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Financial feasibility of seaweed farming in Norway

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Abstract

Seaweed farming is considered to have a high potential in Norway, but some uncertainties about its profitability remain. This thesis investigates the economic feasibility of small-scale seaweed farming in Norway through economic modelling and sensitivity analysis. In total, 768 farming scenarios are constructed in this study to test the profitability of different techniques and methods for seaweed cultivation in a 9 hectares coastal area. The model identifies a number of opportunities to improve profitability and shows that under certain conditions, seaweed farming can be profitable in Norway. Those conditions include using horizontal growlines with a narrow spacing of 4m and the method of partial harvesting. Under those conditions, the seaweed farm model yields a net present value of NOK 1 513 561 after 10 years, considering a discount rate of 10%. Those relatively low profits imply that the risk associated with the project is relatively high, with a -19% decrease of either the yield or the market price of seaweed bringing the net present value to 0. The industry and its stakeholders must therefore continue their efforts to increase profitability of small-scale seaweed farming in order to significantly develop it in Norway.

1 Context

1.1 Introduction

Seaweeds, an informal synonym of macroalgae, have been exploited by humans from millennia. In the last 50 years, the increasing demand for seaweed products in a context of insufficient wild stock for harvesting triggered an extreme growth of seaweed cultivation (Wiencke and Bischof, 2012). The Asian continent is indubitably dominating this industry, being responsible for over 97% of the global production of cultivated seaweed in 2014. China alone is producing 60% of the cultivated seaweed in the world in volume (Ferdouse *et al.*, 2018).

But the dominance of Asia in this industry might be challenged in the future. A starting point of this shift could be placed in 2009, when the Food and Agriculture Organisation and (FAO) and the United Nations Environment Programme (UNEP) came together to produce a report on the substantial contribution of vegetation on coastal ecosystems to sequester carbon. This report was the first to employ the expression "Blue Carbon" (Nellemann and GRID-Arendal, 2009). In it, was highlighted the important role seaweeds can play to address climate change while offering other valuable externalities, including fisheries enhancement or economic development. Since then, the popularity, investments and production of seaweed have been growing at a fast pace, especially outside Asia. Norway has realised there could be an opportunity to pursue, and interest for seaweed has also expanded in the country over the past decade, with the creation of various seaweed farms along the Norwegian coast (Norderhaug *et al.*, 2020; Phyconomy, 2022).

1.2 Scope of the study

Despite being a growing field, with new investments and organisations being created over the world to exploit this resource, it is still unsure whether seaweed farming can hold its promises in term of profitability in the western world, especially in Norway, where labour costs are much higher than in Asia (The Fish Site, 2022).

By investing in marketing and focusing on high-end products with a relatively low volume (e.g., food), a seaweed farm could without a doubt thrive in the Norwegian environment. But this is not the main focus of this study. Instead, the focus is put on whether Norwegian seaweed farms could shape an industry supplying markets with a lower value and a higher volume such as feed, phycocolloids or bioplastics. More specifically, the current study is aimed at knowing whether a

network of small-scale farms could be the backbone of this industry.
The emphasis is put on small-scale farms because seaweed farming have shown to be a good replacement or complement of small-scale fisheries faced with challenges such as climate change (The Guardian, 2020). Additionally, small-scale fisheries are and have been a long contributor to the livelihood of coastal communities in Norway and the decentralized settlement structure of the country (Jentoft and Chuenpagdee, 2015).

Therefore, the questions that are explored in this study are:

- Can a small-scale seaweed farm supplying high volume market segments be profitable in Norway?
- What measures and processes would provide an optimal profitability?

A model of a seaweed farm, presented in section 2, is built in this study to answer those questions. This model is a 9-hectare seaweed farm growing sugar kelp on a coastal area in Norway to supply the feed market. The current study will help determine under which conditions this model displays the highest profitability.
Beforehand, some context about the seaweed industry in the world and more especially in Norway is provided.

1.3 Overview of the seaweed market

Seaweeds, or marine macroalgae, have been used for thousands of years by human societies. The oldest documented use of seaweed is dated 14 000 years ago in the Chilean coast, for food consumption (Dillehay *et al.*, 2008). On the Asian continent, the first evidences of seaweed consumption appeared 1 500 years ago in Japan (Wiencke and Bischof, 2012). Since then, the use of seaweed has expanded to other uses and markets. The 3 main groups of seaweed, namely green seaweeds (Chlorophyta), brown seaweeds (Phaeophyceae) and red seaweeds (Rhodophyta) are now exploited in many different sectors and supply chains (Puppala, 2012). The aim of this section is to describe the main markets in which seaweeds are used and provide an overview of the financial landscape and potential of seaweed cultivation.

Even if the uses of seaweed have expanded since the early days of seaweed harvesting and cultivation, the species exploited are concentrated into a relatively small number of species. Of the 13 000 species of seaweed documented, only about 221 species are of commercial value, of which only 10 species only are intensively produced (Guiry, 2012). Among those, the Japanese kelp (*Saccharina japonica*) account to 33% of the global production (Ferdouse *et al*., 2018). The global seaweed production reaches 32 million tons per year, for a value of over USD 14 billion. This makes it the main aquaculture activity in the world, especially in volume (Ferdouse *et al*., 2018). Some of the seaweed is harvested instead of cultivated, but that proportion remains relatively low globally. China, the main seaweed producer in the world with about 60% of the global production, harvests less than 2% of its production (Ferdouse *et al*., 2018).

1.3.1 Food and feed

The first use of seaweed was as food for human consumption, and this is still the main market for seaweeds nowadays. Between 20% and 45% of seaweed production is destined to the food market, driven by a high demand in Asia. China, Japan and the Republic of Korea are the largest consumers in the world, due to their tradition of using seaweed in their respective cuisines (Ferdouse *et al*., 2018; ANSES, 2020). The popularity of sushi outside of Japan contributed greatly to the consumption of seaweed in other areas of the world, namely Europe and America (Ferdouse *et al*., 2018). Seaweeds are a rich source of iodine, magnesium, calcium, sodium, potassium and vitamin B12, A and K, and therefore using seaweed for human consumption is linked with numerous benefits (Ferdouse *et al*., 2018). The high concentration of iodine is especially advantageous considering iodine deficiency is a major cause of cognitive disabilities which affects about 2 billion people around the world (Zimmermann, 2009). This affliction also concerns Norway, where moderate levels of iodine deficiency have been observed (Aakre *et al*., 2021). However, regular consumption of seaweed could also lead to excessive intake of iodine and arsenic, leading to health risks (Aakre *et al*., 2021).

The benefits of seaweed as a food source also makes it a desirable inclusion into feeds, either for aquaculture or land animals. The use of seaweeds in animal feeds can be traced back to the beginning of the 20th century when seaweeds were used for feeding cows by the shore. Those practices have occurred in France, Scotland, the Scandinavian countries and Iceland. The North Ronaldsay sheep, a breed of sheep living on an island in the North of Scotland even evolved to rely exclusively on seaweed for its diet (Ryder, 1981). Since then, researches have been conducted to study the possibilities of incorporating seaweeds in the feed of different farmed animals, whether as an additive in their usual meal, or as a key component. For example, the seaweed *Asparagopsis armata* was found to drastically reduce methane emission of ruminants in *in vitro* experiments at low concentrations (Machado *et al.*, 2014), and *Ulva lactuca* (sea lettuce) can be fed to lamb with a proportion in their diet of up to 20% (Morais *et al.*, 2020). Improvements in body weight, general health or egg production was also found in poultry after inclusion of seaweed in their diets, both for broilers or laying hens (El-Deek *et al.*, 2011; Al-Harthi, 2014; Makkar *et al.*, 2016; Morais *et al.*, 2020).

Using seaweed in the feed of marine species also shows potential, and this practice is thought to be generally underutilized (Kamunde, Sappal and Melegy, 2019). This use would be particularly suited for Norway considering its extensive aquaculture industry of Atlantic salmon and since this species has shown to benefit from the inclusion of seaweed in its diet. Adding kelp in the feed of salmon smolts improves simultaneously the weight, length and conversion ration of the salmons (Kamunde, Sappal and Melegy, 2019). A study conducted on rainbow trout, another salmonid, also proves that adding sugar kelp (*Saccharina latissima*) to their feed improves the lipid composition of the fillet, as well as protecting the fish against the effects of stress (Morais *et al.*, 2020).

1.3.2 Fertilizers

Similarly to food, using seaweed to act as fertilizer also has a long history. It was already a way to enrich infertile soils in Roman times (Pereira and Cotas, 2019). Ancient Greeks, Chinese and Vikings were also using seaweeds in agriculture, though as mulches instead of fertilizer (Aitken and Senn, 1965). The production of fertilizers from seaweed then developed in Norway in the 18th century with the production of potash (Frangoudes, 2011). This industry expanded throughout the 19th and 20th centuries, before declining following the invention of fertilizers made from nitrogen (Arzel, 1984). Even if artificial fertilizers are predominant nowadays, the positive effect of seaweed on plant growth is now well documented. Seaweed sap could for example be used to increase the yield and the nutrient content of wheat, which is one of the most cultivated cereal in the world (Shah *et al.*, 2013). But the replacement of conventional fertilizers by seaweed fertilizers would face many obstacles, one of which being their higher cost. However, seaweed fertilizers could still expand, driven by the organic market and other niche sectors. Furthermore, due to their superior results in term of carbon footprint and nitrogen cycle, a legislation change such as a higher carbon tax could boost the global use of seaweed fertilizers (Zhou *et al.*, 2019; Seaweed For Europe, 2020)

1.3.3 Bio-packaging

Since its invention about 100 years ago, plastics have developed exponentially and have now a key role on our lifestyles (Puppala, 2012). Already, their ubiquity and long degrading time is causing damages to biodiversity, especially in marine environments. Furthermore, plastic production is expected to triple by 2050, consuming by that time about 20% of the global production of oil (Chia *et al.*, 2020). The use of fossil fuels and the carbon intensive process of their manufacturing could lead the production of plastics to account to as much as 20% of the yearly carbon budget in the near future (Abdul-Latif *et al.*, 2020). Therefore, intents at improving biodegradability and limiting the use of fossil fuels led to the development of bioplastics (Puppala, 2012). As of today, 80% of the bioplastic produced is coming from land crops like wheat or corn, increasing concerns on food security (Greenwell *et al.*, 2010). In addition to requiring no land, low capital, low technology and yielding high level of biomass, seaweeds are also naturally rich in polysaccharides, which is a major component in the manufacture of bioplastics (Rizal *et al.*, 2021). However, bioplastics from seaweeds still display some major flaws that would need to be addressed and researched before seaweeds can be considered as a replacement to oil for the manufacturing of plastics. Thus, bioplastics from seaweeds tend to have lower mechanical and thermal properties, while being a weaker barrier against water than conventional plastics (Rizal *et al.*, 2021). Also, they are still more expensive to produce than conventional plastics (Lim *et al.*, 2021).

