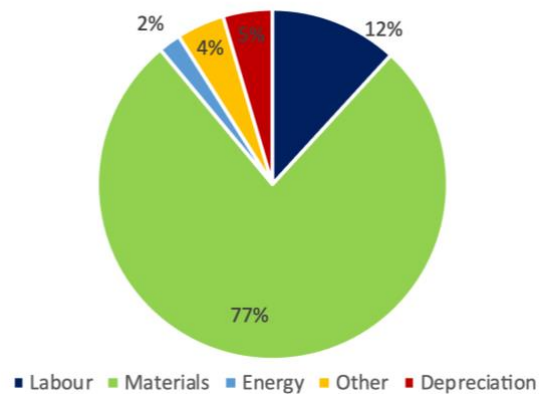


Figure 5: Cost structure of OCU and grow line deployment and maintenance (Percentages) - ORF.

### 3.5 Harvesting

On average 3500 kg WW of macroalgae can be harvested per harvest day, this requires the harvest of approximately 117 good grow lines with a length of 10m each. The average harvest per meter of grow line is calculated at 3 kg WW. Currently, the harvest is performed manually and typically involves three or four people. On occasion, the harvest has been performed with 2 or 5 people on board. The harvest capacity of the boat is 6000 kg WW, however, the maximum capacity at the processing facilities is 3500 kg WW a day which creates a bottleneck for the expansion of daily harvest.

The sources of costs in this part of the value chain are labour, boat, and transport. The labour costs involve travel to a site, harvesting, and cleaning of the boat and equipment. The boat cost per hour is calculated based on the depreciation cost, maintenance cost, fuel costs and consumption, and insurance cost. The transport cost from the harbour to processing facilities is outsourced and fixed per container.

The labour costs and boat costs can vary depending on the number of people on board and the hours it takes to harvest 3500 kg WW of macroalgae. Furthermore, the harvesting hours can be affected by the number of defective grow lines, it is estimated that approximately 10% of grow lines can be defective resulting in a need to harvest more grow lines to reach the 3500 kg WW capacity.

As the number of crew on board increases the number of grow lines harvested per hour increases. This results in a decrease in boat costs. However, the costs incurred from an additional crew member may outweigh the boat cost savings.

Labour accounts for the highest share of the harvesting cost (54%), and another significant share of the costs belongs to the category other (20%) (Figure 7), which is the transport of the macroalgae from the harbour to the processing facilities. Potential cost reduction can be made in this area when the company adopts mechanized harvesting and increases the daily harvest to at least 6000 kg WW (a boatload). Cost development after the introduction of mechanised harvesting and increased harvest are analysed in the focus section.

### 3.5.1 Pre-processing

On a typical working day, the labour activities in the pre-processing are split in the following way: one person operates the forklift, one person washes the macroalgae, and one person sorts and screens the macroalgae for debris and stones.

The costs associated with pre-processing consist of equipment including a forklift, washer and belts, energy costs, and labour costs. The pre-processing equipment is depreciated over six years.

### 3.5.2 Product specific processing

Up to this point of the value chain, the costs of producing biomass for the dried and fermented macroalgae are identical. This includes the hatchery, seeding, deployment, harvest, and pre-processing activities listed above. In addition to these activities, the processing facilities need to be cleaned after each processing day, this activity is outsourced at a fixed daily cost. From this point onwards the value chains for dried (P4) and fermented (P5) macroalgae diverge as they require different processing steps.

After the macroalgae is screened and sorted (the last step of pre-processing) one person spreads and stacks a proportion of the macroalgae on trays in preparation for drying, and one person grinds the remaining macroalgae in preparation for fermentation.

#### *Dried macroalgae (input into P4 – fibres)*

The processing steps for the dried macroalgae are illustrated in Figure 9. The main costs in the processing of dried macroalgae are labour, electricity, maintenance and the

Cost Structure: Harvesting

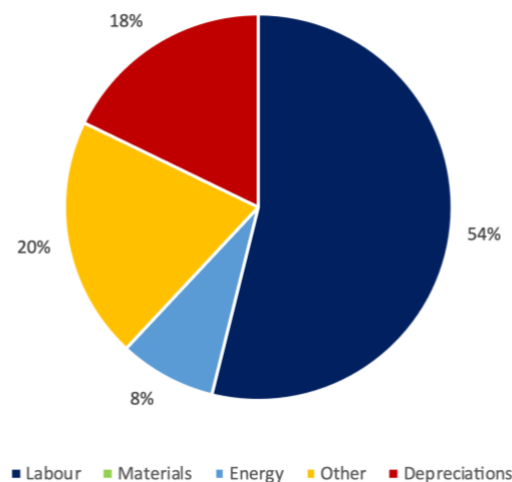


Figure 7: Cost structure: Manual Harvest with four people on board – ORF (Other Transport cost from harbour to processing facilities).

depreciation of the dryer and grinder. The drying process is both labour and energy intensive.

The dried macroalgae are spread on trays and placed in the dryer for 48h hours – the dryer has a capacity of 1000kg WW – which results in 100kg of dried macroalgae. The 100 kg batch is then moved to the post dryer, this step requires one person for one hour.

The trays are then emptied and the dried macroalgae is ground and packaged into different sizes according to customer needs. On average it takes approximately one hour to grind 75kg of dried macroalgae. Grinding and packaging 350 kg WW of dried macroalgae requires three persons for a duration of three to four hours. The drying trays are washed regularly, this is done twice a month and requires two people for two days.

#### *Fermented macroalgae (input into P5 pig feed supplement)*

The processing steps for the fermented macroalgae including the shipping to the customer are illustrated in Figure 8. After the macroalgae is ground into small pieces it is ensiled in IBC tanks and mixed with lactic acid and sugar. This process is not labour or energy intensive and the largest cost comes from purchase of lactic acid and sugar and maintenance cost of the grinder.

The cost structure of pre-processing and processing for dried and fermented macroalgae is shown in Figure 10. The baseline index cost is the pre-processing (labour, energy, other, depreciation) = 1, product-specific processing of the fermented macroalgae is 50% of the baseline costs, while the product-specific processing of dried macroalgae is 946% of the baseline cost. The total cost of processing dried macroalgae is substantially higher than the cost of processing fermented macroalgae.

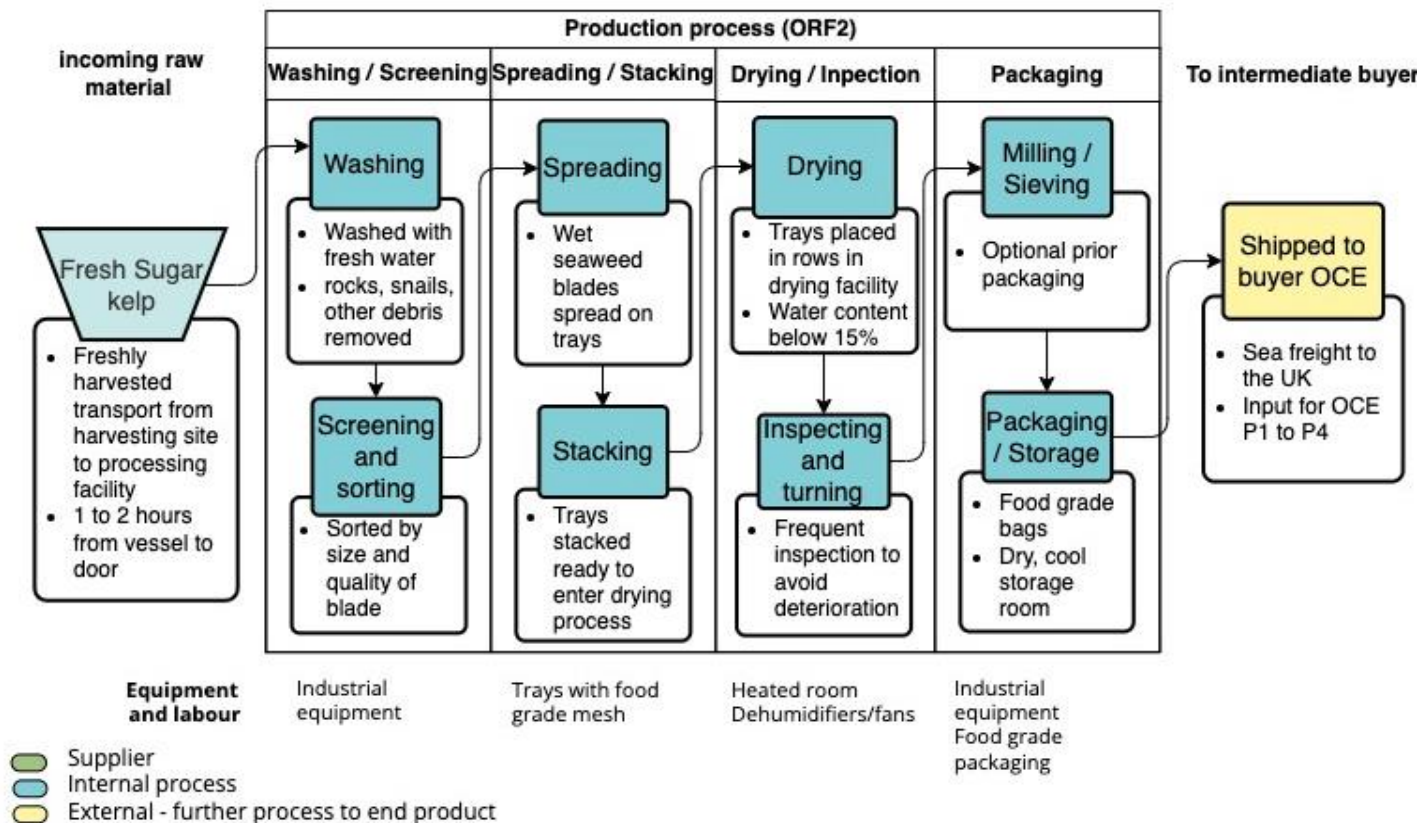


Figure 9: Flow chart for processing of dried macroalgae at ORF to be delivered to P4 – fibres.

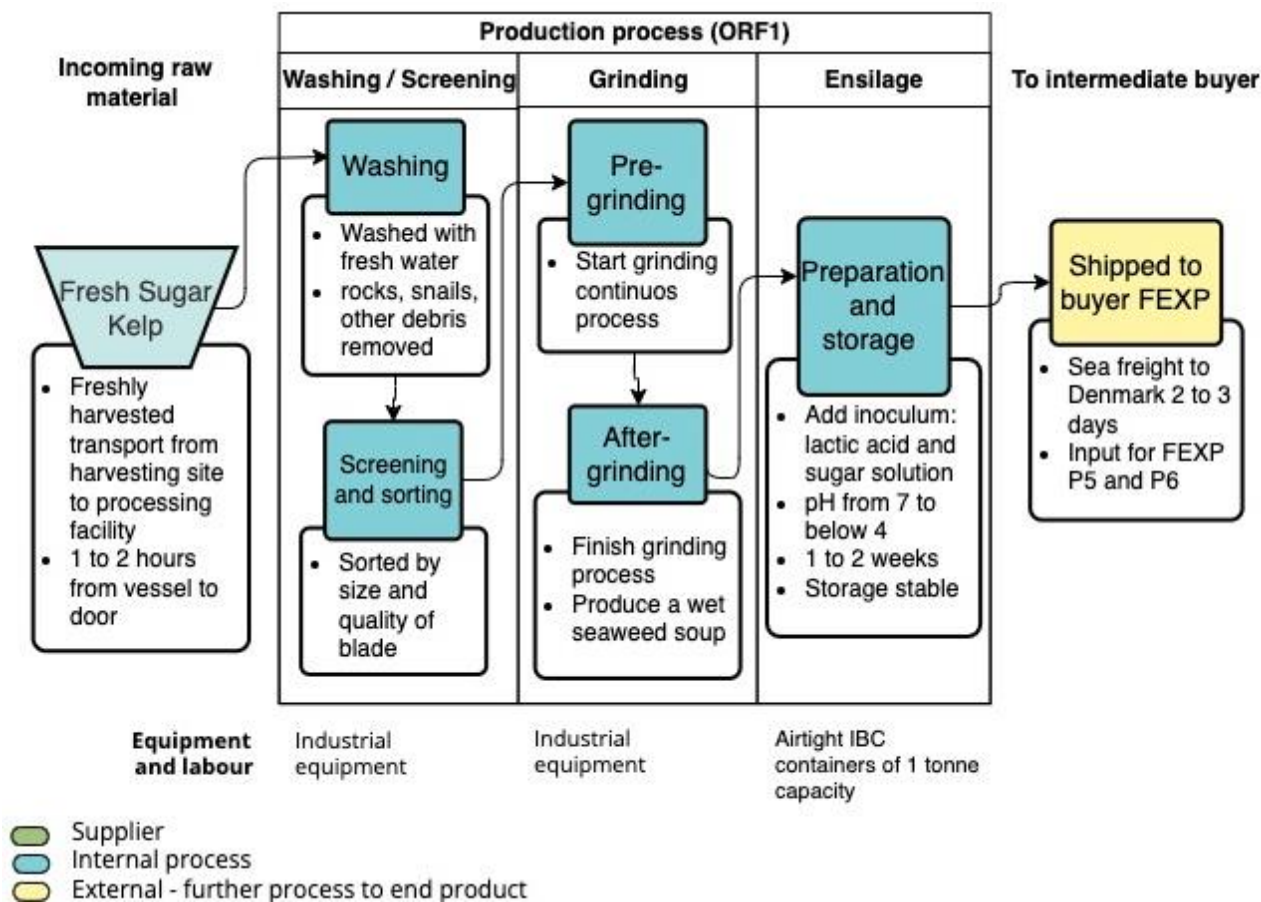


Figure 8: Flow chart for processing fermented *S. latissima* at ORF's processing facility destined for the pig feed supplement (P5).