1.3.4 Pharmaceuticals

Seaweeds have been used as a source for food by different civilisations for millennia. Considering their nutrient-rich nature, the possibility to use them as a pharmaceutical was logically discovered early, and ancient Greeks and Romans were already aware of their benefits. In Asia, seaweeds were also largely exploited in traditional medicine (Hayes, 2012). Following this tradition, the possibility of using seaweed as pharmaceuticals and to exploit their benefits beyond the scope of food consumption has become an important research field (Shannon and Abu-Ghannam, 2019). Many bioactive compounds are present in seaweed, with many yet to be discovered. Already, studies have explored and documented the promising results seaweeds can have, acting as antibacterial, anticancer, antiviral, antidiabetic, anti-inflammatory and anticoagulant (Ganesan, Tiwari and Rajauria, 2019). For example, in the case of type 2 diabetes, a supplement of 48g of dried seaweed proved to have considerable benefits on the blood glucose level of patients. An important property considering over 600 million people suffer from this condition worldwide (Kim *et al.*, 2008). Also, the antibacterial properties of seaweed could be used to address antibiotic resistance, a growing problem that could kill an estimated 10 million people per year by 2050 (Shannon and Abu-Ghannam, 2019).

The benefits of seaweed in the medical sector are however not limited to being used as pharmaceutical. Compounds in seaweed allow the manufacture of biomaterials which, due to their qualities, can be used in regenerative medicine, wound healing and for engineering tissues (Yegappan *et al.*, 2018)

1.3.5 Additives

Polysaccharides are an important component of seaweed. In addition to be a compound used in the manufactures of bioplastics, the 3 polysaccharides derivates which are agar, carrageenan and alginate, are widely used industrially especially as food additives to be used as thickening and sizing agents (Sandford and Baird, 1983). Carrageenan, for example, have been used for over 1 000 years for making gelatine (FAO, no date). Those 3 compounds are called phycocolloids and are mainly responsible for the global trade of seaweed and seaweed derived products. They represent a growing market of USD 1 billion per year (Pangestuti and Kim, 2015) and can be found in many everyday products. 80% of the global production of agar and carrageenan and 30% of the production of alginate is used by the food industry (Pangestuti and Kim, 2015).

1.3.6 Cosmetics

Another large consumer of phycocolloids is the cosmetic industry, that also uses those compounds as thickeners or emulsion stabilizers in many creams, lotions, ointments, or dentifrices. Agar also helps stabilize and control the moisture content of liquid soaps, deodorants, shaving cream or anti-ageing creams (Pereira, 2018). But phycocolloids are not the only compounds from seaweed that are used in the cosmetic industry. Other compounds are used for their bioactive properties, and considering many seaweed species have proved their benefits for human skin, they can be found in numerous skin treatment products including antiaging, antiwrinkle, photoprotection, or moisturizer agent products (Kalasariya *et al.*, 2021). In the future, the proportion of seaweed derived compounds in cosmetic is excepted to grow, benefiting from a large pool of undiscovered bioactive compounds (Hayes, 2012) as well as from a trend favouring naturally sourced products (Kalasariya *et al.*, 2021).

1.3.7 Biofuels

The latest report of the Intergovernmental Panel on Climate Change (IPCC) on mitigation of climate change indicates that to limit climate change to 1,5°C, an important portion of the fossil fuels reserves will need to stay unburnt, and the global CO_2 emissions will need to be nearly halved before 2030 (IPCC, 2022). But despite these findings, the use of fossil fuels is expected to increase in the coming years (IEA, 2021). This opens an opportunity for biofuels, which are renewables and can replace fossil fuels with a much lower carbon footprint. This shift could furthermore be set in motion relatively quickly, considering using biofuels does not necessitate a large modification or replacement of existing engines, fleets and infrastructures (Demirbas, 2008). And indeed, the production of biofuels has increased over the past decade (British Petroleum, 2019). Biofuels can be produced from different sources, including land crops, wastes, genetically engineered organisms and seaweeds (Gambelli *et al.*, 2017). Among those options, seaweeds are a promising source of biofuels considering they are not using any land. However, the profitability of such biofuels is in question, as studies have concluded that the production of biofuels from seaweed is not economically viable (Soleymani and Rosentrater, 2017). The reason behind this high production cost comes in part from the drying process, as seaweeds have a high moisture content (Giostra and Silva, 2018). In the future, some improvements, higher volumes or new transformation processes could bring this cost lower, and make the production of biofuels from seaweed a cost-effective solution (Soleymani and Rosentrater, 2017).

Those different markets uses and the number of companies involved in each for macroalgae and microalgae are presented in Figure 1.

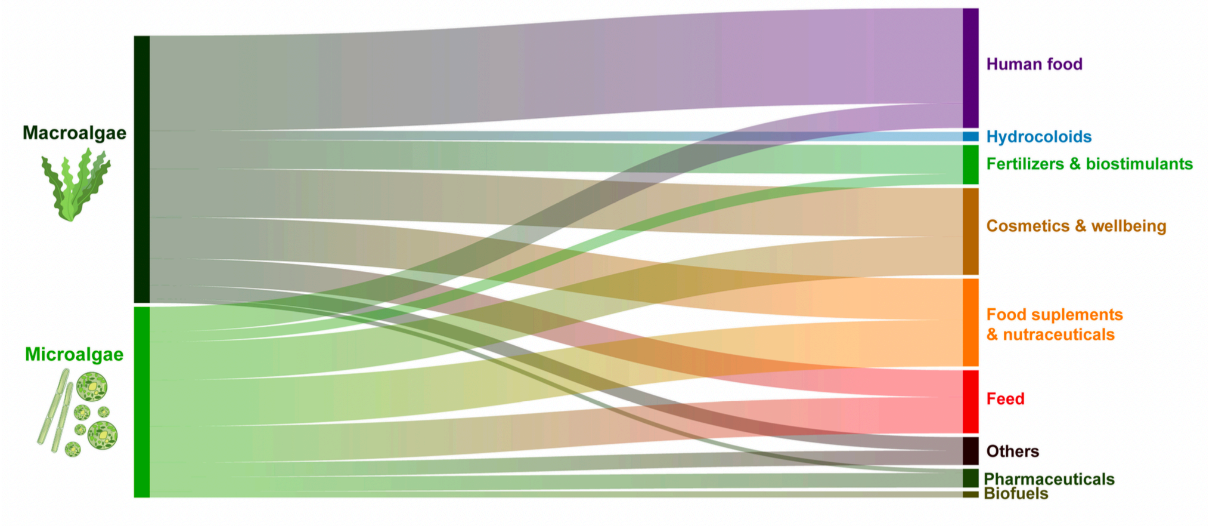

Figure 1 Biomass application of macroalgae and microalgae by number of companies (Araújo et al.*, 2021)*

1.4 Structure of the seaweed market

The many uses of seaweed are structuring the production around different markets. Among those markets, some like food are characterised by small volumes and high value, while others like biofuel rely on the other end on high volume and low quality and value. This structure is illustrated in Figure 2.

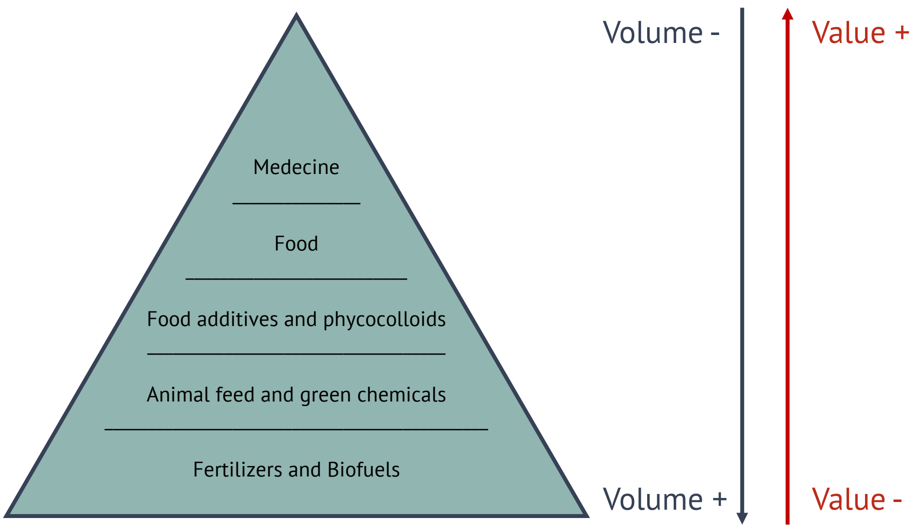

Figure 2 Structure of the seaweed market (adapted from Lange et al., 2020)

The food market for human production represents about 83% to 90% of the production value (Kerrison *et al.*, 2015). Increasing the production of seaweed means increasing the amount of seaweed being consumed as food, but especially it means being able to supply markets with a lower value, like biofuels or bioplastics. In other word, a shift from the top of the pyramid towards its base (Figure 2). Improving the cost-effectiveness of seaweed production would therefore allow more markets to develop.

Faced with higher labor costs than Asia, some companies in Norway chose to invest in high end markets like human food. While this strategy has proven effective for some, this study is instead aimed at determining whether Norwegian seaweed production can produce profitably for other markets, with a lower selling price.

1.5 Seaweed species farmed in Norwegian waters

The coast of Norway counts many species of seaweed along its coast. Five species are already exploited by Norwegian seaweed farms and those species are listed in Table 1. For the rest of the report, those species are referred using their English name.

Table 1 List of seaweed species farmed in Norway

Scientific name	English name	Norwegian name	Type
Saccharina latissima	Sugar Kelp	Sukkertare	Brown seaweed
Alaria Esculenta	Winged kelp / dabberlocks / badderlocks	Butare	Brown seaweed
Laminaria Digitata	Oarweed	Fingertare	Brown seaweed
Laminaria Hyperborea	Tangle / Cuvie	Stortare	Brown seaweed
Palmaria palmata	Dulse	Søl	Red seaweed
Ulva lactuca	Sea Lettuce	Havsalat	Green Seaweed

About 27 companies are exploiting seaweed in Norway (Phyconomy, 2022), with the number of companies farming each species slightly varying depending on the sources. Norway is the country in Europe with the highest number of seaweed aquaculture companies, which makes it the top producer of seaweed biomass in Europe in volume (Araújo *et al.*, 2021). Sugar kelp and winged kelp are the most popular species farmed in Norway. Based on the figures adopted by the European Commission, about 75% of the companies in Norway are dedicated to those two species (Araújo *et al.*, 2021). This represents 10 companies dedicated to sugar kelp, 7 to Alaria species, three to Laminaria species and one company for each of the remaining group of species, as seen in Figure 3.

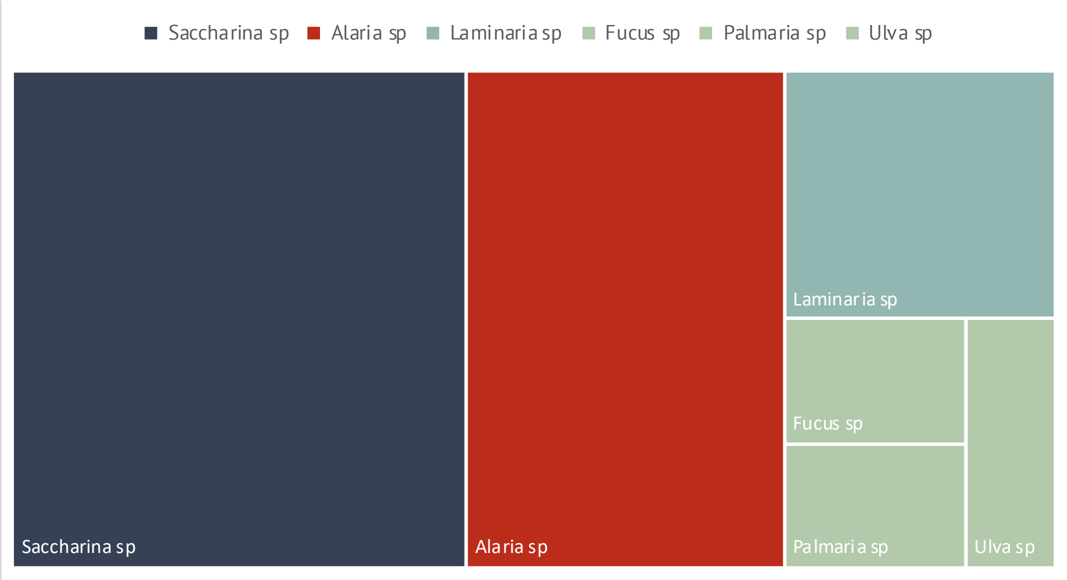

Figure 3 Seaweed species farmed in Norway, by number of companies (data from European comission, 2021)

In term of volume, the difference is even higher, with Fiskeridirektoratet reporting 248t of sugar kelp and 88t of winged kelp farmed in Norway in 2020. All the other species put together represent less than a ton produced that same year (Fiskeridirektoratet, 2021).