This is largely caused by the high labour costs. Labour accounts for 26% of the total pre-processing costs which is identical for both dried and fermented macroalgae, 69% of the processing cost for dried macroalgae and 65% of the cost for fermented macroalgae. The category "other" in pre-processing is the outsourced cleaning of the processing facilities and maintenance cost of the forklift and washer, these account for 58% of the total pre-processing costs. The category "other" in the processing of dried macroalgae includes maintenance of the dryer and grinder. In the processing of fermented macroalgae "other" includes lactic acid and sugar used in the fermentation process and maintenance cost of the grinder.

### 3.5.3 Focus on labour in processing

Labour is a significant contributor to both dried and fermented macroalgae, breaking down the costs into specific labour tasks provides a better understanding of the costly processing

activities. Figure 11 illustrates the labour cost allocation between the various pre-processing and product-specific processing steps. As illustrated the costs of the pre-processing labour activities coloured in blue are identical for the dried and fermented macroalgae, and for the dried macroalgae they constitute a small proportion of the total labour cost of processing.

The current drying methods require manual labour at each step of the product-specific processing making this part of the value chain very costly. 96% of the labour cost for processing is in the product-specific processing steps (Figure 11).

The product-specific processing steps for fermenting macroalgae are not as labour-intensive, whereby in this case, 55% of the processing labour costs are allocated in the product-specific processing steps.

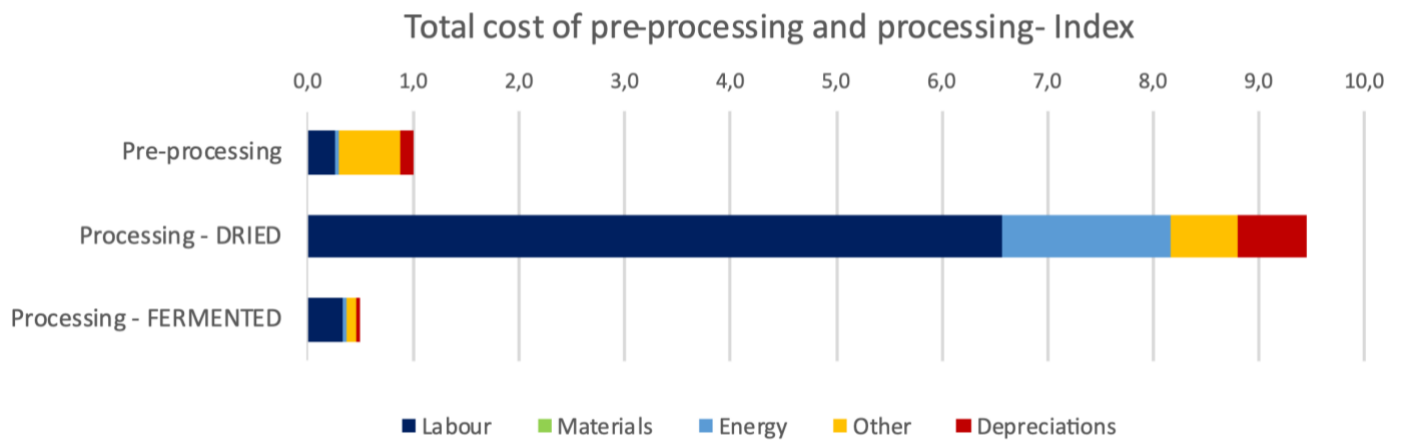


Figure 10: Total cost of pre-processing and processing of dried and fermented macroalgae.

### 3.6 Cost-reducing initiatives in the ORF value chain

Figure 11 shows the labour cost associated with the different processing steps according to the current set-up. During the value chain analysis and interview process several ongoing and planned cost-reducing initiatives have been identified:

- Decreased material cost.
- Mechanised harvesting.
- Increased processing capacity.
- Increased yield.

In this section, we analyse how each of the initiatives can contribute to cost reduction along the steps of the value chain. The results are summarised in **Error! Reference source not found..**

#### 3.6.1 Decreased material cost

As the company continues to upscale and the production volumes increase, a reduction in the cost of materials can be anticipated. ORF estimates a potential 40% reduction in material costs when the company reaches a higher production capacity and can buy ropes, chains, buoys, and anchors in bulk. Currently, the cost of material accounts for 85% of OCU

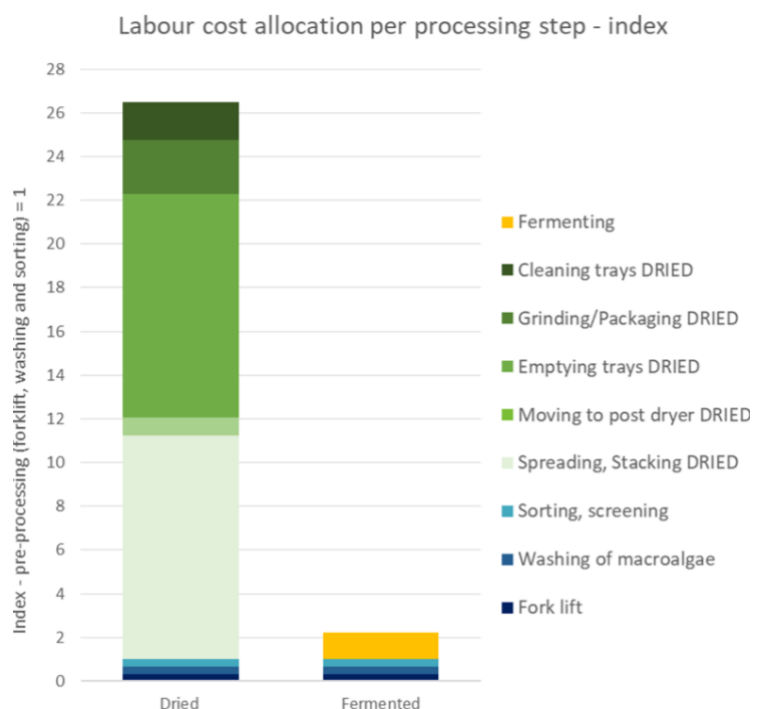


Figure 11: Labor cost allocation per processing step. Index - pre-processing (forklift, washing and sorting) = 1 - ORF.

Table 1: Cost-reducing initiatives and their effects on the ORF value chain.

	Baseline - current cost	Increased yield	Decreased material cost	Mechanised harvesting	Increased processing capacity	Total cost reduction
<b>Cultivation</b>	0%	-33%	-18%	0%	0%	<b>-45%</b>
<b>Harvesting</b>	0%	0%	0%	-58%	-73%	<b>-73%</b>
<b>Pre-processing</b>	0%	0%	0%	0%	-69%	<b>-69%</b>
<b>Processing</b>	0%	0%	0%	0%	-46%	<b>-46%</b>
<b>Total reduction</b>	<b>0%</b>	<b>-15%</b>	<b>-8%</b>	<b>-18%</b>	<b>-38%</b>	<b>-58%</b>

deployment and a 40% cost reduction in this area could have a significant effect on the total cost of cultivating macroalgae.

### 3.6.2 Mechanised Harvesting

ORF is experimenting with mechanised harvesting, which will allow fewer persons aboard the vessel to harvest larger quantities of macroalgae in a shorter time. This will mainly affect the harvesting time, thereby reducing the cost of harvesting, but can also allow for a larger quantity of macroalgae to be harvested in a working day. The calculations here are based on harvesting 125 grow lines per hour compared to 25 grow lines per hour. In addition, there is assumed a reduction in the crew from 4 to 3 people on the vessel.

### 3.6.3 Increased processing capacity

The processing capacity is currently a limiting factor in both the harvesting and the processing part of the value chain. Currently, the processing capacity is limited to around 3500-4000 kg of wet-weight macroalgae per day. The boat can load 6000 kg of macroalgae per trip and the transport from the harvesting site to the factory can load 12000 kg of macroalgae. Therefore, the calculations are based on increasing the processing capacity to 12000 kg per day, which would require two harvests per day.

An increase in the throughput would also reduce the harvesting cost since the increased harvesting would allow for the boat to be more fully utilised.

The calculations are based on the same amount of labour as is currently deployed but with a substantial increase in the equipment cost.

### 3.6.4 Increased yield

Selective breeding makes it possible to increase the yield of macroalgae on the grow lines. Currently, the yield is around 3 kg per meter grow line and the calculations assume a 50% increase in the yield to 4.5 kg per meter grow line. This would significantly reduce the cost of cultivation.

### 3.7 Effects of the proposed initiatives on ORF value chain steps

Table 1 shows the effect of cost-reducing initiatives on the different parts of the ORF value chain. An increase in per kg yield by 50% would reduce the cost of cultivation by 33%. Distributing the cost of cultivation on a larger quantity of output would decrease the per unit cost.

A 40% decrease in the cost of materials alone would reduce the cost of cultivation by 18%. The cost of producing the grow lines and deploying the OCU are both reduced by around 1/3 compared to the baseline, while the costs of the hatchery and

the deployment and maintenance of grow lines are not affected by the reduced material cost.

Introducing mechanised harvesting would significantly decrease the cost of harvesting by 58%. The effect would both come from the reduction in labour involved in harvesting and from the reduction in boat hours spent on the activity.

An increase in the processing capacity would allow for a larger quantity of macroalgae to be harvested on a working day. Going from 3500 kg WW to 12000 kg WW a day would mean that the boat could be fully utilised by doing two trips with a full boatload of 6000 kg each. The calculations are based on mechanised harvesting which implies that the effect of the increased processing capacity comes in addition to the effects of mechanised harvesting. The combined reduction from mechanised harvesting and the increase in processing capacity would reduce the cost by 73%.

An increase in the processing capacity would also lead to a decrease in pre-processing and processing costs, by 69% and 46% respectively. The decrease in cost comes from reduced labour costs, since a higher throughput would require larger equipment and hence increased depreciations and energy cost. The total cost reduction of increasing the processing capacity would be around 38%. Out of the four proposed initiatives increasing the processing capacity would have the most significant effect on reducing the cost.

The overall total cost reduction of 58% is based on a compounded effect since there is an interaction between the initiatives.

### 3.8 Sales prices and cost comparison

There is no real market price for fermented seaweed. The only available reference is the current sales price between ORF and FEXP for Product P5, which is not determined by supply and demand but rather a negotiated price designed to sustain ORF's supply. Both parties acknowledge in interviews that there is a need to reduce the cost of producing seaweed in order to lower the price and that the price is artificially high in the transitioning period.

Currently the price of fermented seaweed aligns with the production cost, leaving no profit margin and no contribution to the overhead expenses, such as administration and marketing.

Similarly, the price of dried seaweed from ORF to Oceanium for (P4 - Fibres) only covers production costs, meaning ORF supplies this product for zero profit.

This pricing structure underscores a critical challenge: reducing cultivation costs is essential to establishing a viable and profitable seaweed industry in Europe.

### 3.9 ORF Value chain - Conclusion and future focus areas

The value chain analysis performed in this report focused on quantifying the costs incurred by ORF at each step of the production. The costs were divided between eight value chain steps (Figure 12) and further grouped into three stages cultivation, harvesting, and processing. The costs were categorised into five cost categories: labour, material, energy, other, and depreciations. The analysis aimed to identify the costliest activities along the value chain and their cost structure. Several value chain activities were identified as areas with great potential for reducing costs and should be prioritised by the company to bring down the total cost of production.

The significant difference in the processing costs between dried and fermented macroalgae results in different cost structures for the two value chains (Figure 12 and 13). For the

fermented macroalgae, a clear focus is the cost of harvesting which accounts for 31% of the total production cost. Combined costs of cultivation account for 44% of the total cost. The biggest contributors to this cost are the hatchery, OCU deployment and seeding – the cost for these three value chain steps is largely made up of material costs and labour. Finally, the third area which contributes substantially to the total cost of fermented macroalgae is the pre-processing, it accounts for 17% of the total cost and its main cost drivers are labour and “other” which is the outsourced cleaning of the processing facilities and maintenance of the grinder.

The category ‘Other’ consists of: Hatchery – microbiological testing, Rig and Growline Deployment and Maintenance – boat maintenance and insurance, Harvesting – transport cost, pre-processing – outsourced cleaning, Processing – lactic acid, sugar, and maintenance cost.

While the dried macroalgae value chain would require cost-reduction initiatives in the same areas as the fermented macroalgae value chain, the large costs associated with processing cannot be overlooked (Figure 13). Processing of macroalgae alone accounts for 64% of the total production cost, making it the costliest part of the value chain.

## Current value chain for fermented macroalgae

Cost expressed as a % of total cost of producing fermented macroalgae

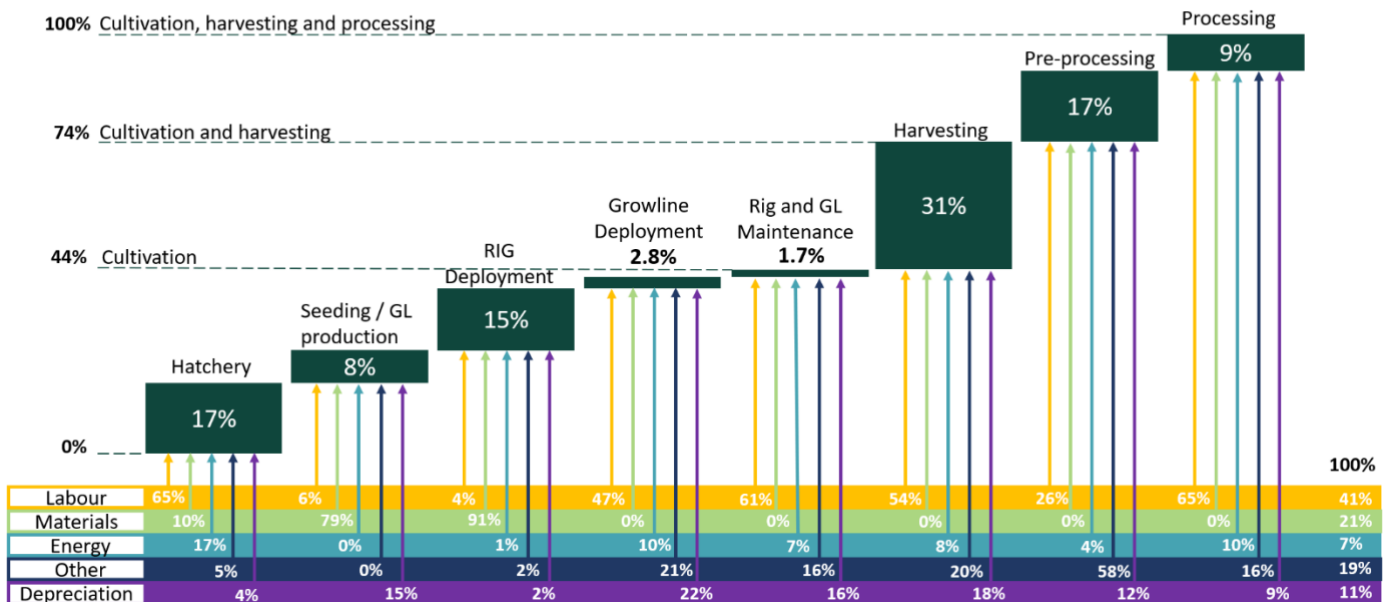


Figure 12: Current value chain for fermented macroalgae

## Current value chain for dried macroalgae

Cost expressed as a % of total cost of producing dried macroalgae

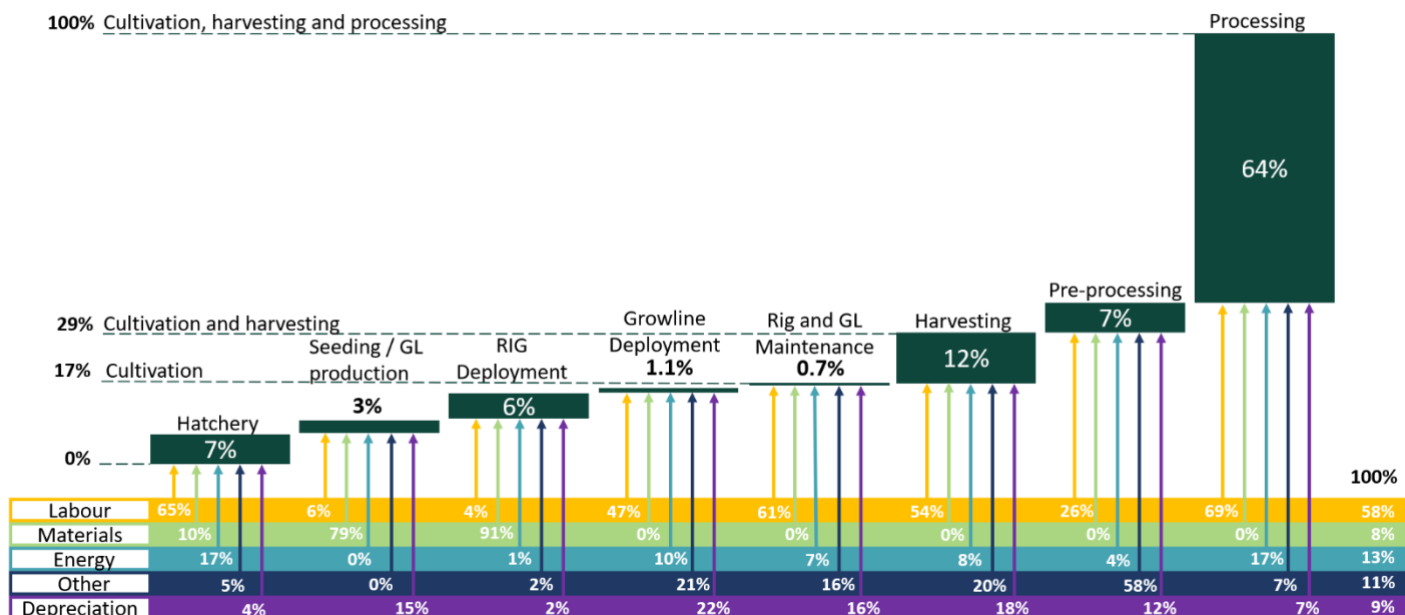


Figure 13: Current value chain for dried macroalgae Cost is expressed as a percentage of the total cost of producing dried macroalgae. Other (hatchery) – microbiological testing, Other (OCU and grow line deployment and maintenance) – boat maintenance and insurance, Other (Harvesting) – transport cost, Other (pre-processing) – outsourced cleaning, Other (Processing) – maintenance of dryer and grinder.

Labour is one of the cost categories that contribute greatly to the final cost of both dried and fermented macroalgae. It constitutes 58% of the total production cost of dried macroalgae and 41% of the total production cost of fermented macroalgae. High labour costs have been identified as a common challenge among macroalgae producers in Europe, and the efforts to bring down these costs are focusing on upscaling production and mechanisation of several value chain steps including harvesting and processing.

The analysis of cost-reducing initiatives allowed for the identification of areas where the initiatives would have the greatest potential to reduce costs in the long term. The biggest cost reduction comes from increasing the processing capacity, this would allow for upscaling the harvesting and taking advantage of the full capacity of the boat and transport container. Thus, increasing the harvested biomass would have a direct effect on reducing the costs of cleaning and transport without the need for near-future investment directed at expanding the boat and transport capacity or increasing the frequency of cleaning.

Material costs account for 21% of total fermented macroalgae production costs and 8% of the total costs for dried macroalgae. Reduction of material costs by 40% can be achieved by upscaling of the production.

Several cost categories can be reduced by simply upscaling the production and producing at full capacity. This would decrease the costs associated with materials and depreciations of equipment as the throughput increases. Furthermore, it would

enable the company to take advantage of the economics of scale that comes with expanding production and enable them to buy materials in bulk at a lower price.

The cost of energy is quite significant in the dried macroalgae value chain, the majority of the cost is located in the processing part of the value chain as drying macroalgae requires a high energy consumption.

## 4. FIBRE (P4)

### 4.1 Oceanium – Fibre product for food and pet food

Production of P1 Bioactive beta-glucan by OCE from *S. Latissima* supplied by ORF has not been successful due to the low amount of beta-glucan in the raw material. The preliminary techno-economic assessment (D8.3) demonstrated that process was not economically viable neither on its own or as one of the joint products (fibre, fucoxanthin). It was decided to change the flagship product to P4 - Fibre for further economic assessments in SeaMark.

The present analysis therefore provides an updated value chain analysis of the biorefinery with the focus on fibre for food and pet food applications. In addition, this chapter will consider a value chain for fibre that assumes production upscaling, co-location and vertical integration of biorefinery with macroalgae farming. This scenario is used to estimate socio-economic effects of seaweed sector in D8.4. As previously (D8.2, D8.3), the cultivation part of the value chain for P4 is covered in a separate section analysing *S. latissima* production at ORF farm (Figure 14).

### Fibres (P4)

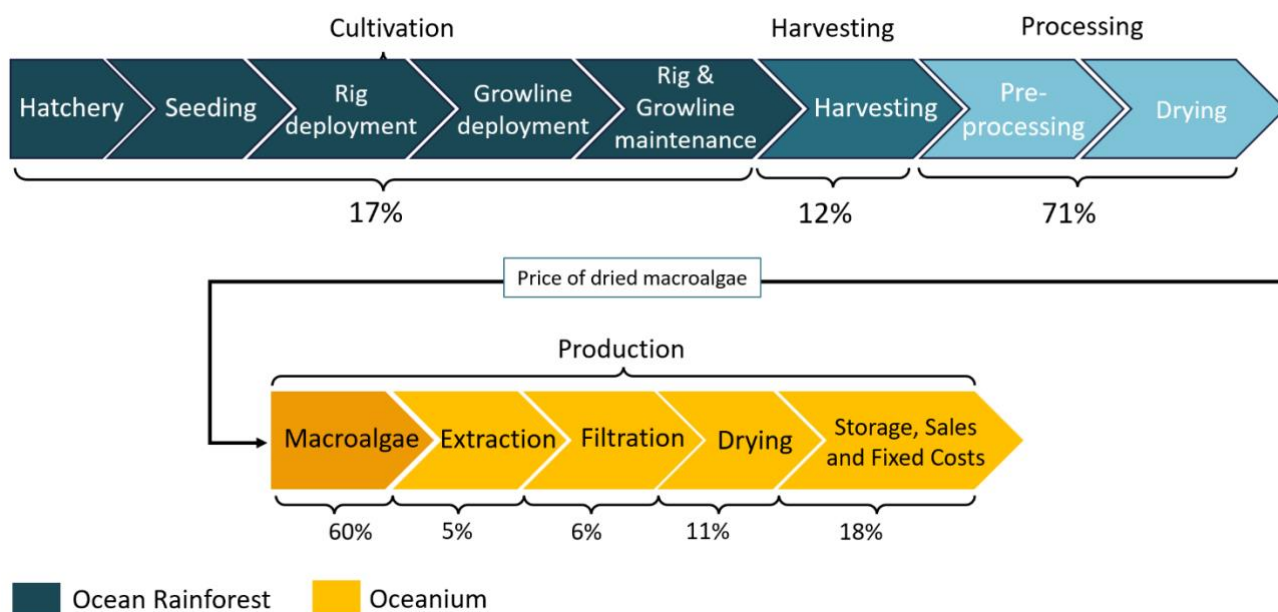


Figure 14: Summary of fibres (P4) value chain – ORF and OCE.

The updated cost model will consider cost on each production step with aggregation by cost types (fixed cost, labour, energy, inputs). Coupled with available estimates of market prices of fibre and fucoidan, this representation will allow analysis of value added and profitability along the value chain.

We grounded our assumptions in the available data to the extent possible. Sensitivity of the results to key parameters is considered. These parameters include prices of macroalgae and the end products, yields and the length of harvest season. Findings from the updated values chain analysis will be used to estimate profitability of the fibre production under selected technological options in an updated TEA for the biorefinery (D8.6, due M40).

OCEs current biorefinery concept implies two outputs: fucoidan and fibre for food/pet food. Fibre is a residual stream after the extraction of the main product (fucoidan) and has considerably lower market value. However, the volume is relatively high, enabling valorisation.

Depending on the species and processing methods fibre can have various properties and composition making it suitable to specific applications. There are, however, little experience on this type of valorisation of biorefinery byproduct. One of the published examples of fibre product from biorefined *S. latissima* (from wild stock) demonstrated that nutritional value was enriched in the optimized process making it a valuable product for food applications (Schiener et al., 2017).

The green processing at OCE allows targeting high value food and pet food markets. Currently, the pet food application is

prioritised due to lower regulatory barriers and lower requirements regarding sensory characteristics such as colour, taste and odour. The product is now in testing with for nutritional value and market acceptance.

#### 4.2 Value chain baseline

Despite the change of the product in focus, the value chain remains the same as previously reported (D8.2, D8.3). Cultivation of *S. latissima* is described in a separate section as the biomass is used to produce both P4 (fibre) and P5 (pig feed supplement). Here, we consider post-harvest part of the value chain, main processing steps being extraction, filtration, drying and storage of the end products (Figure 15). Since the biorefinery jointly produces fucoidan (main product) and fibre (byproduct), the analysis considers both products. The updated cost model is given in Figure.

Figure 15 illustrates a simplified and aggregated cost structure for the biorefinery. Here, investment in the factory includes physical infrastructure for the processing and laboratory. The set up is described in D3.2 (sensitive, public summary available). These costs are reflected in annual cost as depreciation. Cost of licenses and other intangible assets will normally be present but are not included in the present analysis due to uncertainty. Maintenance, insurance and financial cost are also associated with buildings and equipment and are included in the annual cost. Since macroalgae is the main input, annual cost of the biomass is represented separately. In the demonstration site, dried *S. latissima* is used, which increases efficiency of transport. Cost of transport depends mainly on the volume and site location, and less on the actual distance. The main categories of variable costs are

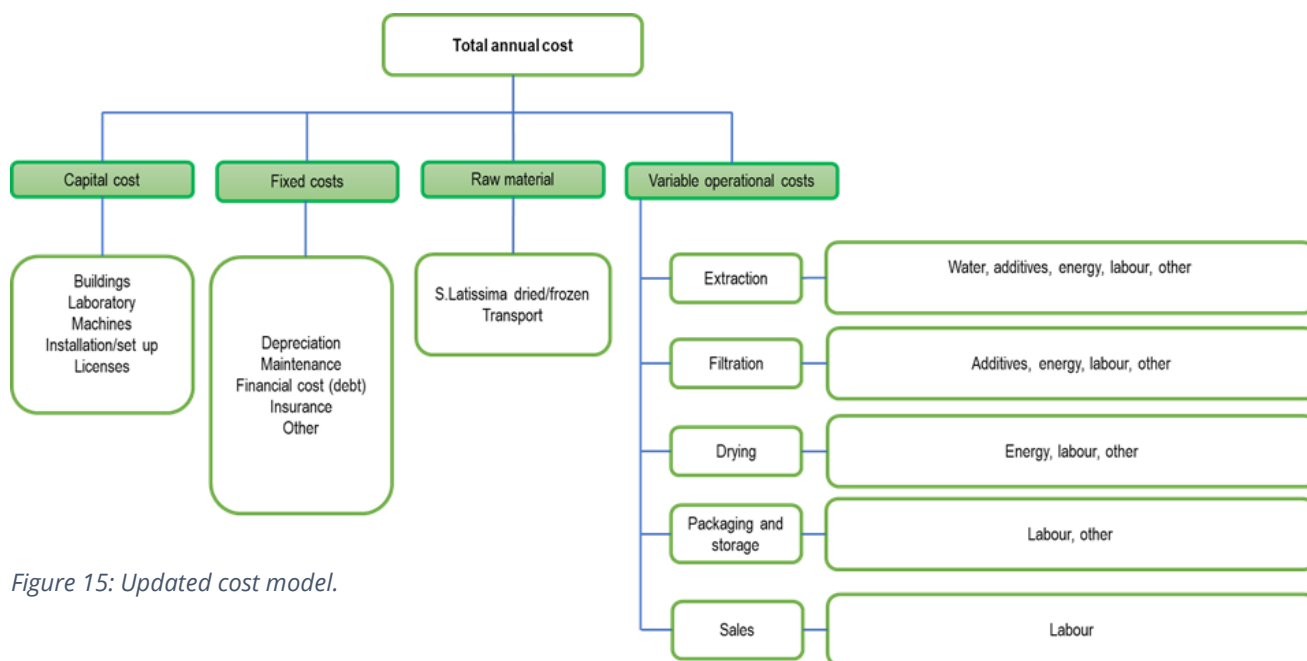


Figure 15: Updated cost model.

energy, labour and additives. Administrative cost and sales are included as labour cost. Other administrative costs are not included as their proportion changes considerably with upscaling and is uncertain at this point.