The different species of seaweed farmed in Norway are illustrated in the sections below, with the list of companies cultivating them (Phyconomy, 2022).

Sugar kelp (*Saccharina latissima*)

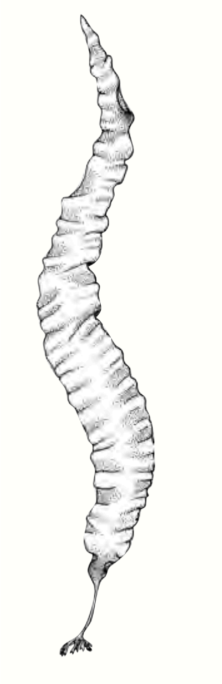

Figure 4 Sugar kelp (Redmond et al.*, 2014)*

Sugar kelp is the most popular species farmed in Norway, representing about 74% of the production of the country, for a total of 248t in 2020 (Fiskeridirektoratet, 2021). It is the most farmed species in the entire Europe, both in term of production volume and number of companies involved in its farming (Araújo *et al.*, 2021), and is often destined for the food market and direct human consumption (Stévant, Rebours and Chapman, 2017). It also attracts most of the interest and the research efforts, which makes data about sugar kelp more available than other species. This is due to its rich nutritional content for food and feed, its broad geographical distribution and its potential for high biomass yields (Araújo *et al.*, 2021). For this reason, this study is focused on this species.

Figure 5 shows how the production of sugar kelp evolved in Norway in the 5 years period ranging from 2015 to 2020.

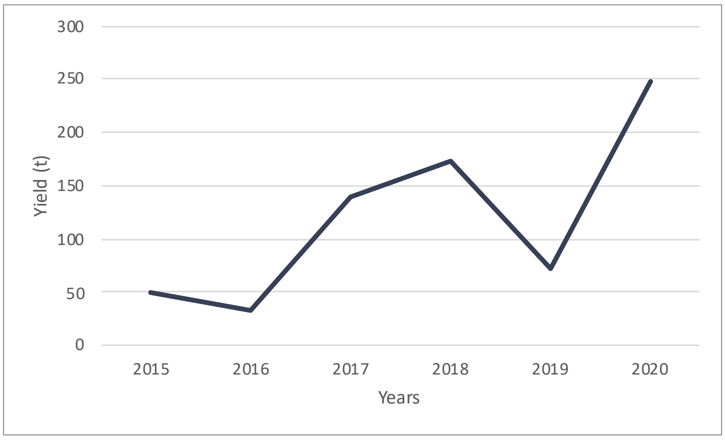

Figure 5 Production of farmed sugar kelp in Norway (data from Fiskeridirektoratet, 2021)

Companies cultivating this species in Norway: Ocean Forest, seaweed solutions, Tango Seaweed AS, Folla Alger AS (Phyconomy, 2022).

Winged kelp (*Alaria esculenta*)

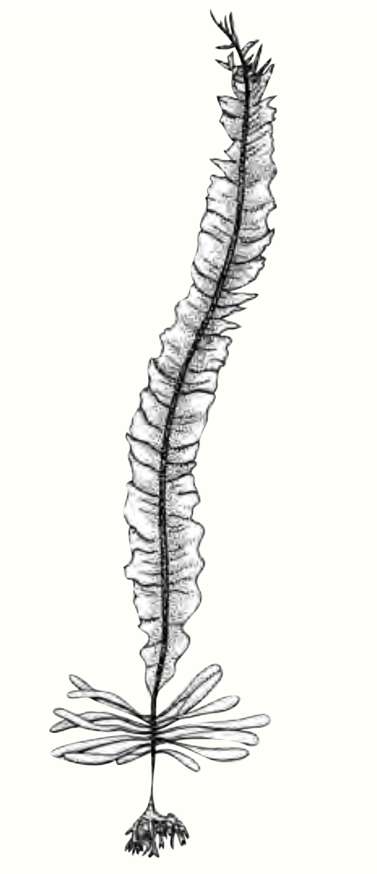

Figure 6 Winged kelp (Redmond et al.*, 2014)*

Winged kelp is the second most popular species farmed in Norway, representing about 26% of the total farmed seaweed in the country. The production was 88t in 2020 (Fiskeridirektoratet, 2021). The evolution of this production can be seen in Figure 7.

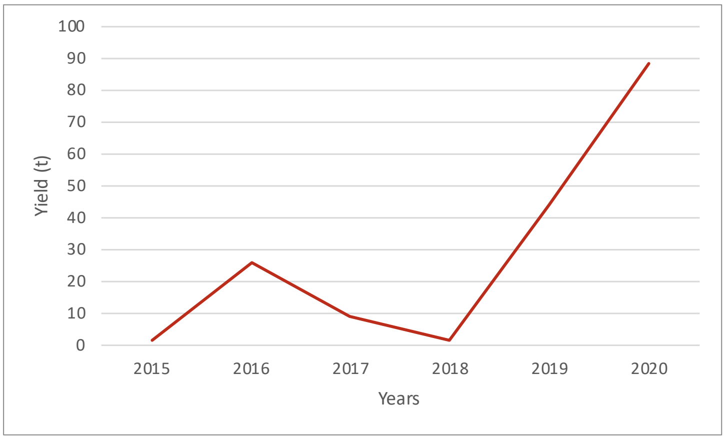

Figure 7 Production of farmed winged kelp in Norway (data from Fiskeridirektoratet, 2021)

Companies cultivating this species in Norway: Ocean Forest, seaweed solutions, Alaria AS, Tango Seaweed AS, Laminaria AS (Phyconomy, 2022).

Oarweed (*Laminaria digitata*)

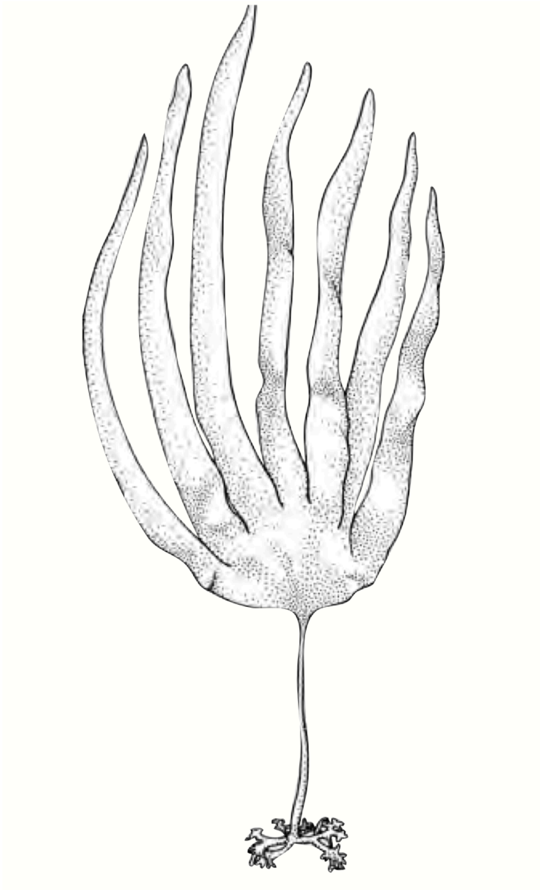

Figure 8 Oarweed (Redmond et al.*, 2014)*

Despite some licenses being granted to companies for the cultivation of oarweed, this species is mainly wild harvested rather than cultivated in European waters (Araújo *et al.*, 2021).

Companies cultivating this species in Norway: Ocean Forest, Alaria AS (Phyconomy, 2022).

Cuvie (*Laminaria hyperborea*)

Figure 9 Cuvie (Wikimedia, 2022a)

The other name of cuvie is tangle, or sea tangle. However, the English name “tangle” is a generic name for different kelp species. Tangle could be used as a name for cuvie (*Laminaria Hyperborea*), oarweed (*Laminaria Digitata*) or kombu (*Saccharina japonica*). Therefore, the name “cuvie” is preferred to describe the specie *Laminaria Hyperborea*.

Similarly to oarweed, cuvie is an important species for aquaculture, but it is mainly sourced from wild harvesting in Europe (Araújo *et al.*, 2021).

Companies cultivating this species in Norway: Ocean Forest (Phyconomy, 2022).

Dulse (*Palmaria palmata*)

Figure 10 Dulse (AlgaeBase, 2022)

Dulse is one of the most popular seaweed species in the Western world to be consumed as snacks and condiments in the food market. It has been consumed in Europe for centuries, however its use for human diet have greatly decreased in recent history in Norway (Mouritsen, Rhatigan and Pérez-Lloréns, 2019). Apart from the food market, this species is also showing high potential to be used as feed in abalone aquaculture (Evans and Langdon, 2000).

Companies cultivating this species in Norway: Ocean Forest, seaweed solutions (Phyconomy, 2022).

Sea Lettuce (*Ulva lactuca*)

Figure 11 Sea Lettuce (Wikimedia, 2022b)

From the report established by Phyconomy, only one company in Norway is cultivating this species, Seas of Norway (Phyconomy, 2022). However, the future of the cultivation of this species in Norway is believed to be uncertain, due to profitability reasons (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022).

2 Method

The present study is a feasibility analysis built using the software Microsoft Excel (version 16.60) and applied on a bioeconomic model of a seaweed farm. The analysis studies and compares through the use of the Net Present Value (NPV) different farming processes and techniques in order to determine which displays the highest profitability.

2.1 Feasibility analysis

A feasibility analysis is a tool used to investigate how a project would perform under a set of assumptions and see if it is technically and economically feasible. Different scenarios are created and evaluated to determine which of them display the highest potential (Matson, 2004).
The feasibility analysis is accompanied by a sensitivity analysis, which analyses the responses of the model when the base assumptions are changed (Matson, 2004). Sensitivity analyses are used

to identify the most significant risks to the project and help decision-making towards risk mitigation. Furthermore, those results are playing an important role in the verification and validation of the model (Christopher Frey and Patil, 2002).

This type of study helps determine whether a project should be developed, redesigned or abandoned (Mesly, 2017). The objective of the analysis is to determine the profitability of the project, which is the measurement using the total revenue and the total cost. It is assessed using various indicators, but mainly the net present value is used throughout the study.