### 4.3 Upscaling, co-location and co-integration

The cost components are the same in an upscaled production. However, a general cost reduction and change in relative costs and benefits is anticipated. Investment in buildings, equipment and laboratory as well as related fixed cost will be lower per unit output due to the increased production efficiency. Larger volumes of macroalgae cultivated and sold for processing will also have a price reduction effect due to increased efficiency at the cultivation stage. It is difficult to say whether the upscaling of entire macroalgae sector in Europe will have an effect on market prices. We assume unchanged market prices for biorefinery outputs in this model.

As upscaling will most likely happen in parallel to co-location of biorefineries with cultivation sites, much of the stabilisation and transport cost can be eliminated, reducing the cost of raw material for the biorefinery. Processing of fresh macroalgae will be possible through the harvesting season, while for the rest of the year, stabilisation and storage will still be required. Skipping stabilisation steps and associated losses of the biomass will also potentially increase yields of targeted compounds. Thus, the cost per unit output can be further reduced.

SeaMark partners have earlier indicated the need for a coordination between cultivation and processing steps, where cultivation technologies and processes are optimised for specific products and applications. Research suggests that biochemical composition and properties of macroalgae depend on species and their populations/strains, locations, depth, light, temperature, salinity, deployment and harvesting times (e.g., Schiener et al., 2015; Manns et al., 2017; Sharma et

al., 2018; Zhang & Thomsen, 2019; Birgersson et al., 2023; Bogolitsyn et al., 2023; Arlov et al., 2024; Diehl et al., 2024; Vasconcelos et al., 2024). Technological developments such as precision farming (Antonucci & Costa, 2020) and rig design (e.g., mobile floating rigs, Mortensen, 2017) present a possibility to adjust some of these parameters, thus optimising cultivation to processing needs and specific products.

Coordination and co-location of farming and processing also allows reduction of labour and operational cost due to continuous production and more efficient utilisation of resources. Better circularity (reduction of waste streams) and traceability of the products are also among the benefits. These processes, however, will require large capital investments and more management resources.

While in agriculture, a variety of coordination forms have been established since 1960s (Martinez & Davis, 2002), in aquaculture it is a more recent tendency. However, similar types of incentives such as economy of scale and capital intensity drive vertical integration in aquaculture (Kvaløy & Tveterås, 2008). In the European macroalgae industry, which is in its early development, optimal forms of such cooperation are yet to be found. In this report, we will consider a coordination that allows the buyer (biorefinery) to influence the farming process, without referring to specific cooperation forms.

### 4.4 Methods

We estimate the costs on each step depicted on Figure 15 and aggregate by step and type for the baseline and upscaling scenario. Since fibre has substantially lower market value, it is considered a byproduct for cost accounting purpose. The cost per kg fibre and fucoidan are calculated using net realisable values method for joint cost allocation (Datar & Rajan, 2021).

Revenues are estimated using current market prices for fibre and fucoïdan. Application for pet food is considered. Operational cost in case of food application will be slightly higher due to increased quantity of additives. However, administrative costs are considerably higher.

A simple static CBA is performed for both value chain scenarios. A sensitivity analysis is performed to account for variation in the key parameters such as prices of macroalgae and the end products and yields of fucoïdan and fibre. Here, minimum and maximum values of profitability are presented. General assumptions for both scenarios are given in Table 2.

Table 2: Assumption used for P4 value chain analysis.

Assumption	Baseline value chain	Upscaled value chain
Biomass processed per year	2000 tonnes wet weight	20 000 tonnes wet weight
Main product	Fucoïdan	Fucoïdan
Byproduct, application	Fibre for pet food	Fibre for pet food
Co-location	No	Yes
Co-ordination with farming (vertical integration)	No	Yes
Dry content in <i>S.Latissima</i>	10%	10%
Number of batches per year	250	250
Batch size	8 tonnes wet weight	80 tonnes wet weight
Fucoïdan content in dry biomass	7%	7-9% (average 8%) The increase is due to adjusting farming parameters
Fucoïdan yield	40% of content	40-60% (average 50%) The increase is due to adjusting farming and processing parameters
Fibre yield	40% of content	40% no increase is anticipated
Market price of output	+/- 10% of average	+/- 10% of average
Market price of macroalgae	+/- 10% from average, price constant through the year and includes cost of stabilisation	15-25% reduction due to larger volume and farming efficiency (average 20%)
Cost of additives	average	20% reduction at scale
Use of inputs (water, additives, energy)	average	Increase proportionally to biomass processed with 20% efficiency increase at scale
Transport cost	Included	Not included
Harvesting period	-	2-6 months (1/6 - 1/2 of total processed biomass is fresh, therefore price of macroalgae does not include stabilisation/drying, average 3 months)
Investment cost	average	Increases x4
Other fixed cost	average	Increases x5
Labour	average	Increases x3
Sales/administrative	2 people	4 people

### 4.5 Results

#### 4.5.1 Baseline value chain (demonstration site, 2000 tonne ww per year, no co-location and no integration)

As seen from Figure 16, biomass represents 60% of the total cost. Fixed cost, associated with investment in the biorefinery accounts for 11%. The most expensive processing stage is drying, as was found before.

Figure 18 shows the distribution of operational cost within each stage of processing. The highest cost is associated with

energy use for drying of fucoidan and fibre. Labour is a major part of cost in all stages.

As seen from Figure 17, the average loss under given assumptions is at 25.7%, and it is slightly higher for fibre than for fucoidan (however, these results may depend on the cost allocation method).

Table 3: Revenue estimates in million euros.

	Average	Conservative estimate*	Optimistic estimate**
<b>Investment cost</b>	4.55		
<b>Annual fixed</b>	0.57		
<b>Cost of biomass including transport</b>	3.1	3.4	2.8
<b>Total cost of processing</b>	1.25		
<b>Administrative and sales</b>	0.28		
<b>Total cost</b>	5.2	5.5	4.9
<b>Total revenue</b>	4.14	3.72	4.55
<b>Profit</b>	-1.11	-1.78	-0.35

\*market price of macroalgae +10%, price of output -10%)

\*\*price of macroalgae -10%, price of outputs +10%

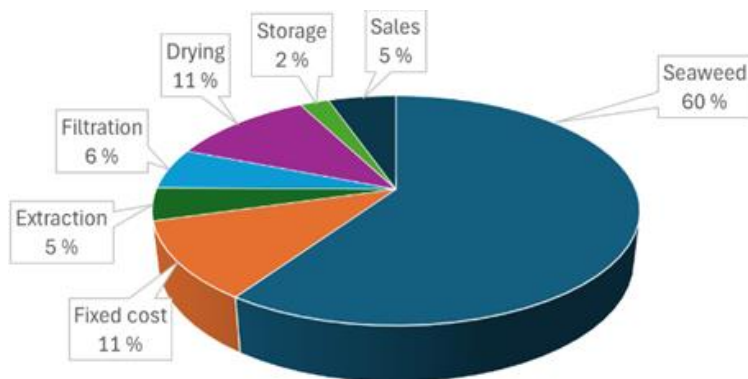


Figure 16: Distribution of costs in the baseline scenario.

Table 4: Cost and revenues allocation between the two products (fibre and fucoidan) under conservative and optimistic set of assumptions.

	Average		Conservative		Optimistic	
	Fucoidan	Fibre	Fucoidan	Fibre	Fucoidan	Fibre
<b>Total cost, million EUR</b>	4.22	0.98	4.46	1.04	3.98	0.92
<b>Cost per kg, EUR</b>	753	13	796	13	711	12
<b>Total revenue, million EUR</b>	3.36	0.78	3.02	0.7	3.7	0.85
<b>Margin, %</b>	-25.6	-26.5	-47.4	-49.3	-7.7	-7.9

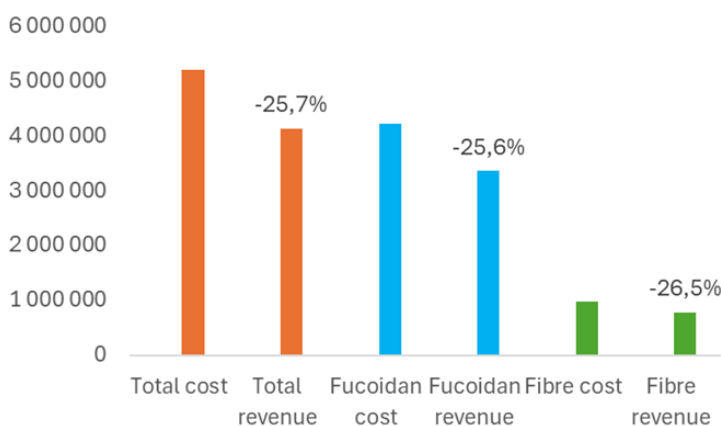


Figure 17: Allocation of costs and revenues between the two products in the baseline value chain under average prices.

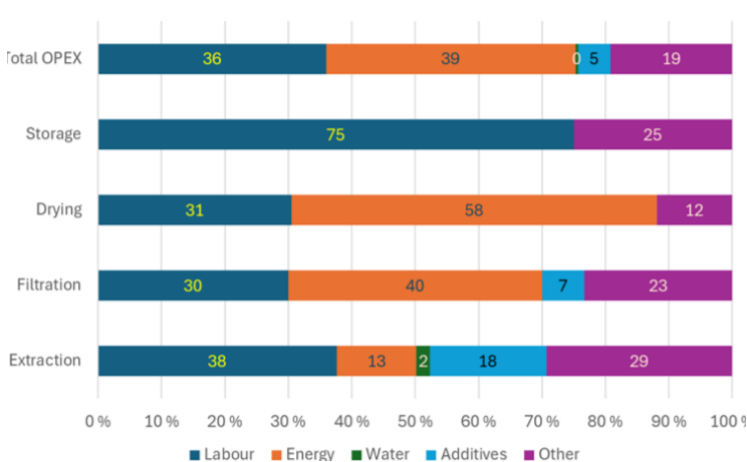


Figure 18: Distribution of costs by operation.

### 4.5.2 Upscaled value chain (20,000 tonnes wet weight per year, with co-location and integration)

Similar set of results is presented below.

	Average	Conservative estimate*	Optimistic estimate**
<b>Investment cost</b>	18.2		
<b>Annual fixed cost of biomass including transport</b>	2.34		
<b>Total cost of processing</b>	20	23.4	16.9
<b>Administrative and sales</b>	0.56		
<b>Total cost</b>	28.62	32.03	25.53
<b>Total revenue</b>	55.68	37.24	79.6
<b>Profit</b>	27.02	5.21	54.08

\*assumptions that give highest profitability

\*\*assumptions that give lowest profitability

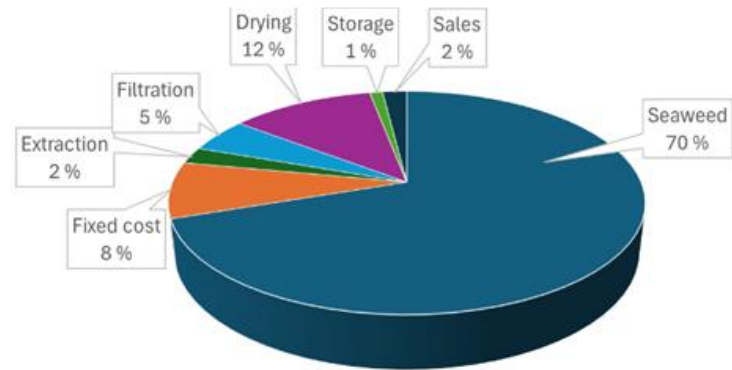


Figure 21: Distribution of costs in the upscaled scenario.

Table 5: Estimated costs and revenues for the upscaled value chain in million euros.

	Average		Conservative		Optimistic	
	Fucoxanthin	Fibre	Fucoxanthin	Fibre	Fucoxanthin	Fibre
<b>Total cost, million EUR</b>	24.57	4.08	26	6	22.58	2.94
<b>Cost per kg, EUR</b>	307	5	464	8	209	4
<b>Total revenue, million EUR</b>	48	7.68	30.24	7	71.28	8.32
<b>Margin, %</b>	48.8	46.9	14.0	13.9	68.3	64.6

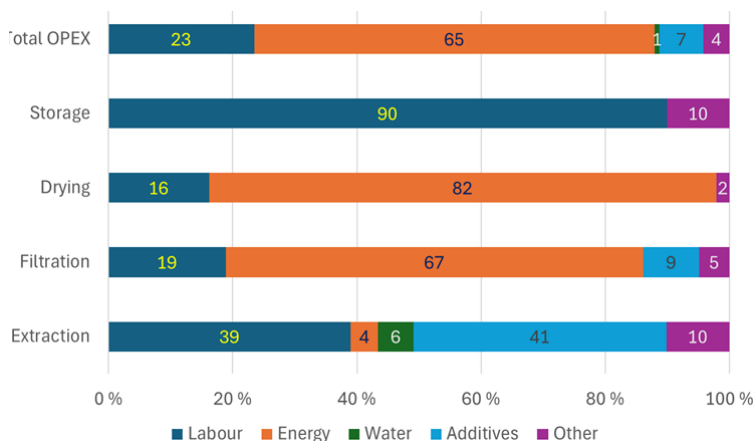


Figure 19: Distribution of costs by operation in the upscaled scenario.

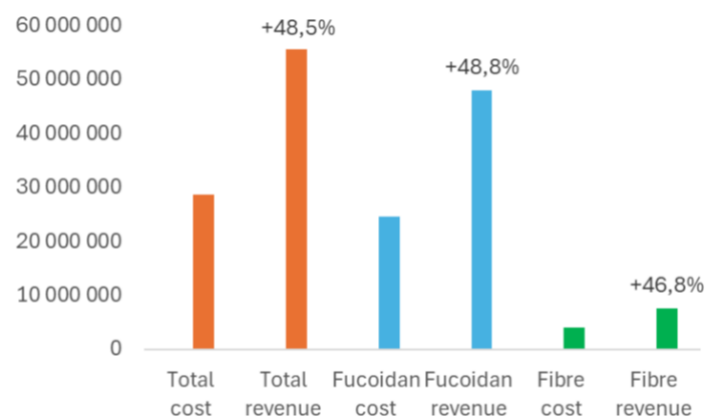


Figure 20: Allocation of costs and revenues between the two products in the upscaled value chain under average values.

#### 4.6 Discussion

Sensitivity analysis (estimation under conservative and optimistic sets of assumptions) demonstrated that the results are strongly influenced by parameters such as prices and yields. At the same time, these parameters are highly uncertain. Other model elements, such as investment cost, amounts and costs of inputs, are approximations and are subject to error due to variation and confidential nature of the data. Therefore, the results, especially regarding upscaling scenario, should be considered as illustration of potential costs and benefits.

The main findings from the updated value chain analysis:

- Price of macroalgae is the major cost component for a biorefinery and plays a key role in its profitability. With more macroalgae processed, its share in the total cost increases. Cost efficiency and upscaling of the farming is therefore needed for the entire value chain being economically viable.
- Profitability is highly sensitive to the product prices. In the demonstration site scenario, break-even prices of fucoïdan and fibre are 20% higher than the current average prices. Given the high market uncertainty, it is difficult to predict possible price changes. 20% higher prices may be realistic under specific conditions.
- With the current market prices of fucoïdan and fibre, upscaling is necessary for biorefinery to achieve margins above the risk-free level. Increase of the volume of processed macroalgae together with co-location and some form of integration with farming results in positive margins under the given assumptions. However, we consider the estimates somewhat optimistic due to simplifications made in the model. It is likely that transaction costs, administrative barriers, biological and environmental conditions will influence the upscaling process, reducing the profits.
- In the upscaled scenario, production of only fucoïdan is profitable (again, under assumptions). However, the byproduct (fibre) valorisation is justified by positive margins. There is an indication that production of fibre may increase the costs slightly more than it increases the revenue. This result might be related to specific assumptions and the chosen method for cost allocation. Apart from business economic perspective, valorisation of the side stream (fibre) is in line with the circularity concept underlying biorefinery models.

Presented value chain analysis will be used to evaluate specific technological options for increased profitability in the updated TEA (D8.6, due M40). In the preliminary TEA (D8.3, public summary available) we considered the effect of increased yields, higher energy efficiency and different stabilization

methods on profitability with the focus on beta-glucan. In the updated TEA, we will look at specific technological options to achieve those effects with the focus on fibre and fucoïdan. Waste stream valorisation will be considered in addition.

## 5. PIG FEED SUPPLEMENT (P5)

Product P5, Pig Feed supplement (EP199), is a fermented supplementary feed, primarily sold to pig farmers for its many vital benefits for productivity and gut well-being stemming from the fermentation process. The product is produced by the Danish company FEXP with seaweed from the Faroese company ORF.



Figure 22: The finished product as sold to feed distributors or pig farmers. Picture: FEXP.

The pig feed supplement is mixed with other feed, normally at a ratio from 0,1 to 20 percent, depending on whether it is intended for piglets or sows. The fermentation is carried by lactic acid bacteria which produce substantial lactic acid in the finished product. This has several benefits of wellbeing and good gut balance for the animals.

FEXP highlight that the fermented feed supplement means that the sows produce more liveborn piglets and at the same time they also produce more milk so they can take care of their piglets. Another benefit is that the farmer can lower the feed usage due to the improved protein uptake.

The increased production and lower feed usage are regarded to be the main selling points of the product since the farmers see a beneficial economic gain of the product. For a more detailed analysis of the product's competitive advantages, see SeaMark D7.1. For more information on the production process, see SeaMark D8.1.



Figure 23: One of the unique selling points of the product are improved wellbeing benefits, improving productivity and milk production of sows. Picture: Depositphotos.

### 5.1 FEXP – pig feed supplement (P5)

The value chain analysis builds upon the work carried out in D8.1 where the supply chain for Pig Feed Supplement was mapped out and the product flow and key processes carried out at FEXP were described in detail. The value chain analysis extends the analysis by analysing the cost structure in the supply chain (Figures 25 and 26)

The data from FEXP does not allow for an analysis of the individual steps in the value chain, since the same labour is involved in all the steps of the production process and there are no detailed data on the individual steps. Nevertheless, the steps have quite distinct inputs, e.g. 'Mixing-fermenting' step uses rapeseed, macroalgae and inoculum while 'Drying' uses almost all of the energy input, therefore, the lack of separation does not limit the analysis in any substantial way.

### 5.2 Current value chain for pig feed supplement (P5)

Purchase of the raw materials (rapeseed, macroalgae, inoculum, etc.) makes up a substantial part of the total cost of production. Rapeseed alone constitutes around 51% of the total cost of production, while macroalgae and inoculum are an additional 16% of the total cost (Figure 25). This means that the raw materials constitute two-thirds of the total production costs.

The cost of rapeseed is determined by the market price of rapeseed on the world markets and FEXP has no influence on this price, therefore, the price of rapeseed is not treated further in this analysis.

FEXP mainly purchases the macroalgae from ORF and the cost of macroalgae is treated extensively in the section about ORF and will not be treated further here. However, it should be mentioned that the analysis of the initiatives at ORF could entail a reduction of around 50% of the cost of seaweed which would lower the total cost of Pig Feed Supplement by around 5%.

Since the raw materials are outside the scope of this section of the analysis, the rest of the analysis will focus on other costs excluding materials.

### 5.3 Current value chain for P5 excluding materials

Figure 26 shows that excluding material costs, the major cost groups are Administration and Sales (40%), Equipment (20%) and Energy (21%). In total these three groups are 81% of the total cost when the materials are excluded. Labour costs, which often is a major cost in production industries, comprises only 6% of the costs and is on level with Maintenance, which also is 6% of the total cost. The rest is Packaging (1%), Storage (2%), Waste Disposal (1%) and Insurance (2%), in total 6%. Low packaging cost comes from the fact that the company sells most of its products to local customers who buy in bulk, where there is no need for packaging.

From the cost structure, it is clear that the largest cost groups that FEXP can influence are 'Administration and Sales', 'Equipment' and 'Energy'. We propose that any analysis aiming for a cost reduction focusses on these three cost groups.

#### 5.3.1 Administration and Sales' and 'Equipment'

'Administration and Sales' seem comparably high compared to other cost groups. FEXP explain the reason is a need to research and document the health benefits of their products and to expand their sales on the market. There is a strong need to communicate the health benefits of this product to the potential customer as the cost of seaweed makes the pig feed product much more expensive.

Pig feed supplement EP199 is a novel product that requires a high level of marketing and customer engagement. In order to do this, they need administrative staff for both documentation and for sales. This means that the 'Administration and Sales' will most likely not fall unless the production expands, distributing the costs of Administration and Sales on a larger quantity of output, thus leading to a decrease in the cost per unit.

In the same manner, the equipment cost is a fixed cost that only changes in the long run when the current equipment is replaced by other equipment. FEXP has a wide product portfolio and EP199 is only one of many products processed at FEXP facilities. Although it is a relatively novel product on the market, the production facilities are already heavily mechanised and dependent on equipment as the company uses forklifts, mechanised shovels, mixers, dryers, and transport systems. Given the novelty of the product, the set-up of the processing facilities provides an advantage as the company can avoid high labour costs.

'Administration and Sales' and 'Equipment' can thus be considered to be fixed costs that are not related to the level of production. An increase in the level of production would thus relatively lower the cost of these cost groups and thus lower the cost per unit of output.

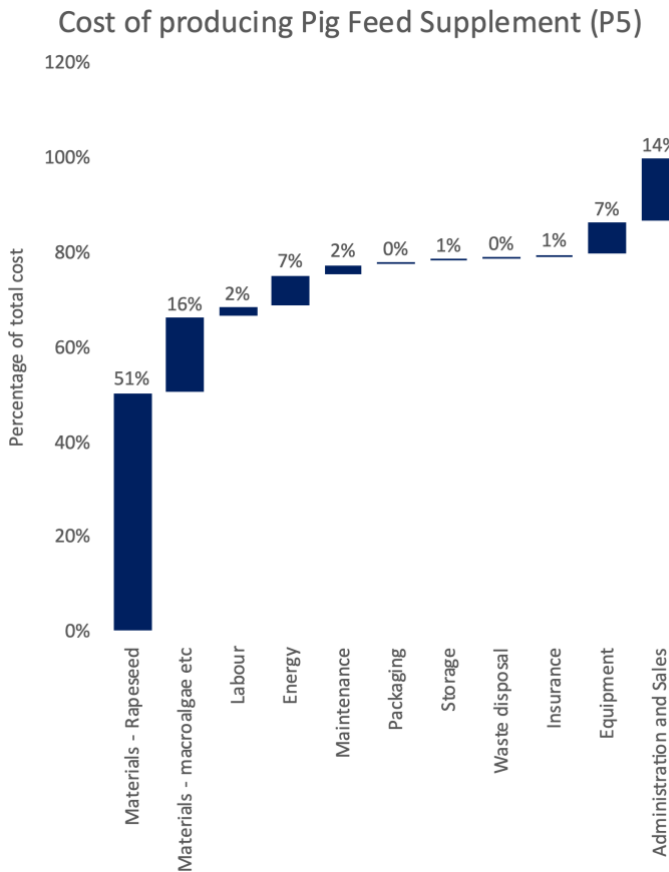


Figure 25: Cost of producing pig feed supplement (P5) at FEXP.

Figure 24 depicts a calculation of the development in the fixed costs as production increases. Three levels are depicted. The first level is the current level where 'Administration and Sales' are 14% of total costs, 'Equipment' is 7% and variable costs (excl. materials) are around 13%.

The calculation shows, that as the production expands to 1,5 and 2 times the current production level, the variable costs stay the same (compared to the current total cost of production), while the two fixed costs fall relatively as production expands. A doubling of the production level would entail the fixed costs to be halved from around 20% to around 10%.

### 5.3.2 Energy

The cost group 'Energy' is mostly comprised of natural gas and to a lesser degree district heating for drying the fermented products. Natural gas is an energy source with a high price volatility where changes in the global geopolitical arena can cause large shifts in the price of natural gas. In addition to the price volatility, natural gas is a fossil fuel and FEXP has done some effort to shift the energy source from fossil-based sources towards greener alternatives such as use of excess energy from waste burning. FEXP thus has shifted the energy source towards district heating, which might lower the cost

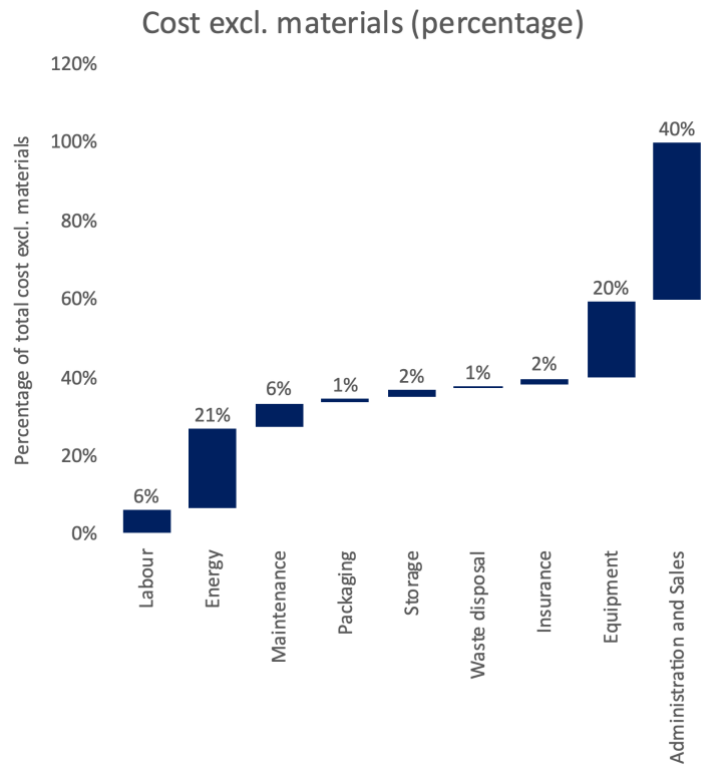


Figure 26: Current value chain for pig feed supplement excl. materials - FEXP.