The net present value (NPV) is chosen because it is often regarded as the most reliable indicator to determine the economic performance of a project (Brealey, Myers and Allen, 2017). Especially, it is used to characterize the profitability of a project, using the following formula (Berk and DeMarzo, 2020):

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t}$$

With:

- R_t = net cash flow during a time period t
- i = discount rate
- n = number of time periods

NPV has been identified as a relevant indicator to analyse the feasibility of aquaculture projects (Mejía-Ramírez, Rocha and Pérez-Rostro, 2020). In our case, it is relevant for two main reasons. The first reason is that NPV integrates the notion of the time value of money. In other words, it recognizes that a monetary unit today is worth more than a monetary unit tomorrow, because of the financial interest it would gather in this timeframe. Therefore, it makes it possible to compare different projects given their potential as an investment regardless of the length of time during which the project runs. Secondly, the NPV relies only on forecasted cash flows of the project. Hence, the NPV is not dependent on the project accounting methods like the way depreciation are computed and reported in the income statement (Brealey, Myers and Allen, 2017). The NPV of a project is then the present value of the future cash flows of a project (Berk and DeMarzo, 2020).

The NPV is first a decision-making tool. Expressing future cashflows in present monetary unit allows to decide whether an investment makes economic sense. Adopting the assumption that investors are looking to increase their wealth, they will invest in projects having a positive NPV with regard to a discount rate (DR) taken as reference. The discount rate represents the return that could be earned in alternative investments, and also integrates the risk component of the investment. If the NPV of a project is negative, then the project costs exceed its benefits and following this rationale, the project should be discarded. On the other hand, a positive NPV increases the wealth of the investor, and a NPV as high as possible is usually sought (Berk and DeMarzo, 2020).

This feasibility analysis therefore determines which project would be the most profitable in the socio-economic environment of Norway by comparing their respective NPVs. Alongside the NPV, other indicators are used, as described in Table 2. The formulas used to calculate them are also added. For NPV and Internal rate of return (IRR), the built-in function included in Excel is used.

Table 2 List of indicators

Indicator	Unit	Excel Formula
Net Present Value (NPV)	NOK	Function NPV applied on DR and the cash flows for each year
Internal Rate of Return (IRR)	%	Function IRR applied on sum of cash flows for each year
Debt	NOK	(Total expenses of year 1) + NOK 200 000
Yield	kg	(Length of growlines for selected layout in m) * (Yield in kg/m)
Breakeven yield	kg	(Average of total expenses for each year) / (price of 1kg of landed product)
Breakeven price	NOK	(Average of total expenses for each year) / (Production)
Cumulated P&L after taxes	NOK	(Sum of P&L for each year) * (1 - 22%)

The IRR is the discount rate that would give a NPV equal to 0. It is therefore expressed in percentage and similarly to the NPV, it depends only on the amount and timing of the cash flows (Berk and DeMarzo, 2020).

The debt represents the money loaned from financial institutions on year 1. Apart from covering all expenses in year 1, it also includes a slack of NOK 200 000 to anticipate the possibility of unexpected expenses on year 1 (contingency value).

The yield is the total production of the farm per year. Unlike the other indicators, it is not financial. It is still added however in order to give an idea of the theoretical production of the 9-hectare sea area and to compare the yield of each scenario.

The breakeven price and breakeven yield are calculated using the average of the total expenses over the 10-year period. Those indicators determine at which yield or selling price the sales would exactly covers all expenses engaged during the period (including depreciations).

The cumulated profit and losses (P&L) after taxes is the sum of all P&L over the 10-year period of the project. The profits are taxed with the 22% corporate tax used in Norway.

2.2 Collection of variables and building of options

Performing a feasibility analysis and producing income statements requires an itemization of revenues and costs for the period studied (Engle, 2012). Therefore, variables dependent on the socio-economic environment of Norway have been collected for all items by both ways:

- Through a literature review using a variety of sources such as scientific papers, online shops or social medias of farms.
- Data collection through interviews with farmers. This qualitative data collection has been used to source new variables, but more importantly it was used as a confirmation that previously found data points and results were in accordance with the hands-on experience of farmers.

Those variables are of different type:

- Production variables such as yield,
- Financial variables such as debt interest rate,
- Equipment variables such as the cost of a buoy or a meter of line.

But not all variables have the same importance in the profitability of the project. The general profitability is mainly dictated by three main variables and group of variables, which are 1) the running cost of the farm, 2) the yield and 3) the market price of the landed product.

The general cost of running the farm could be isolated as one group of variables that is independent from the species studied. This is because the methods for farming kelp species, or even some other species of seaweed, are very similar, and so are the operating costs (Bak, Mols-Mortensen and Gregersen, 2018). However, the variable associated to the yield in Norway and the selling price of the landed product are both species dependent and have a substantial influence on the profitability of the project as a whole (Figure 12).

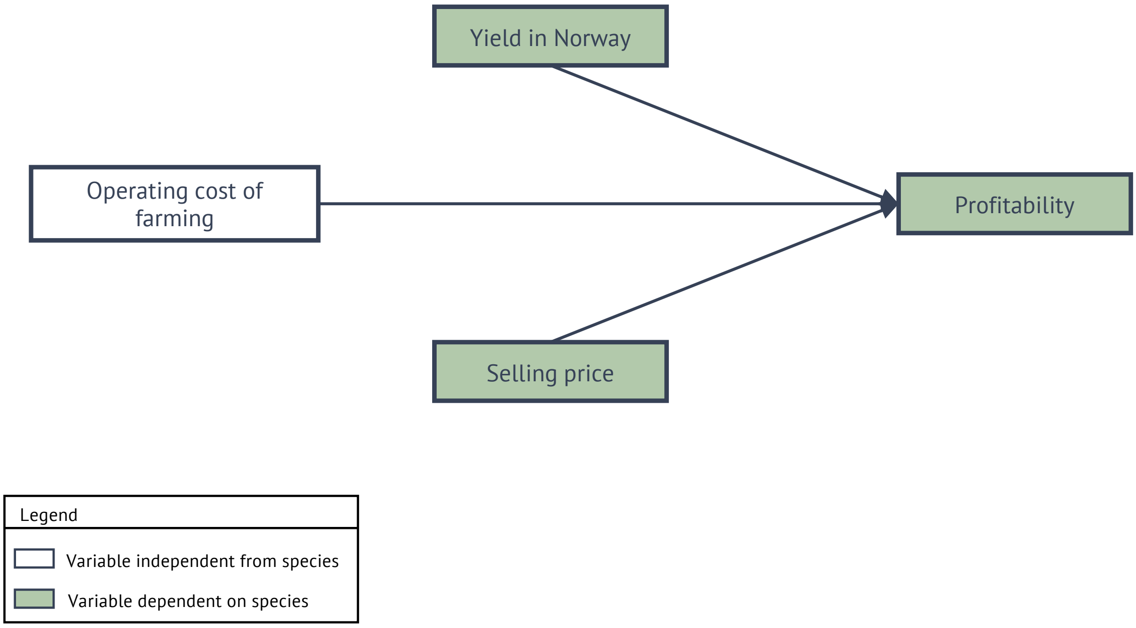

Figure 12 Structure of the variables

Most variables described in this section are related to the cost of operating the farm, but because of the importance of the yield and the selling price, those 2 variables are detailed in depth in separate paragraphs (see sections 2.2.7.1 and 2.2.7.2). Considering yield and market price have been sourced with adequate confidence for one species only, this feasibility study is focused on sugar kelp exclusively. However, finding the selling price and the yield for another species with enough accuracy would allow to easily expand the results of this feasibility study to more species than only sugar kelp.

The production process is divided into 6 main steps as seen in Figure 13. Two cycles are repeated periodically in this production process:

- Material replacement happens every 15 years for structural sea gear, and every 5 years for active sea gear
- Re-seeding occurs once a year in case of full-harvesting and once every 2 years in case of partial harvesting.

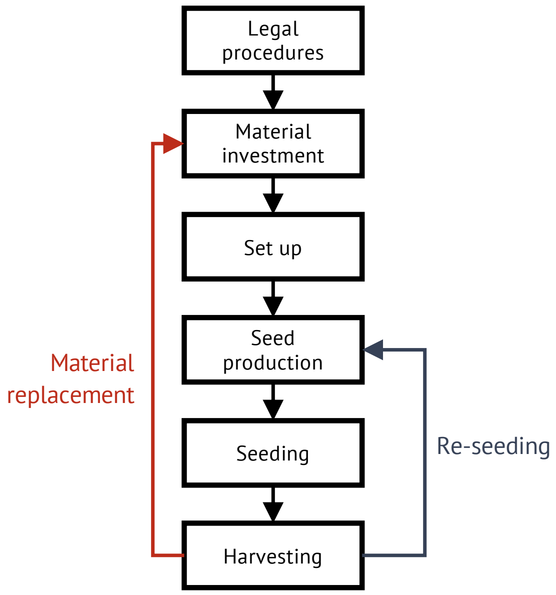

Figure 13 Steps of the production process

Each step of the production can be achieved by different ways or is the consequence of different decisions, and the different possibilities for each step are referred throughout the study as "options". The collection of variables has been executed simultaneously with the construction of the options for each step of the production process. Some steps of the production process also include some sub-steps, as seen in figure 2.

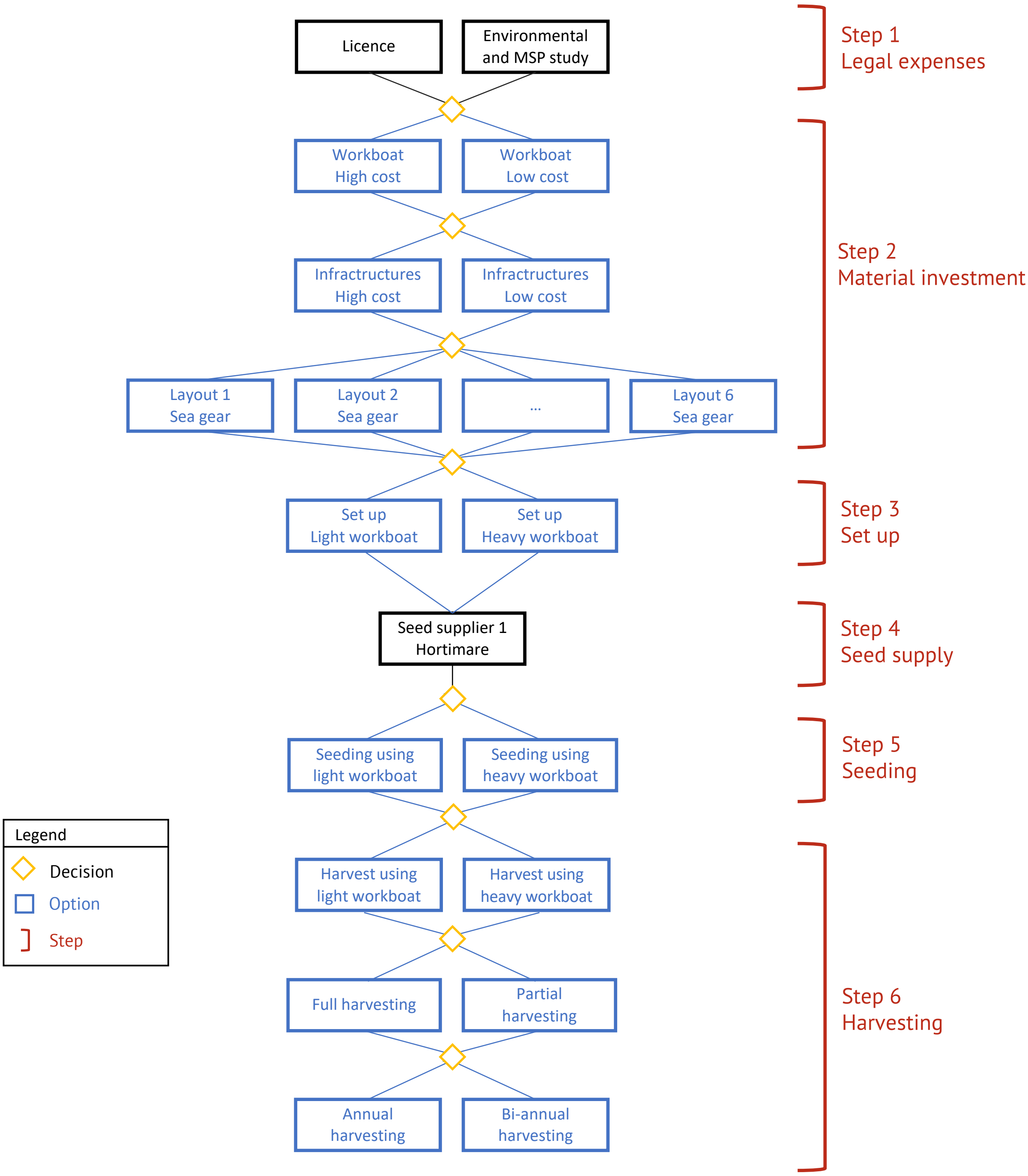

Figure 14 Flowchart options

2.2.1 Step 1 – Legal expenses

The step 1 designating the legal expenses has the particularity of not containing options, as the different expenses in this section can be considered compulsory, either by law or by business rationale.