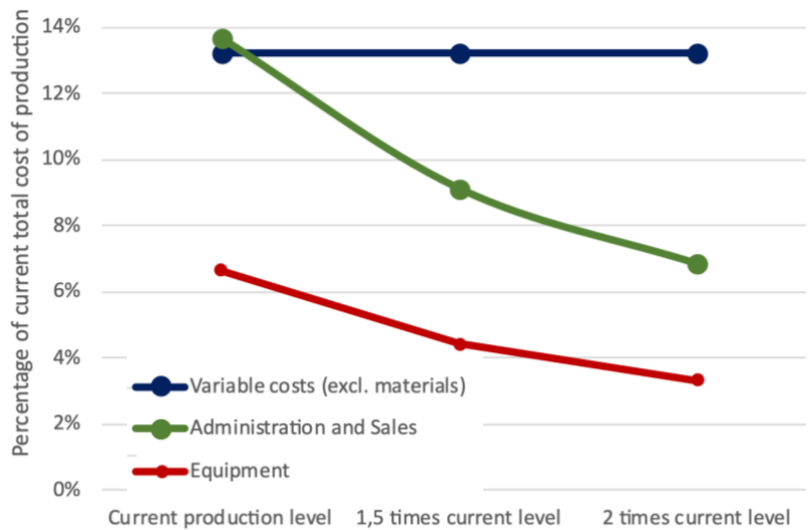


Figure 24: Cost development of costs (excl. materials) as production expands - FEXP.

somewhat, but the main positive effect will according to FEXP be the cleaner and greener energy source. For the foreseeable future, the main energy source will still be natural gas, since there are no other affordable energy sources that can fill the large energy requirement when drying the products.

It is clear that a closer look at better utilization of the energy and alternative energy sources should be a focus area in the techno-economic analysis.

To get a feeling of the importance of a reduction in the cost of energy it can be seen that the cost of energy as a proportion of the total cost of producing P5 is around 7%. A reduction in the cost of energy of e.g. 30% would lower the total cost of producing P5 by around 2%.

**5.4 Summary of pig feed supplement (P5) value chain – ORF and FEXP**

For the fermented macroalgae value chain, the largest share of the cost (38%) is found in the cultivating part of the value chain (Figure 27). The material costs account for 55% of the total

cultivation costs, these include the rope, mainline, buoys, anchors, and chains. Cost-reducing initiatives focusing on material costs must be undertaken to bring down the final price of macroalgae.

With regards to the harvesting costs, several initiatives have been analysed including mechanised harvesting and increased processing capacity which has been identified as a bottleneck for increasing daily harvesting volume.

**Pig Feed (P5)**

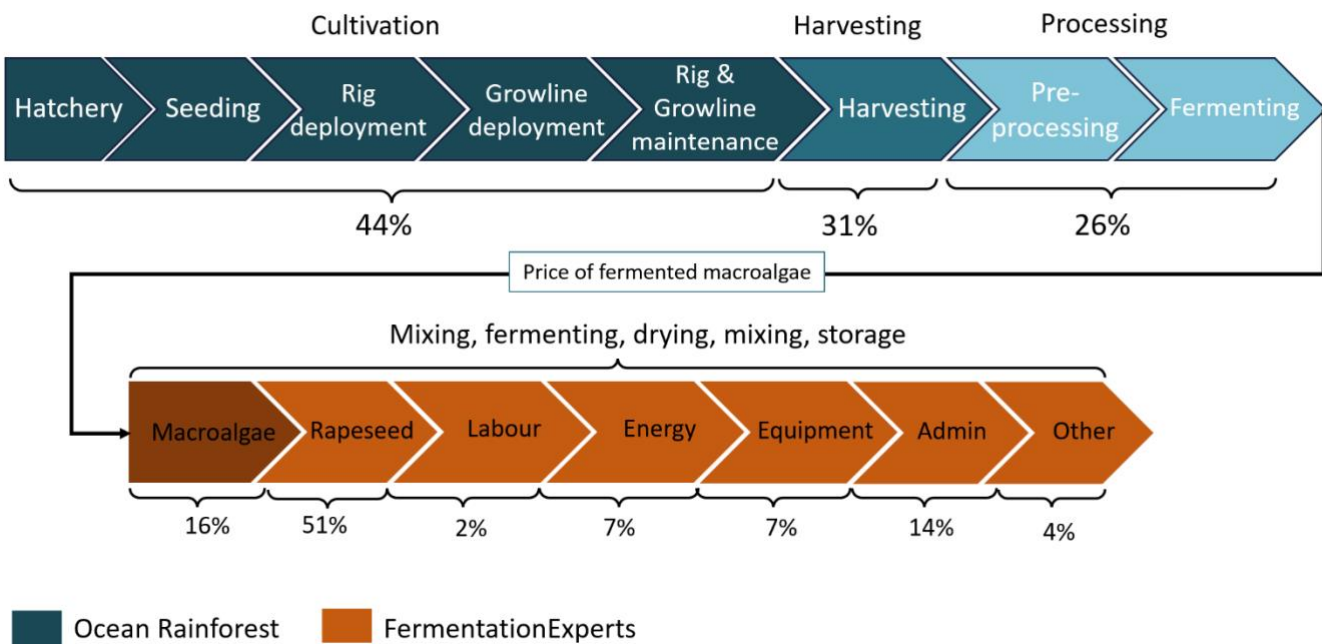


Figure 27: Summary of pig feed supplement (P5) value chain – ORF and FEXP.

The analysis showed that two-thirds of the production costs of Pig Feed Supplement (P5) are from the acquisition of the materials, which are rapeseed, macroalgae and inoculum. FEXP have only limited influence on these cost groups and therefore the analysis focuses on the other cost groups.

Three cost groups were identified as being the major cost groups, excluding materials. Two of these, 'Administration and Sales' and 'Equipment' can be considered as fixed costs where an expansion of the production will reduce the cost per unit of output. The last group, 'Energy', is a variable cost, mainly natural gas used for drying the product, where the cost can only be reduced by shifting to an alternative and preferably cheaper and greener energy source.

The total potential cost reduction identified in the document is

- Reduction in the cost of macroalgae from ORF (5%)
- Reduction in 'Administration and Sales' and 'Equipment' as production increases (5-10%)
- Reduction in energy costs (2%)

The total reduction in costs can thus be summed up to 12-17% of the total cost of producing P5.

Finally, it should be noted, that most of the identified reductions originate from a reduction in the cost of macroalgae, which FEXP have limited influence on. FEXP can focus on upscaling the production volume and thus distributing the fixed costs on a larger quantity of output, thus leading to a decrease in the per unit cost.

**6. GREEN ALGINATES (P7)**

Green alginates are produced by SeaMark industry partner ALG, with head offices in Lannilis in France. ALG's factory has more than 40 years' experience in extracting alginate from brown seaweeds.

The calculations below look at the prospect of farming *S. latissima* for the production of green alginates. For reasons of confidentiality, this analysis does not include absolute

numbers on the costs. Instead, relative shares and changes are presented. The analysis consists of the following elements:

- An analysis of the current costs of producing *S. latissima* at ALO and analysis of changes of costs of production under various scenario.
- An analysis of the expected changed costs of producing alginates when ALG shifts from current alginate production processes to green alginates.
- A description on the prospects of using farmed seaweed to produce green alginates.

**6.1 Algolesko - Seaweed cultivation in France**

ALO produces *S. latissima* and *Undaria pinnatifida* (Wakame). The company is based in Lesconil, South Finistère, Brittany, France. They operate a cultivation site of 150 hectares in the heart of a Natura 2000 classified area of the coast, see Figure 28. Since 2013, they grow several species of brown laminarian seaweeds with as of now an approximate production volume of 200 tonnes per year. All their production is certified as organic farming.

In the studied SeaMark value chain, ALO is expected to deliver their biomass to ALG, who use it to produce products P7 – P10. This is currently not an established practice, seaweed produced by ALO are sold mainly for food (80%) and cosmetic (20%) use. For the value chain analysis, we are looking at P7 “green alginates”.

In Figure 29, we can see the flow chart detailing ALO’s cultivation of *S. latissima*. The internal process is described

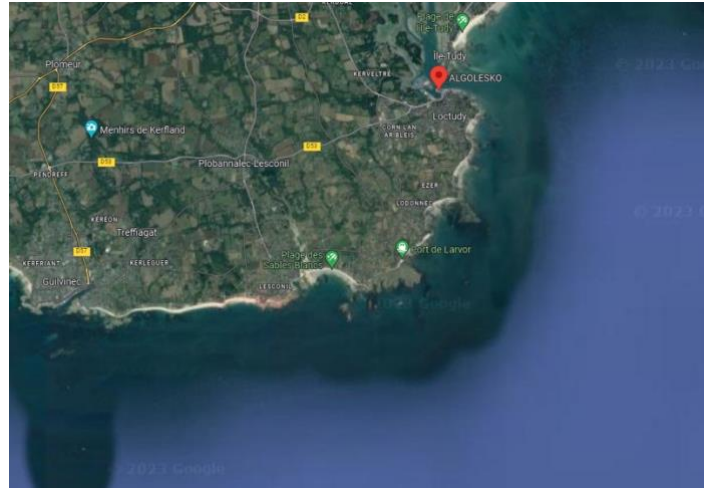
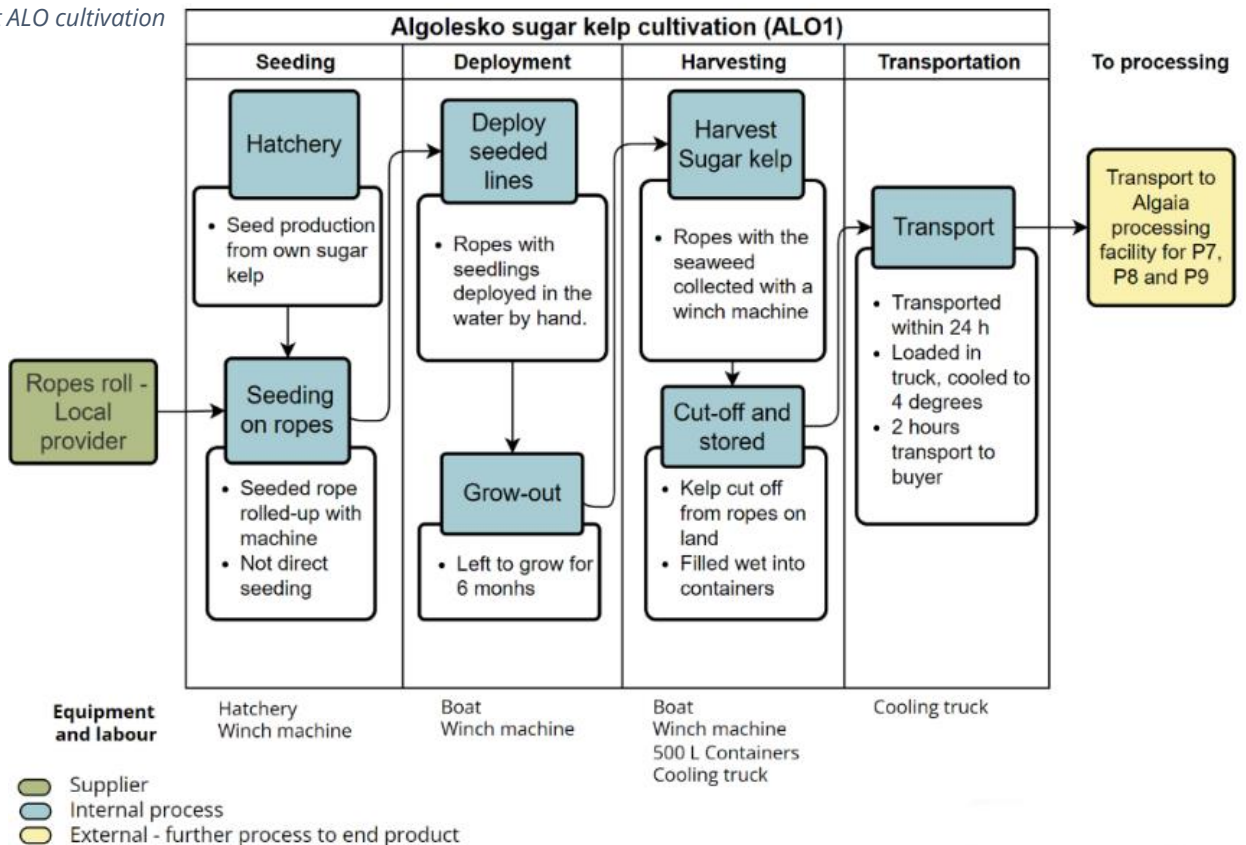


Figure 28: Production area in the open sea. Source: google maps

below in 7 different production steps: hatchery, seeding on ropes, deployment of seeded lines, the grow-out, the harvesting of *S. latissima*, the cut off and storage and the final step the transportation. ALO buys their ropes rolls from a local supplier. The details of ALO’s cultivation process can be found in deliverable 8.1.

Figure 29: Flow chart ALO cultivation of *S. latissima*.



### 6.1.1. Data collected

The data underlying the analysis in this chapter was provided by ALO. The study team prepared an Excel document, populated with data by ALO. Where needed, the inserted data was discussed to clarify. Table 6 provides an overview of the data collected and how the cost items are grouped in cost categories used in the analysis.

### 6.1.2 Results

The first part of the value chain analysis looks at the current cost structure for producing *S. latissima*. This analysis is based on data provided by ALO. For reasons of confidentiality, the absolute numbers are not presented in the figures below. Figure 30 presents the relative share of costs for each of the three phases in the production process.

Also, relative shares of various cost categories are presented. Figure 31 shows how the production cost for *S. latissima* by ALO are made up, looking into 6 main costs categories.

The main share of production costs is related to the seed production for *S. latissima* with a share of 35%. ALO has their own hatchery and produces their own seedlings from their own seaweed. They have an own machine that rolls up the ropes. Two other important cost categories are labour costs and the boat owned by ALO. Both comprise 20% of the total cost of producing *S. latissima*. The three minor cost categories are materials (10%), transport (6%) and other costs (9%).