2.2.1.1 License

A license is compulsory for any aquaculture project in Norwegian waters. The conditions of the attribution of new licenses for farming seaweed are described in the section FOR-2004-12-22-1799 of the Aquaculture act, titled "Regulations on permits for aquaculture of species other than salmon, trout and rainbow trout". This license gives right to farm all species of seaweed. The application fee is set at NOK 3 000, with a ceiling price of NOK 200 000 if the application is accepted (Lovdata, 2004). The delay for the processing of the application seems to vary between 6 months and 10 months (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). Furthermore, the Directorate of Fisheries (Fiskeridirektoratet) may withdraw an aquaculture permit if no production has occurred in the 2 years following the approval of the license (Lovdata, 2004).

2.2.1.2 Environmental and Marine Spatial Planning study

The environmental survey is necessary to determine which spot would be best for the implantation of a farm. This step is important considering the yield of seaweed can significantly vary depending on the location (see section 2.2.7.1 about the yield in Norway). Not only it is important, but it is also largely required. The application often requires to provide information on the current at the site, as well as environmental data. In theory, and as described in the Aquaculture Act, the realization of a so-called NS-9410 or B-Survey (B-undersøkelse in Norwegian), which is the environmental study required for the implantation of a fish farm, is not required for an application for seaweed farming. In practice however, this extensive study, only performed by an approved body, is usually asked to be included in the application as well.

In addition to an environmental survey of the desired location, the application process requires to assess issues related to marine spatial planning (MSP). Therefore, the applicant must make sure the farming activity does not come in conflict with other types of aquaculture, other uses for the site or with biodiversity and conservation, as described in the paragraph 7 of the forementioned act (Lovdata, 2004).

The cost of such an environmental and MSP study is around NOK 120 000 (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). Among the companies accredited to perform a B-Survey in Norway there are Akerblå, Aqua Kompetanse, Akvaplan-niva, Argus Miljø, Møreforsking MARIN or Bio Consult.

Table 3 Options of step 1 - Legal expenses

Options	Unit	Value
1 Legal expenses		
1.1 Licence	NOK	203 000,00
1.2 Environmental and MSP study	NOK	120 000,00
Total legal expenses	NOK	323 000,00

2.2.2 Step 2 – Material Investment

The step 2 about material investments contains 3 sub-steps related to the light workboat to monitor the farm during the year, the land infrastructures and finally the sea gear (buoys, anchors and lines) which depends on the layout decided for the farm.

2.2.2.1 Light workboat

Mainly 3 groups of operations need to be performed on the farm: monitoring operations, light operations and heavy operations.

Monitoring operations include measuring the growth and biofouling of the seaweeds, as well as inspection of the state of line and buoys, from the surface or by carrying a diver. Those operations can be performed by a small open boat without cabin or inboard engine.

Light operations require a winch mounted on an open decked boat, a device needed in order to regularly lift the growlines to the surface. Considering the growline is empty and light, setting the seeded line around the growline in autumn is a light operation.

On the other hand, heavy operations consist mainly of harvesting every summer, where the weight of the growline and of the harvested seaweed usually requires the use of a larger boat equipped with a crane and a winch. The initial set up of the farm, with the lowering of anchors, would also be considered a heavy operation.

The feasibility analysis will be based on the use of a light workboat in order to perform monitoring and light operations. This workboat is owned by the farm and this step contains 2 options, a low-cost option and a high cost one, as presented in Table 4.

Looking at the cost of each option and their years of service, it appears clear that the low-cost option is more cost-effective and should therefore be favoured. The high-cost option is added in order to provide a range of costs for such an item, both to cover uncertainty and to determine the impact of a different cost on the general profitability of the project. Those two options therefore provide the possibility of performing a sensitivity analysis on this item.

See appendix for additional information on what type of boat and which models could be used as a light workboat (Section 5.2.1).

2.2.2.2 Land infrastructures

The land infrastructures encompass all the buildings needed in order to allow the farming of seaweed at sea. The main costs included in this step are a dock and a warehouse in the vicinity of the farm. The dock is needed to moor the service boat, and a warehouse is necessary to store the sea gear between the harvest and the seeding season, to perform maintenance work and preparation work. A low-cost and a high-cost option are available in this step, presented in Table 4.

Similarly to the workboat, the low-cost and high-cost options of the land infrastructures are provided in order to perform a sensitivity analysis and see how the cost of land infrastructures is impacting the profitability of the scenario.

See appendix for calculations and additional information (Section 5.2.2).

2.2.2.3 Sea gear

The sea gear represents all the gear that is laid in the water column to allow farming: anchors, lines, buoys, etc. The cost related to sea gear is highly dependent on the farm layout chosen, and the different layouts are described below. To analyse the cost of the sea gear, it is divided into 2 categories: the structural sea gear and the active sea gear. The anchors, deadweigths and anchor lines are the structural sea gear and have a lifespan of 15 years, while the growlines and surface buoys are the active sea gear, with a lifespan of 5 years. Those lifespans have been estimated based on the findings from the Ocean Rainforest project in the Faroe islands (Bak, Mols-Mortensen and Gregersen, 2018).

The farm layout is the step that includes the most options and is likely to impact the most the profitability of the project as a whole. The farm layout describes the many ways an area of water could be filled in order to grow seaweed. Along the Norwegian coast, we can already observe many different layouts being used. All the layouts used in the feasibility analysis are shortly described here, with the length of growline, cost of active sea gear and cost of structural sea gear for each, presented in Table 4. The layouts are described in length in the Appendix section, with the detail of the costs.

Layout 1 - Single line layout with fluke anchors

In this layout, the growlines are independent and attached on each side by an anchor. This layout is the simplest, and the cheaper to install, considering a light workboat can set up the structural sea gear (a fluke anchor weights 35 kgs). However, fluke anchors need 5 times more length of anchor line than depth in order to be effective (GreenWave, 2022), which limits the length of growline in the sea area. The spacing between each growline is 12m, which allows for a total of 3 200m of growlines.

Costs are presented in Table 4 and details and drawings are in section 5.2.4.1 of the appendix.

Layout 2 - Single line layout with deadweigths

This layout is an adaptation of layout 1, with fluke anchors replaced by deadweigths. This change is not only changing the cost of sea gear and their efficiency, but especially it is changing the amount of growlines in the farm. Deadweigths operate with a lower line to depth ratio of 3 to 1 (GreenWave, 2022). Therefore, the farm area can fill more growlines in the same space as the layout 1, for a total of 5 000m of growlines. On the other hand, setting up deadweigths of 1 200 kgs is not feasible with a light workboat and a heavy workboat must be used for the set up of this layout, as well as all the layouts based on deadweigths.

Based on the yearly cost of sea gear per meter of growline presented in Table 4, it can be seen that layout 2 has lower costs than layout 1. The higher density of growlines also displays financial benefits for lowering the weight of fixed costs such as the licence, the workboat, infrastructures on land, etc. This outweighs the higher cost for setting up the sea gear on year 1, as is shown in the results section. Therefore, the next layouts are based on deadweigths instead of fluke anchors.

Costs for this option are presented in Table 4 and details and drawings are in section 5.2.4.2 of the appendix.

Layout 3 - Single line layout with deadweigths, low sea gear use

Layout 3 is based on layout 2, but with a reduced use of sea gear. The previous layouts were based on the farm simulator provided by Greenwave, from which the necessary sections, buoys and weight of anchors was determined. Unlike the US, where Greenwave is based, Norway has many fjords which offer considerable protection from waves, winds, and depending on the location, currents. Layout 3 was then created to explore the financial performance of a farm based on a sheltered location allowing a lesser need of sea gear. Therefore, in this layout, the weight of the deadweights is halved and the number of buoys supporting the structure is reduced. The section of the ropes, both as active and structural sea gear are kept.

The costs are summarized in Table 4 and the detail of sea gear used for this layout is visible on section 5.2.4.3 (page 69) of the appendix.

Layout 4 - Single line layout with deadweigths, 4m width between growlines

The distance between each growlines in the layout 1, 2 and 3 was 12m, based on indications from GreenWave. Layout 4 is based on layout 2 (single line with deadweigths), but the distance between each growline is greatly reduced. In their paper exploring mariculture of *Saccharina japonica* or Kombu, Zhang et al. (2012) studied a kelp farm in Sungo bay, China, having 4m between each growline (Zhang *et al.*, 2012). China has developed a mature and extensive seaweed farming industry, which supports a high level of confidence that this spacing is adequate to offer optimal yield while allowing farming operations to take place. Kombu being a kelp species quite similar to sugar kelp, the same distance between each growline will be set in this layout. Therefore, instead of having 50 growlines of 100m each in the layout 3, the layout 4 contains 150 growlines of 100m, for a total of 15 000m of growline.

See Table 4 for costs summary and section 5.2.4.4 of the appendix (page 70) for details on this layout.

Layout 5 - Single line layout with deadweigths, low sea gear use, 4m between growlines

The layout 5 is based on the layout 4, so it is a single line layout anchored with deadweigths, with 4m between each growlines. The number of growlines as well as their length is unchanged from layout 4. However, the sizing of the sea gear is reduced compared to layout 4, to accommodate a sheltered area. Those changes induce a reduction in overall cost of the layout.

Costs for this option are presented in Table 4 and details are in section 5.2.4.5 of the appendix (page 71).

Layout 6 - Vertical growlines layout with deadweigths

Layout 6 marks a significant change compared to the layouts previously described. Instead of having a horizontal growline anchored at both ends, this layout is made by a horizontal fix line at 10m depth, as part as the structural sea gear. The growlines are attached to this fix line on one end and floating towards the surface with a buoy on the other end. Therefore, instead of having one long growline, there is a multitude of 10m growlines, spaced every 2m on the fix line. This layout has the characteristic of having a very high density of growline per unit of surface. However, this density reduces the yield harvested per meter of growline, calculated at 3,5176kg/m instead of 5kg/m for the single line layouts (see section 5.2.7.2 of the appendix for calculations). Furthermore, this layout is more time consuming to harvest and seed. The lower yield and longer time to operate the lines is taken into consideration when calculating the financial performance of this layout. Details, calculations and drawing of this layout are presented in section 5.2.4.6 of the appendix, while costs are summarized in Table 4.