In the second step of the analysis, the data provided by ALO was used for scenario analysis, assessing the effect of change in costs of inputs on the total cost of production of *S. latissima*. At this stage, the scenarios are developed by the research team. The following four scenarios were tested:

- Scenario 1: considering current price developments, this scenario assumes an increase in the cost of boats, labour and materials. All other costs remain equal.
- Scenario 2: Innovation in seeding is expected to reduce costs for seed production. All other costs remain equal.
- Scenario 3: In this scenario, we assess the impact of reducing costs for boat and transport while other costs remain equal.
- Scenario 4: In this scenario, a reduction of all costs of inputs by 25% is assumed.

Table 6: Data collected for ALO.

Phase	Item	Unit	Cost-category
<b>Output</b>	Output per year	KG	-
<b>Cost of rig-structure</b>	Materials (ropes etc.)	€	Materials
	Boat	€	Boat
	Labour costs	€	Labour costs
	Cleanup costs	€	Other costs
<b>Grow lines</b>	Other costs	€	Other costs
	Seed production	€	Seed production
	Materials (ropes etc.)	€	Materials
	Boat	€	Boat
	Labour costs	€	Labour costs
	Cleanup costs	€	Other costs
<b>Harvesting</b>	Other costs	€	Other costs
	Materials	€	Materials
	Boat	€	Boat
	Labour costs	€	Labour costs
	Transport	€	Transport
	Other costs	€	Other costs

Share of costs per phase

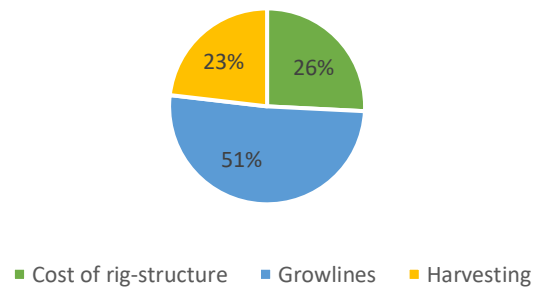


Figure 30: Share of costs per phase.

Distribution of production costs

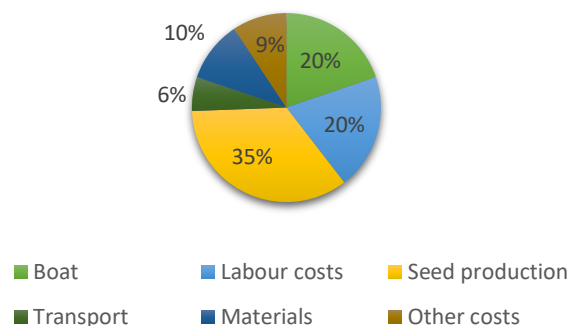


Figure 31: Distribution of production costs of ALO.

Table 7: Overview of scenarios.

Cost category	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Boat	+10%	0	-25%	-25%
Labour costs	+10%	0	0	-25%
Seed production	0	-25%	0	-25%
Transport	0	0	-25%	-25%
Materials	+10%	0	0	-25%
Other costs	0	0	0	-25%

*Method for calculating expected impact on cost of production*

To calculate expected impact on the cost of production, a stochastic model was developed to predict statistical properties of possible outcomes. The model accounts for random variance in one or more parameters over time. Input parameters are per cost factor. A Monte Carlo model was developed that shows the spectrum of probable outcomes for a scenario. This technique assigns multiple values to uncertain variables, obtains multiple results, and then takes the average of these results to arrive at an estimate. In the model developed, 250 calculations are made, the average of which is presented.

Monte Carlo analysis enables us to examine the effect of the expected change in cost of production considering uncertainties. In the analysis presented, we assume for each input that it falls between a range of minus and plus 25%. For example, looking at scenario 1 and using hypothetical numbers, if the cost of boat is currently 10,000, the scenario assumes it falls between 11,000, plus or minus 25%, which is between 9,900 and 12,100. The model randomly selects a value between these two extremes for 250 times. For each scenario, this is done for all cost categories, and this results in 250 calculated costs of production. The figures below visualize how these 250 calculated costs of production compared to the current cost of production.

*Results scenarios*

In scenario 1, the costs for boat, labour and materials are expected to increase by 10%, all other costs remaining equal. This scenario is tested because inflation rates, shortage of workers and insecurity about the availability materials have a price-raising effect. The results show that the cost of producing one kg of seaweed will increase. A total of 50 of the 250 calculations results in a cost price between 105% and 110% of the current cost of production (Figure 32)

In scenario 2, the costs of producing seed are expected to be lower, all other costs remaining equal. This could be the result of innovation in seeding technologies. **Error! Reference source not found.** below shows the categorized results of the 250 calculations. The total costs of production are likely to go down but there is some variation. The three ranges 85%-90%, 90%-95%, and 95%-100% of current production costs all feature strongly among the 250 calculations.

In the third scenario, the costs for boat and transport are expected to go down by 25%. This scenario could become reality if a reduced demand for boats and transport means the prices paid for these means go down, or for example of transport would be subsidized. The results presented in Figure 34 shows the effect on total costs of production of most, with most of the 250 calculations resulting in a range between 95% - 105% of current costs of production.

Scenario 1

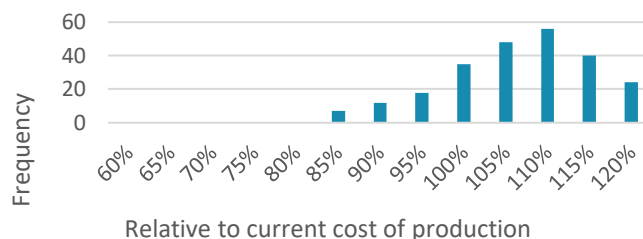


Figure 32: Results of scenario analysis for scenario 1.

Scenario 2

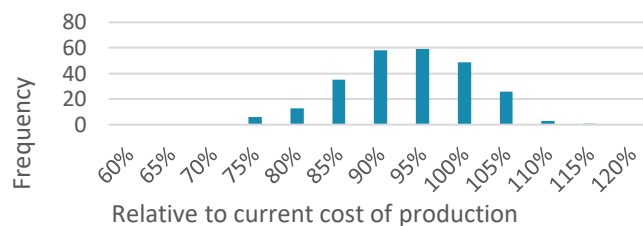


Figure 33: Results of scenario analysis for scenario 2.

Scenario 3

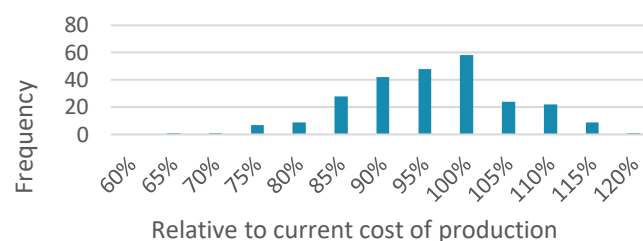


Figure 34: Results of scenario analysis for scenario 3.

Scenario 4

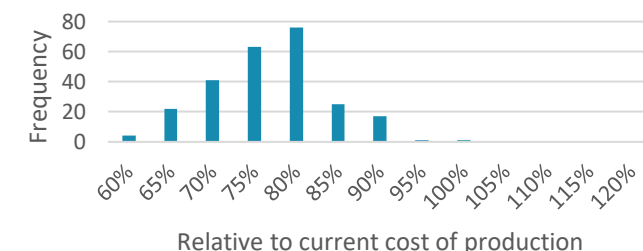


Figure 35: Results of scenario analysis for scenario 4.

The last scenario analysed assumes that all costs of production go down by 25%. The results of the calculations are presented in Figure 35 with many of the 250 calculations resulting in new cost prices hovering around 75-80% of current costs of production. Given that uncertainty is included in the analysis, this does not automatically result in a reduced costs price of 25%, as the model assumes there is variation in the assumed new costs.

### 6.1.3 Next steps

This analysis of the cost of producing *S. latissima* by ALO has given first insight into the current cost structure and the possible developments of costs of production in the future. A few remarks need to be made.

- For reasons of confidentiality, the absolute numbers are not presented in this analysis.
- Without presenting the absolute numbers on cost of production, it is impossible to conduct a full value chain analysis for *S. latissima* produced by ALO and used by ALG to process green alginates (P7).
- The scenarios are developed by the research team. Future interaction with ALO could help to refine and detail the scenarios, providing valuable insights into the expected effects of innovations on cost structure.

## 6.2 Algaia - Green alginate production

This chapter reviews the impact of transitioning from the current process for alginate production towards a greener alginate production process. This transition implies limiting the usage of chemicals and preservatives in the extraction process of alginate from seaweed. Several chemicals are traditionally used in the alginate production including formaldehyde, for preserving the seaweed but also to avoid bacterial contamination, flocculants based on carbon sources to facilitate alginate flocculation, and sodium hypochlorite to wash and whiten the alginates. The reduction in the use of chemicals is believed to enhance environmental sustainability and contribute to the wellbeing of the local community via better protection of biodiversity and water resources. The transition entails an initial investment in equipment and production processes. This chapter presents an analysis of the costs and benefits associated with this transition.

The next section reviews the required upfront investment for the green transition. This is followed by an initial estimation of the changes in the selling price of green alginate. Next, we analyse the effect of green alginate on production cost, especially on the costs of inputs, followed by an initial assessment of cost and benefits of green transition based on the information of previous sections. The final section summarizes the report and discusses some consideration for completing the analysis.

It is crucial to highlight that the analysis does not incorporate the value of the environmental benefits of the green transition due to data limitations. We emphasize the noteworthy long-term environmental advantages tied to reduced chemical

usage. This review, however, only considers direct costs and benefits as they are pertinent to ALG. The reason is that ALG does not internalize the positive environmental effects. Simply put, ALG bears the complete costs but realizes only the economic benefits, excluding the environmental gains. Finally, it should be noted that there is uncertainty about the potential market for green alginate that is not reflected in the analysis.

### 6.2.1 Up-front investment

Moving to the green production system is estimated to require a fixed investment of around €12 million. Table 8 shows the breakdown of the estimated required investment. These estimations are based on rough assessment of each equipment category based on guideline prices. An updated estimation would be required for making investment decisions.

The equipment for green alginate production also requires maintenance and repair. Maintenance costs associated with this equipment line (for both current and green alginate production) are about €500,000 per year. Green alginate production requires a separation machine which is more sensitive to foreign material (possibly resulting in higher costs), but because less pumps and filtration systems are required for green alginate production, the maintenance costs are estimated to remain equal when switching from current to green alginate production. These associated maintenance costs might depreciate at different rates compared to current equipment. At the moment, we do not have the necessary information regarding the difference of depreciation rates between current and new equipment.

Table 8: Upfront investment for transition to green alginate (million euro).

Investment venue	Amount (Million euro)
<b>Pre-processing equipment and machines</b>	2
<b>Tanks</b>	2
<b>Extraction tanks and pumps</b>	2
<b>Centrifugation and filtration systems</b>	3
<b>Energy recycling</b>	1
<b>Press and malaxing machine</b>	2
<b>Total</b>	12

### 6.2.2 Market for green alginate

Brown seaweed is processed to produce a variety of alginates. Currently, ALG produces a mix of 70 types of different alginates. Among them there are two prominent range of products: Sodium and Potassium alginates. The sales prices of (current) sodium and potassium alginates start at €18,000 per ton. In the Seamark project, ALG aims to develop the process producing green sodium alginate with an estimated market price of €20,000 per ton. The green alginate production process is also believed to enable ALG to produce green

potassium alginate with an estimated market price of €22,000 per ton. These sales prices for green alginate were estimated to be higher in preliminary value chain analysis (D8.2). There is currently high competition from Chinese alginate producers, selling for much lower prices, hence ALC also has to lower the sales prices they aim for.

It should be noted that despite the positive prospect, there are uncertainties regarding the price that customers are willing to pay and the demand for this new type of alginate.

### 6.2.3 Production cost of green alginate

Production process of alginate production involves six major stages as shown in

Figure 366. Each stage of production requires inputs such as energy, labour, chemicals, etc. (See SeaMark D8.1).

Based on information from ALG only three of the six stages are affected by the transition to green alginate in terms of input consumption. The three stages that are affected include

extraction, separation and press and neutralization. In addition, the green transition does not affect output capacities of production stages. Beside the costs of inputs that are affected for some stages, the processing time of some stages will change, mainly for the separation stage (Figure 36 36). In the current process, the Separation stage takes 48 hours because floatation takes time and you need to wait a few days. In the green alginate production process where a centrifuge is used, this is much faster; it will be reduced to only 1 hour when switching to green alginate production.. There will be a small reduction in time in the Press and Neutralization stage. The other stages are not affected in time. Therefore, the green transition affects the production process through changing the cost of inputs and the processing time.

For brevity and clarity, we focus on the three stages that are affected and do not include those stages that are not affected. Table 9 shows the share of required inputs for each of these stages and the associated cost of the input for a kilo of production.