Table 4 Options of step 2 - Material investment

Options	Unit	Value
2 Material investment		
2.1 Light workboat		
2.1.1 High cost		
Cost of boat	NOK	750 000,00
Years of service	Years	15,00
Annual maintenance	NOK	5 000,00
2.1.2 Low cost		
Cost of boat	NOK	250 000,00
Years of service	Years	10,00
Annual maintenance	NOK	5 000,00
2.2 Land infrastructures		
2.2.1 High cost		
Cost of warehouse	NOK	3 000 000,00
Years of service	Years	30,00
Annual maintenance	NOK	5 000,00
2.2.2 Low cost		
Cost of warehouse	NOK	1 000 000,00
Years of service	Years	30,00
Annual maintenance	NOK	5 000,00
2.3 Sea gear		
2.3.1 Layout 1 - Single line layout with fluke anchors		
Growline - Length	m	128,00
Growlines - Number		25,00
Growline - Length total	m	3 200,00
Total structural sea gear	NOK	129 266,50
Total active sea gear	NOK	20 370,00
Yearly cost of sea gear per meter of growline	NOK/y	3,97
2.3.2 Layout 2 - Single line layout with deadweigths		
Growline - Length	m	100,00
Growlines - Number		50,00
Growline - Length total	m	5 000,00
Total structural sea gear	NOK	180 535,50
Total active sea gear	NOK	32 850,00
Yearly cost of sea gear per meter of growline	NOK/y	3,72
2.3.3 Layout 3 - Single line layout with deadweights, low sea gear use		
Growline - Length	m	100,00
Growlines - Number		50,00
Growline - Length total	m	5 000,00
Total structural sea gear	NOK	126 423,00
Total active sea gear	NOK	27 052,50
Yearly cost of sea gear per meter of growline	NOK/y	2,77
2.3.4 Layout 4 - Single line layout with deadweigths, 4m width between growlines		
Growline - Length	m	100,00
Growlines - Number		150,00
Growline - Length total	m	15 000,00
Total structural sea gear	NOK	541 606,50
Total active sea gear	NOK	98 550,00
Yearly cost of sea gear per meter of growline	NOK/y	3,72
2.3.5 Layout 5 - Single line layout with deadweigths, low sea gear use, 4m between growlines		
Growline - Length	m	100,00
Growlines - Number		150,00
Growline - Length total	m	15 000,00
Total structural sea gear	NOK	379 269,00
Total active sea gear	NOK	81 157,50
Yearly cost of sea gear per meter of growline	NOK/y	2,77
2.3.6 Layout 6 - Vertical growlines layout with deadweigths		
Growline - Length	m	10,00
Growline - Number		2 500,00
Growline - Length total	m	25 000,00
Total structural sea gear	NOK	202 535,50
Total active sea gear	NOK	221 250,00
Yearly cost of sea gear per meter of growline	NOK/y	2,31

2.2.3 Step 3 – Set up

The set up describes the laying of the sea ger in the water. This step is done on the beginning of year 1, and considering the lifetime of the structural sea gear is 15 years, this event is only happening once during the 10 years length of the study. This step contains 2 options.

2.2.3.1 Set up using light workboat (owned)

The cheapest option is to set up the sea gear with a light workboat, which in our study, is bought by the farm on year 1. However, this option is only compatible with the layout 1, which uses fluke anchors weighing 35 kgs. See Table 5 for details.

2.2.3.2 Set up using heavy workboat (rented)

For any other layout than 1, the sea gear is anchored with deadweights, weighing either 1 200 kgs or 600 kgs. Therefore, the use of a heavy workboat is necessary. The set up can be done in one day with a heavy work boat, for a cost of NOK 250 000 (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). The details are presented in Table 5.

Table 5 Options of step 3 - Set up

Options	Unit	Value
3 Set up		
3.1 Set up using light workboat (owned)	NOK	
Day of workboat operation (including employee and fuel cost)	NOK	10 000,00
Days needed for set up	day	2,00
Total cost of setup	NOK	20 000,00
3.2 Set up using heavy workboat (rented)		
Day of boat rental	NOK	250 000,00
Days needed for set up	day	1,00
Total cost of setup	NOK	250 000,00

2.2.4 Step 4 – Seed supply

This step has been created at the beginning of the study with the ambition to create several options for the supply of seeds. However, sufficient data has been collected only for one option, which is to buy seeds or seeded lines from a hatchery in the Netherlands, Hortimare. This hatchery is probably the main supplier of seeds for seaweed farms in Norway, and their pricelist made it possible to create this option and the costs associated. Other farms along the coast have chosen to develop their own hatchery, and different motivations for this move are observable. From a business rationale, some decided to develop their hatchery because they ambition to scale up their farming activities (e.g. Ocean Forest) or because they plan to sell seeds to other farms (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). Even if no precise data has been collected on the cost of a hatchery, it is safe to assume such an investment would be unprofitable for a small farm such as the space area of 9 hectares that is used as a reference in this study. However, such an investment is still being considered by some relatively small farms, not out of a business logic, but based on reliability. Some farms have experienced unexpected low yields on some years, and the cause was believed to be the low quality of seeds received, in this case from Hortimare (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). Whether it is due to the process occurring at the Hortimare facilities (hence, specific to that supplier) or because of long transport time to deliver the seeds to Norway has not been specified.

The quality of the seeds, possibly impacting the yield and the profitability, is not studied in depth in this model, but the possibility of such an event occurring is considered in the results and discussion section on an individual basis. The capacity of the theorical profits to be high enough to cover such an event is part of the assessment of each scenario.

Table 6 Option of step 4 – Seed supply

Options	Unit	Value
4 Seed supply		
4.1 Supplier 1 - Hortimare		
Cost seeded lines (between 3 000m and 8 000m)	NOK/m	38,00
Cost seeded lines (>8 000m)	NOK/m	36,25
Shipping	NOK	15 000,00

2.2.5 Step 5 – Seeding

Seeding describes putting the seeds on the growlines and have them laid in the water in autumn at the beginning of the growing season. In our case, the seeding consists of wrapping seeded twine (bought from an external supplier) around the growlines. Over the growing season, the holdfast will attach to the growlines until harvest in spring. The seeding time is not the same whether the layout chosen uses horizontal or vertical growlines, and a heavy workboat can seed and lay the lines faster than a light workboat. Details about the costs and calculation for both options presented below are available in appendix (Section 5.2.6, page 78).

2.2.5.1 Seeding using heavy workboat (rented)

One option to conduct seeding is to rent a heavy workboat, similarly to what is done during the harvesting phase. This option is presented in Table 7, detailing the difference of efficiency between the seeding of horizontal growlines compared to the seeding of vertical growlines. See appendix section 5.2.6.1 for calculations.

2.2.5.2 Seeding using light workboat (owned)

As described in step 2, the farm owns a light workboat for general monitoring of the farm and light operations. Unlike harvesting, seeding does not imply the need for heavy machinery considering the growlines are empty. This opens the possibility to use a light workboat for that purpose. This option is presented in Table 7 and details and calculations are provided in section 5.2.6.2 of the appendix.

Table 7 options of step 5 - Seeding

Options	Unit	Value
5 Seeding		
5.1 Seeding using heavy workboat (rented)		
Price of boat rental per day	NOK	250 000,00
Meters of growline seeded per day (horizontal)	m/day	10 000,00
Meters of growline seeded per day (vertical)	m/day	715,00
5.2 Seeding using light workboat (owned)		
Cost of workboat operation per day (including employee and fuel cost)	NOK	10 000,00
Meters of growline seeded per day (horizontal)	m/day	2 500,00
Meters of growline seeded per day (vertical)	m/day	180,00

2.2.6 Step 6 – Harvest

The harvest usually occurs in spring, when the seaweed has reached a satisfying yield but is not yet subject to biofouling. It is an important period in the year for a seaweed farm and tends to engage substantial spendings.

2.2.6.1 Harvest boat

In step 2 about material investment (section 2.2.2.1), the need for a light operation boat was described to be used around the farm year-long, for monitoring operations. Considering such a boat has a high frequency use, its ownership by the farm has been considered a necessity. As described, it is a boat under 8m, operated by a single person, with no heavy machinery except for a manual winch to help lift the lines. At the expense of a longer harvesting period, such a light workboat could potentially be used for harvesting.

In addition, renting a heavy workboat is another possibility that several farms in Norway have chosen (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). A heavy operation boat is operated by a crew of about 4 people and is equipped with a crane and hydraulic machinery allowing heavy operations such as the setup of the structural gear (in the case of deadweigths) or the fast harvesting of the seaweed at the end of spring.

This sub step therefore contains two options: using the light operation boat owned by the farm or renting a heavy operation boat. The efficiency and total cost of the operation is dependent on the boat, the length of growlines and the layout. Harvesting up to 10 000m of horizontal growline can be done in a single day with a heavy operation boat. Such a boat costs NOK 250 000 per day (crew and fuel costs included) while a light operation boat already owned costs NOK 10 000 per day (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). From the experiment in the Faroes, it can be seen that a heavy operation boat can only harvest 715m of growline per day in a vertical layout (Bak, Mols-Mortensen and Gregersen, 2018). A similar ratio is set for the difference between those 2 layouts when harvested by a light operation boat. Those 2 options and the value associated are indicated in Table 8 and details about the efficiency of each option for harvesting is presented in section 5.2.4.6 of the appendix.

2.2.6.2 Harvesting method

This sub step contains 2 options: full harvesting and partial harvesting. The harvesting method of partially harvesting seaweed have gained a lot of interest since the experiment conducted in the Faroe Islands and the subsequent publication of the study explaining the economic benefits of partial harvesting in comparison to full harvesting was published (Bak, Mols-Mortensen and Gregersen, 2018). It had attracted a lot of attention as an innovation that could substantially reduce the production cost of seaweed. The rationale is that by partially harvesting the seaweed, it regrows from the same holdfast, therefore avoiding the need to re-seed the lines every season. The data from Bak et al. (2018) assumes a higher financial performance of the partial harvesting compared to full harvesting, so this option is tested in this step of the production process. The species grown by Ocean Forest was sugar kelp and winged kelp, but considering the results from winged kelp were deemed too unreliable for analysis, the assessment is only performed on sugar kelp (Bak, Mols-Mortensen and Gregersen, 2018).

Unfortunately, partial harvesting in the Faroes was not studied separately, and the performance of partial harvesting was mixed with other factors influencing the yield, especially the occurrence of multiple harvests per year and a vertical layout. The weight of partial harvesting compared to the other factors is explored and presented in section 5.2.7.2 of the appendix (page 83), and the consequences on the farming process are summarized in Table 8.

2.2.6.3 Harvesting frequency

This step is also inspired from the experiment conducted in the Faroes (Bak, Mols-Mortensen and Gregersen, 2018). Usually, kelp is harvested only once a year, which in Norway occurs around spring or early summer. In the experiment conducted by Ocean Rainforest, it was decided to increase the harvesting frequency, from one harvest a year to two harvests per year. This option of having multiple harvests in a single year is explored in this step. As can be seen in Figure 14, this step can be chosen independently from the previous step about the harvesting method (partial or full). One could decide to employ partial harvesting in a farm, while harvesting only once a year, as is usually done for kelp. Alternatively, having two harvests per year could be done while using partial harvesting or full harvesting. However, those two options are still closely related, as harvesting and re-seeding more than once a year would induce considerably higher costs in seeding and seed supply if partial harvesting is not used. Therefore, choosing full harvesting and multiple harvesting for cultivating seaweed is theoretically possible, but is excluded following business rationale.