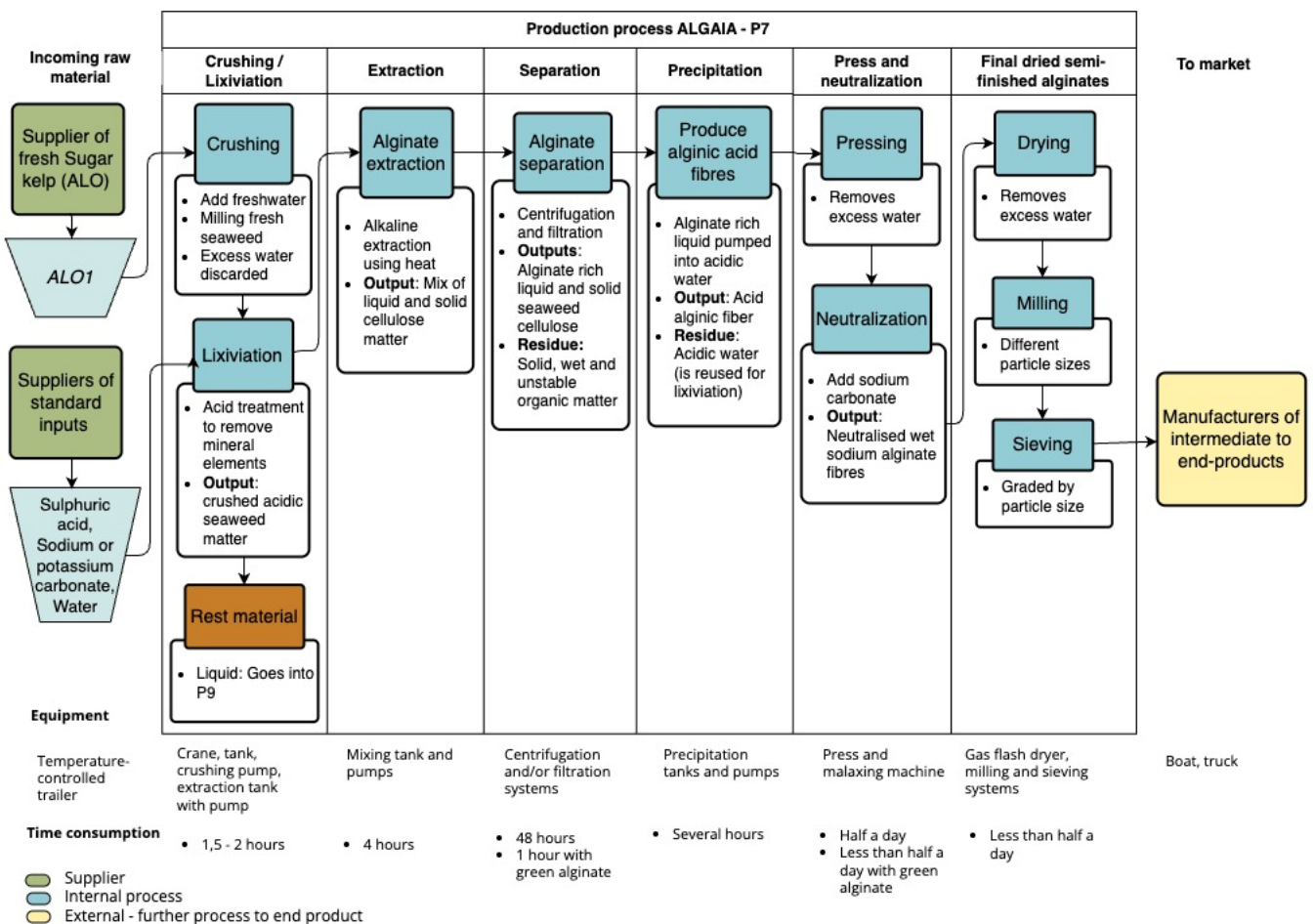


Figure 36: Production process of ALG

Table 9: Input consumption share of production stages and the price per kilo of production for classic alginate production at ALG.

Input	Extraction	Separation	Press and Neutralization	Cost per kilo of production (€)
Fresh water - processing of fresh water	25%	20%	25%	0.000003
Supplies including Sodium and Potassium	20%	60%	20%	3.14
Energy (gas, electricity)	30%	10%	10%	0.84
Water	25%	20%	25%	0.000003
Maintenance costs	60%	20%	20%	1
Waste disposal	60%	5%	0%	0.26

Two points are worth mentioning about table 9. First, note that the sums of the percentages in the rows do not add to 100 percent. This is because Table 6 shows only three stages. So, the remaining percents belong to the stages that are not affected. Second, note that labour is not included as one of the resources. This is because the green transition has no effect on labour, according to ALG. Compared to the previous deliverable (D8.2), there were some updates on the shares of production stages. This is why:

- Better estimates on the supplies are now included. In the Extraction and Separation stage the shares increased compared to the numbers in D8.2, while the use of supplies in the Press and Neutralization stage should be lower than first estimated. The biggest share of supplies is used in the Separation stage, because a lot of chemicals are used here.
- The shares of energy input (including both gas and electricity) are slightly differently distributed than estimated before. Most energy is used in the Extraction stage, because the biggest pumps of ALG are used in this stage and heat is required for the alginate extraction.
- The maintenance costs are higher than estimated before, mainly in the Extraction stage. The distillers and pumps require high maintenance because stones and sand within the seaweed biomass damage the machines, so a frequent change of the inside material is needed.

Green transition affects input consumption in Extraction, Separation, and Press and Neutralization. Table 10 shows the change in input consumption in the form of percentage change due to green transition. A negative number means reduction in consumption due to green transition.

As Table 7 shows, the green transition results in saving of most inputs and moderate increase in the consumption of some inputs. What stands out is the 100% reduction of supplies in the Separation stage. In the current alginate production, a lot of chemicals are required for the Separation. When switching to green alginate production, the Separation stage is still needed, but no chemicals are required anymore. The share of supplies in the separation stage decreases to 0% (leaving 50% for extraction and 50% for press and neutralization). For

energy input, there is no change expected in the Extraction stage for at least the coming two years. Further in the future, energy input could be reduced by reducing the incoming viscosity level of the alginate paste before the Separation stage. In theory, this would require the decanter to work at a lower speed and therefore using less energy. However, this will need more running trials. For Press and Neutralization, it is not known yet if there will be a change in energy input, but ALG assumes no change (0%). The maintenance costs in the Extraction stage will slightly decrease (-5%), however these costs could be reduced further (-40%) if ALG changes equipment. Currently, a frequent change of machinery is needed due to the damage of sand and stones. With new (other) equipment the sand and stones could be removed beforehand and a 40% reduction in maintenance costs could be reached. However, this is not within the scope of the SeaMark project, and the focus is now on the Separation stage. This will therefore be left out of the analysis, but could be a future step to reduce costs (although it is expected to require a big investment upfront).

We can use the information in Table 10 and 11 to estimate the total effect on the cost of inputs due to green transition. This is done in Table 12. The column 'Net change in costs' shows the total change in the consumption of an input. The total change in consumption is calculated by multiplying the share of the input usage by the percentage change due to green transition. For example, consider the first row, Fresh water processing, the total net change due to transition is calculated as

$$(-0.35 \times 0.25) + (-0.1 \times 0.20) + (-0.1 \times 0.25) = -0.1325$$

The same applies to other inputs as well. Finally, the net change in the input consumption is multiplied by the cost of that input to derive the total net change in the cost of the input. Note that the time savings in the different stages are not included in this calculation of change in costs. ALG would save almost two days in processing time when switching to green alginate production, which is associated with a financial benefit. By removing the slowest part of the process (the Separation stage), the production capacity will increase. ALG is able to reach a 5-7% increase in production because of this, with the same fixed costs.

Table 10: Percentage of input consumption change, from changing from classic alginate to green alginate production.

Input	Extraction	Separation	Press and Neutralization
Fresh water - processing of fresh water	-35%	-10%	-10%
Supplies including Sodium and Potassium	0%	-100%	0%
Energy (gas, electricity)	0%	10%	0%
Water	-35%	-10%	-30%
Maintenance costs	-5%	10%	0%
Waste disposal	-10%	-70%	0%

Table 11: The change in cost of input per one kilo of output.

Stage Input	Extraction		Separation		Press and neutralization		Net input consumption change	Cost per kilo of production (€)	Net change in costs
	Input share	Change	Input share	Change	Input share	Change			
Fresh water - processing of fresh water	25%	-35%	20%	-10%	25%	-10%	-0.1325	0.000003	0
Supplies including Sodium and Potassium			60%	-100%			-0.6	3.14	-1.8840
Energy (gas, electricity)			10%	10%			0.01	0.84	0.0084
Water	25%	-35%	20%	-10%	25%	-30%	-0.1825	0.000003	0
Maintenance costs	60%	-5%	20%	10%			-0.01	1	-0.01
Waste disposal	60%	-10%	5%	-70%			-0.095	0.26	-0.0247
Total change in € per kilo of production									-1.9103

### 6.2.4 Conclusion

From the preliminary data that we have, it can be concluded that the transition to green alginates requires a considerable upfront investment of almost €12 million. This initial investment results in green alginate types which generate a higher revenue. The green transition results in an increase in the sale price of €2,000 to €4,000 per ton of alginate. In addition, the green transition reduces the costs of supplies, maintenance and the operating costs of water and waste disposal. The total reduction in cost, is about €1.91 per kilo of production or €1910 per ton.

Therefore, ALG needs to produce a minimum of 2,444 tonnes of green alginate to break even, excluding maintenance, capital and opportunity costs (= 12,000,000/(3000+1910)). Because the switch to green alginate results in a 5-7% increase in production, this break-even volume will be reached relatively quicker than with the current production process. Furthermore, there could be better changes to valorise the

byproduct of this new separation process, because it will be less contaminated with external intrants and chemicals.

There are two points worth mentioning here.

- First, the analysis does not include the positive environmental effects of green transition. As a result, the total benefit of green transition is (even) higher than what we estimated here.
- Second, we did not incorporate the financial costs of the upfront investment in the analysis. It matters how the company is going to finance the investment, from its own resources or by other means such as a loan or issuing equity.

### 6.3 Discussion and recommendations

The two analyses presented above have focussed respectively on (1) the cost of producing *S. latissima* at ALO and (2) the expected change in the cost of producing alginates when shifting from current to green alginates.

For reasons of confidentiality, no absolute numbers could be presented. Based on the data presented we cannot conclude whether it is economically feasible to use ALO produced *S. latissima* to produce green alginates.

Currently, ALG uses wild-harvested seaweed to produce alginate. From data available in other publications, it is clear that – looking at the price – cultivated seaweed cannot currently compete with seaweed harvested from the wild. Besides the price being an obstacle, there is also the needed production volume that seaweed farming at this point in time cannot realise. Cultivated seaweed could become an alternative to wild harvesting if natural resources would decrease, if harvesting the required volumes would no longer be possible, or if the production costs of cultivation would dramatically decrease. Another consideration could be to cultivate *Saccharina* strains with higher alginate content.

If we look at the costs of the green alginate production process, it is worth noting that this process not only yields alginate with an expected higher sales price, but also at lower costs. Cost reductions are especially expected from the changed separation process, where no additional input is needed and time consumption is decreased enormously.

Future considerations for ALG to further reduce the price include investing in machinery to reduce maintenance costs, reducing energy costs by reducing the viscosity level of the alginate paste and better valorising the by-product generated. Analysis on the potential of valorising byproduct of green alginate could not be done in the time-frame of this deliverable.

## 7. DISCUSSION AND CONCLUDING REMARKS

In this deliverable, we have conducted value chain analyses for three innovative seaweed products. Fibre (P4) derived from dried *S. latissima* produced in the Faroe Islands; pig feed supplement (P5) containing fermented *S. latissima* cultivated in the Faroe Islands and green alginates (P7) using fresh *S. latissima* cultivated in France. The main purpose of the analyses was to get a good understanding of the cost of producing and processing seaweed into the flagship products.

For all the flagship products, the cost of cultivated seaweed represents a major cost. Due to this, a lot of focus has been on identified how the cultivation cost can be reduced. The value chain analysis on *S. latissima* production in the Faroe Islands highlighted that labour cost contributes greatly to the final cost of both dried (48%) and fermented macroalgae (38%). High labour costs have been identified as a common challenge among macroalgae producers in Europe. The analysis showed that the biggest cost reduction comes from increasing the processing capacity. This would allow for upscaling the harvesting and taking advantage of the full capacity of the boat

and transport container in seaweed cultivation. Additionally, several cost categories can be reduced by simply upscaling the production and producing at full capacity. This would decrease the costs associated with materials and depreciations of equipment as the throughput increases. Furthermore, it would enable the company to take advantage of the economics of scale that come with expanding production.

The cost of energy is quite significant in the dried macroalgae value chain, the majority of the cost is located in the processing part of the value chain as drying macroalgae requires a high energy consumption. Alternative ways to reach storage stable products should therefore be explored in the near future and the upcoming techno-economic analysis in Deliverable 8.5 could investigate potential solutions.

For the biorefinery process of fibre (P4), sensitivity analysis (estimation under conservative and optimistic sets of assumptions) demonstrated that the results are strongly influenced by parameters such as prices and yields. At the same time, these parameters are highly uncertain. Other model elements, such as investment cost, amounts and costs of inputs, are approximations and are subject to error due to variation and confidential nature of the data. Therefore, the results, especially regarding upscaling scenario, should be considered as illustration of potential costs and benefits.

The two analyses on green alginate production have focused respectively on the cost of producing *S. latissima* at ALO and the expected change in the cost of producing alginates when shifting from current to green alginates. For reasons of confidentiality, no absolute numbers could be presented. Based on the data presented we cannot conclude whether or not it is economically feasible to use ALO produced *S. latissima* for the production of green alginates.

Green alginate production means using less harmful chemicals and preservatives and more environmentally friendly techniques. Based on the information provided by the company, the green transition requires an upfront investment of €12 million. Production of green alginates improves the market position of ALG and enables it to sell alginates for €2000 to €4000 more per kilo. In addition, the green transition results in a reduction in the costs of inputs, €1.91 per kilo of production.

Having identified the areas of potential cost reduction the work carried out in this deliverable will serve as a basis for further analysis. Upcoming deliverables will focus on exploring alternative technologies and changes to the production process and how these may affect the cost structure of the value chains. Although it is clear there are many areas where the cost of cultivation and processing should be reduced there is significant potential of macroalgal products in various product application. Reducing costs upstream will not only have a benefit on the three products explored in this paper but are likely to contribute to overall industry expansion.

## DATASET

For this deliverable surveys and interviews of companies have been added to a dataset, which is confidential. The description of this dataset can be found in the Data Management Plan of SeaMark openly available to Zenodo: <https://doi.org/10.5281/zenodo.7261409>.

The dataset in itself will not be publicly available as it contains information that are commercially sensitive for the companies.

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