In the previous step about the performance of partial harvesting compared to the performance of full harvesting, the assumption was stated that the difference of yield observed at Ocean Rainforest compared to the average yield observed on the Norwegian coast is due to the layout. This means that no benefit in term of yield comes from multiple harvests per year and that growth of the seaweed is not impacted by a partial harvesting. It could therefore be concluded that multiple harvesting does not bring any apparent financial benefits. The option of multiple partial harvests is however added to the study because smaller harvested volumes over a longer period through multiple harvest could provide some other benefits than financial. For example, it could allow using a light operation boat for harvesting and avoid the need of renting a heavy operation boat. Furthermore, not having all the biomass produced in a season landed at once could prove beneficial for the sizing of post-harvest infrastructure for conservation and processing. Those options are summarized in Table 8.

Table 8 Options of step 6 - Harvesting

Options	Unit	Value
6 Harvesting		
6.1 Harvest boat		
6.1.1 Harvest using heavy workboat (rented)		
Day of boat rental	NOK	250 000,00
Meters of growline harvested per day (horizontal lines)	m/day	10 000,00
Meters of growline harvested per day (vertical lines)	m/day	715,00
6.1.2 Harvest using light workboat (owned)		
Day of workboat operation (including employee and fuel cost)	NOK	10 000,00
Meters of growline harvested per day (horizontal lines)	m/day	1 500,00
Meters of growline harvested per day (vertical lines)	m/day	110,00
6.2 Harvesting method		
6.2.1 Full harvesting		
Number of harvest before re-seeding		1,00
Yield ratio		100%
6.2.2 Partial harvesting		
Number of harvest before re-seeding		2,00
Yield ratio		90%
6.3 Harvesting frequency		
6.3.1 Annual harvesting		
Number of harvest per year		1
Ratio of annual yield per harvest		100%
6.3.2 Bi-annual harvesting		
Number of harvest per year		2
Ratio of annual yield per harvest		50%

2.2.7 Other variables

In addition to the variables and expenses described in the previous section, some other variables must be taken into consideration in the financial analysis. Those variables or expenses are independent from any option chosen.

2.2.7.1 Yield in Norway

Determining the financial viability of seaweed cultivation in Northern Norway is first determining the yield to be expected in the region, which is itself dependent on the ecosystem conditions. Both the ecosystem conditions and the yield they can be sourced using a narrative literature review, that will complement the yield found on different farms along the coast.

The annual yield will be given in kilos of wet material per meter of growline per year, so in kg/m/y, also simply written kg/m throughout the study, as the yield is only expressed yearly. This is a widely used unit for farms, considering that farms have different layouts, and so have different length of growline in the water per hectare of sea area farmed. Having the yield expressed in kg/m allows us to have the potential of a location and so to calculate the yield depending on different layouts. However, studies conducted to assess the biomass of wild population are given as weight per area, in kg/m^2 or kg/h. Without the information of the number of growline and how far they are spaced, one unit cannot easily be translated into another (Kerrison *et al.*, 2015).

The yield is calculated specifically for sugar kelp, which is the species on which this study is based. A valuable contribution to a narrative literature review aimed at finding the yield of sugar kelp along the coast is a paper from Forbord et al. (2020), who conducted a study on the coast of Norway in 2017, measuring among other factors the frond length and biomass production on 9 different locations. The locations span from Kristiansand to Tromsø, and at each location the yield is studied at 2 different depths, 2m and 8m. The study found that the highest biomass yield were achieved at the latitude of Trondheim during summer and at the latitude of Tromsø in autumn, with a maximum of 14kg/m at the shallowest depth (Forbord *et al.*, 2020). A yield of 14kg/m would sound very promising, however this yield does not represent what a farm growing sugar kelp for food and feed markets could harvest. Past a certain time during the year, the quality of the kelp decreases, even if the biomass keeps increasing. This time point depends on the latitude, as harvests occurs later in northern location compared to farm located further south. This decrease in quality is mainly due to biofouling, which is taking hold on the sugar kelp fronds throughout the summer. Therefore, in order to keep the high quality required for food or feed markets, the kelp needs to be harvested before it can reach its highest yield. The study shows that biofouling was less pronounced on the northern location, but it still covered about 20% of the fronds by September. In the previous months the yield was far lower, at about 5 kg/m in June, 6 kg/m in July and 7 kg/m in August, considering only the most productive and shallowest depth of 1 to 2m (Forbord *et al.*, 2020). A farm specialised in food and feed production was suggesting an early harvest in Northern Norway, around June, which would imply an expected yield of 5 kg/m for those markets. This is consistent with studies conducted further south in Europe, concluding that harvesting after April or May resulted in high fouling and low quality, making the seaweed unproper to be used as a food source (Bak, Mols-Mortensen and Gregersen, 2018). Similarly, in the Faroes it was found that the protein and essential amino acid concentration was significantly higher in May and June than in July and August (Mols-Mortensen *et al.*, 2017).

An average yield of 5kg/m is therefore used in this study. This does not take into consideration the difference of yield existing between different locations. For sugar kelp, this difference can reach 10-fold between two cultivation sites from the same area (Bruhn *et al.*, 2016). More specifically, in Norway offshore locations tend to have a higher yield than inshore regions, due to limitation in nutrient availability. Some inshore regions are nonetheless suitable for seaweed cultivation owing to high vertical mixing of seawater. The latitude have been found to have little effect on the yield, whereas there is a difference of growth period, which occurs 2 months later in the North of the country than in the South (Broch *et al.*, 2019). These differences of yield depending on the location are addressed in this model through the use of an environmental study, which ensures that the farm is located at a location where a nominal yield can reasonably be expected.

This yield of 5 kg/m per year chosen for the rest of this study is however only applicable for single line layouts. For vertical layouts, the yield is set at 3,5176 kgs/m/y, due to a lower exposure to UV light, as detailed in section 5.2.7.2 of the appendix (Bak, Mols-Mortensen and Gregersen, 2018). Furthermore, a 10% reduction of yield is applied in case of a partial harvesting.

2.2.7.2 Market price of sugar kelp

The market price of sugar kelp has been acquired using two different sources. The first one is the statistics published by Fiskeridirektoratet, the Norwegian Directorate of Fisheries. Statistics about the aquaculture sector are published each year, and a section is dedicated to seaweed aquaculture. Figure 15 is an abstract of the data published for the period from 2015 to 2020. The price is generated by dividing the total production by the total sales in order to have the average selling price for one kg of seaweed (Fiskeridirektoratet, 2021).

		2015	2016	2017	2018	2019	2020
Sugar kelp	Total production (kg)	49 100	33 380	139 736	173 589	72 673	247 538
	Total sales (NOK)	160 000	100 000	355 300	815 000	2 599 286	6 401 100
	Price per kg (NOK/kg)	3,26	3,00	2,54	4,69	35,77	25,86
Winged kelp	Total production (kg)	1 750	25 975	9 186	1 760	44 206	88 477
	Total sales (NOK)	17 500	817 000	341 800	472 000	1 754 714	2 207 500
	Price per kg (NOK/kg)	10,00	31,45	37,21	268,18	39,69	24,95

Figure 15 Selling price of seaweed in Norway from 2015 to 2020 (Fiskeridirektoratet, 2021)

Figure 15 shows how the average selling price of seaweed have been fluctuating between 2015 and 2020, both for sugar kelp and winged kelp. Such an average selling price would be the most accurate with a higher production volume, as can be seen in 2020 when the average selling price for both species was around 25 NOK/kg. Such an average hides the disparities which could exist between farms producing for high-end markets such as food compared to the ones producing for markets such as feed, characterized by lower value and higher volumes (see Figure 2). During the years displaying a lower production volume, one would therefore expect to find higher average prices. At the exception of 2015, this trend is visible for winged kelp. However, this does not apply for sugar kelp, and the average selling price for the years prior to 2019 appears to be remarkably low.

This data only would indeed prove insufficient to determine a selling price for sugar kelp in our model. Fortunately, interviews were able to validate the results found in 2020 from Fiskeridirektoratet. The Ocean Forest farm from Lerøy indicated in an interview that their selling price for their production is 25 NOK/kg, a production that they destine at 98% to the feed market. At the date of the interview, at the end of 2021, their production was 177t per year, with the objective of raising it to 300t for 2022. They are therefore representing a major part of the Norwegian production of sugar kelp, which increase the confidence in this selling price. Furthermore, two other interviews conducted with other farms in Norway confirmed this selling price of 25 NOK/kg for wet sugar kelp as accurate (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). A selling price of 25 NOK/kg for wet sugar kelp landed at the dock is consequently used for the rest of this feasibility study.

As an indication, dried sugar kelp can be found at 880 NOK/kg retail price in Europe, after processing, transportation and distribution costs (Araújo *et al.*, 2021). 10 kgs of wet sugar kelp are necessary to obtain 1kg of dried sugar kelp (Bak, Mols-Mortensen and Gregersen, 2018).

2.2.7.3 Fuel

As described in step 2, a seaweed farm needs to own a light workboat for monitoring and light operation of the farm. Apart from special event like seeding and harvesting, for which the fuel costs are included in those options, the use of fuel throughout the year for the light workboat is set at NOK 2 500 (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022).

2.2.7.4 Labour costs

Some tasks on the farm need to be performed regularly throughout the year, and so the presence of a regular employee is needed. Those tasks include controlling the gear, measuring the growth of the seaweed, verifying the occurrence of biofouling before the harvest, or preparing the farm in case of exceptional events (tides, storms). On land, the equipment needs to be serviced and prepared (boat, lines, buoys). Finally, some administrative tasks require some time: managing suppliers, customers, marketing and accounting. It is estimated that all those tasks, spread in an entire year, require a half time equivalent. This is excluding special periods, like seeding, harvesting and the set up of the farm, for which the labour costs are directly tied to those events.

Based on the salary calculator provided by Altinn.no, a full-time equivalent will cost about NOK 600 000 to the company, for a salary of NOK 500 000. Hence, a half time equivalent will cost the farm NOK 300 000 every year (Altinn, 2021).

2.2.7.5 Insurance

Based on similar studies, it is estimated that the salmon industry is paying around 2% of revenues in insurance costs. Considering it is part of the same general industry, a similar rate is applied for a seaweed farm (Liu and Sumaila, 2007; Liu *et al.*, 2016)

2.2.7.6 Interest loan

The interest rate for the loan was estimated after an interview with a Norwegian bank. Each project is getting a personalised rate after evaluation by the bank, so the rate chosen for this study is an estimation. Currently, the rate for an aquaculture project is around 5%, however it is expected that this interest rate will increase to around 7% in the near future (SpareBank Nord Norge, 2022). An interest rate of 7% is kept for this study.

2.2.7.7 Dock for harvest

The landing of the wet seaweed post-harvest requires renting a dock to transfer the production from the harvest boat to a truck or processing facility for the time the harvest lasts. The cost of this was set at NOK 5 000.

2.2.7.8 Corporate tax

The tax on corporate income is equal to 22% in Norway (PwC, 2021).

2.2.8 List of expenses

Table 9 is summarizing all the expenses being used in the financial analysis. The cost of each item is not added to this table because apart from the environmental study and the MSP study, the cost of each item is changing, depending on the option chosen for this item or depending on the options chosen previously at earlier steps of the production process. In other words, the cost of each item is depending on the scenario analysed.

Table 9 Sum-up of expenses

1	Legal expenses
	Environmental study
	MSP study
2	Infrastructure expenses
	Workoat
	Workboat maintenance
	Dock for harvest
	Land infrastructure
	Land infrastructures maintenance
	Structural sea gear
	Active sea gear depreciation
3	Set up
	Set up
4	Seed supply
	Seed supply
5	Seeding
	Seeding
6	Harvesting
	Harvesting
Other operating expenses	
	Fuel
	Salaries
Total	
Other expenses	
	Insurance
	Interest loan
	Corporate tax

The value associated with each expense can be found in the income statements and balance sheets for each scenario presented in Appendix in section 5.4.

2.3 Construction of scenarios

Different farming options are possible along the production process, and a combination of those options is called a "scenario". The goal of the financial analysis is to determine which scenario, or set of options, offers the best profitability after landing of the final product, which is wet seaweed. The cost of each option is not fixed, but rather dependent on the scenario in which it is used. For example, the cost associated with harvesting is much higher if the layout chosen is the layout 4, with 15 000m of growlines, instead of the layout 1, with only 3 200m of growlines to harvest. Therefore, different scenarios are constructed from the list of available options presented in Table 10.

Table 10 List of steps, sub-steps and options

List of options	
1 Legal expenses	
2 Infrastructure investments	
2.1	Light workboat
2.1.1	High cost
2.1.2	Low cost
2.2	Land infrastructures
2.2.1	High cost
2.2.2	Low cost
2.3	Sea gear
2.3.1	Layout 1 - Single line layout with fluke anchors
2.3.2	Layout 2 - Single line layout with deadweigths
2.3.3	Layout 3 - Single line layout with deadweights, low sea gear use
2.3.4	Layout 4 - Single line layout with deadweigths, 4m width between growlines
2.3.5	Layout 5 - Single line layout with deadweigths, low sea gear use, 4m between growlines
2.3.6	Layout 6 - Vertical growlines layout with deadweigths
3	Set up
3.1	Set up using light workboat (owned)
3.2	Set up using heavy workboat (rented)
4	Seed supply
4.1	Supplier 1 - Hortimare
5	Seeding
5.1	Seeding using heavy workboat (rented)
5.2	Seeding using light workboat (owned)
6	Harvesting
6.1	Harvest boat
6.1.1	Harvest using heavy workboat (rented)
6.1.2	Harvest using light workboat (owned)
6.2	Harvesting method
6.2.1	Full harvesting
6.2.2	Partial harvesting
6.3	Harvesting frequency
6.3.1	Annual harvesting
6.3.2	Bi-annual harvesting

Considering the number of steps, sub-steps and options, there are in total 768 possible scenarios (details in section 5.1 of the appendix). However, only 6 of them are selected, and the method employed to select them is detailed below.

Those 6 scenarios were chosen because they have good profitability or because they provide some insight on the development of the sector in the future. Scenarios with a negative profitability were largely excluded. The method for either selecting or rejecting a scenario was to extensively use the model and try different options. Some options, after being coded in the model and analysed, were found to have no positive effect on profitability, nor did they provide any useful information for the understanding of the dynamics behind seaweed farming. This explains why some options described in method are not included in any of the 6 scenarios presented in this section, due to profitability reasons.

For all scenarios, a table summarizing the options chosen is presented.

2.3.1 Scenario 1

Table 11 Scenario 1 - List of options

Name	Option
2 Infrastructure investments	
Service Boat	Low cost
Land infrastructures	Low cost
Sea gear	Layout 1 - Single line layout with fluke anchors
3 Set up	
Set up	Set up using light workboat (owned)
4 Seed Supply	
Seed supply	Supplier 1 - Hortimare
5 Seeding	
Seeding	Seeding using light workboat (owned)
6 Harvesting	
Harvest boat	Harvest using light workboat (owned)
Harvesting method	Full harvesting
Harvesting frequency	Annual harvesting

The scenario 1 has a focus on low cost and low technology. The use of fluke anchors is cheaper and allows the use of the light workboat for the set up of the farm, saving some costs on installation. However, this layout does not offer a high density of growlines in the farm space, with only 3 200m. To improve density, deadweigths are used in scenario 2.

2.3.2 Scenario 2

Table 12 Scenario 2 - List of options

Name	Option
2 Infrastructure investments	
Service Boat	Low cost
Land infrastructures	Low cost
Sea gear	Layout 2 - Single line layout with deadweigths
3 Set up	
Set up	Set up using heavy workboat (rented)
4 Seed Supply	
Seed supply	Supplier 1 - Hortimare
5 Seeding	
Seeding	Seeding using light workboat (owned)
6 Harvesting	
Harvest boat	Harvest using light workboat (owned)
Harvesting method	Full harvesting
Harvesting frequency	Annual harvesting

The scenario 2 improves density by using deadweights to reach a total of 5 000m of growlines while keeping a focus on low costs. The set up with a heavy workboat has to be selected due to the impossibility of laying deadweigths using a light workboat, as is done in scenario 1.

2.3.3 Scenario 3

Table 13 Scenario 3 - List of options

Name	Option
2 Infrastructure investments	
Service Boat	Low cost
Land infrastructures	Low cost
Sea gear	Layout 4 - Single line layout with deadweigths, 4m width between growlines
3 Set up	
Set up	Set up using heavy workboat (rented)
4 Seed Supply	
Seed supply	Supplier 1 - Hortimare
5 Seeding	
Seeding	Seeding using light workboat (owned)
6 Harvesting	
Harvest boat	Harvest using light workboat (owned)
Harvesting method	Full harvesting
Harvesting frequency	Annual harvesting

In scenarios 1 and 2, the spacing between growlines is equal to 12m. In scenario 3, layout 4 is used, which improves density of growlines by having a spacing of 4m. This allows to have 15 000m of growlines in the farm space. This considerably higher length of growlines consequently makes the harvest, still accomplished using a light workboat, a much longer process reaching 10 days.

2.3.4 Scenario 4

Table 14 Scenario 4 - List of options

Name	Option
2 Infrastructure investments	
Service Boat	Low cost
Land infrastructures	Low cost
Sea gear	Layout 4 - Single line layout with deadweigths, 4m width between growlines
3 Set up	
Set up	Set up using heavy workboat (rented)
4 Seed Supply	
Seed supply	Supplier 1 - Hortimare
5 Seeding	
Seeding	Seeding using light workboat (owned)
6 Harvesting	
Harvest boat	Harvest using heavy workboat (rented)
Harvesting method	Full harvesting
Harvesting frequency	Annual harvesting

Scenario 4 is similar to scenario 3, but instead of using 10 days for harvesting using a light workboat, the harvesting is done in two days using a rented heavy workboat.

2.3.5 Scenario 5

Table 15 Scenario 5 - List of options

Name	Option
2 Infrastructure investments	
Service Boat	Low cost
Land infrastructures	Low cost
Sea gear	Layout 6 - Vertical growlines layout with deadweigths
3 Set up	
Set up	Set up using heavy workboat (rented)
4 Seed Supply	
Seed supply	Supplier 1 - Hortimare
5 Seeding	
Seeding	Seeding using heavy workboat (rented)
6 Harvesting	
Harvest boat	Harvest using heavy workboat (rented)
Harvesting method	Full harvesting
Harvesting frequency	Annual harvesting

Scenario 5 is using the layout 6 made of vertical lines used in the Faroes Islands (Bak, Mols-Mortensen and Gregersen, 2018). In this scenario, the density of growlines reaches 25 000m in total in the farm space. With a heavy workboat, seeding and harvesting those lines would take 35 days for each process, whereas using a light workboat would take 228 days. Using a light workboat is then unfeasible and a rented workboat is used in this scenario for both seeding and harvesting.

2.3.6 Scenario 6

Table 16 Scenario 6 - List of options

Name	Option
2 Infrastructure investments	
Service Boat	Low cost
Land infrastructures	Low cost
Sea gear	Layout 4 - Single line layout with deadweigths, 4m width between growlines
3 Set up	
Set up	Set up using heavy workboat (rented)
4 Seed Supply	
Seed supply	Supplier 1 - Hortimare
5 Seeding	
Seeding	Seeding using light workboat (owned)
6 Harvesting	
Harvest boat	Harvest using light workboat (owned)
Harvesting method	Partial harvesting
Harvesting frequency	Annual harvesting

Scenario 6 is using layout 3 (horizontal growlines, 4m spacing) to test the impact of partial harvesting on profitability. Scenario 6 is then similar to scenario 4 but instead of having a full harvest every spring followed by seeding the next autumn, the seaweed is partially harvested to avoid seeding on the following autumn. The lines are fully harvested and re seeded every 2 years.

Table 17 is providing a sum-up of all the options used in the 6 scenarios studied.

Table 17 List of options used for all scenarios

Name	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
2 Infrastructure investments						
Workboat	Low cost	Low cost	Low cost	Low cost	Low cost	Low cost
Land infrastructures	Low cost	Low cost	Low cost	Low cost	Low cost	Low cost
Sea gear	Layout 1	Layout 2	Layout 4	Layout 4	Layout 6	Layout 4
3 Set up						
Set up	Light workboat	Heavy workboat	Heavy workboat	Heavy workboat	Heavy workboat	Heavy workboat
4 Seed Supply						
Seed supply	Hortimare	Hortimare	Hortimare	Hortimare	Hortimare	Hortimare
5 Seeding						
Seeding	Light workboat	Light workboat	Light workboat	Light workboat	Heavy workboat	Light workboat
6 Harvesting						
Harvest boat	Light workboat	Light workboat	Light workboat	Heavy workboat	Heavy workboat	Light workboat
Harvesting method	Full harvesting	Full harvesting	Full harvesting	Full harvesting	Full harvesting	Partial harvesting
Harvesting frequency	Annual harvesting	Annual harvesting	Annual harvesting	Annual harvesting	Annual harvesting	Annual harvesting

2.4 Financial model

The 6 scenarios presented in the previous section are then exploited in the last step of the analysis. The end goal is to determine which scenarios display the highest profitability and evaluate them.

The financial model is defined inside this framework:

- The analysis spans over 10 years,
- The sea area in which the farm is installed is fixed at 300m by 300m, for a surface of 9 hectares
- The depth of the farm is 20m
- All suppliers and customers are paying cash
- There are no stocks and all production is sold the same year it is harvested
- The delay of attribution of a farming licence is considered null, licence and environmental study are paid and approved by the beginning of year 1
- The discount rate is set at 10%
- The salvage value at the end of the lifetime of an investment is null, except for the land infrastructure.

The surface of 9 hectares was chosen as a basis using the seaweed farm simulator provided by Greenwave. In the US, it is considered that a 4 hectares farm is the smallest surface expected to be above the breakeven point and generate profits (GreenWave, 2022). Considering the higher costs in Norway, this surface was doubled and set to fit in a square of 300m by 300m, hence the model of 9 hectares used in this study. The objective, by choosing this size, is to test whether seaweed farming could be a profitable venture for an individual willing to manage their own business of moderate size. Therefore, economies of scale are not studied in relation to farm area in this study. It is possible that unprofitable scenarios applied in a 9 hectares farm would turn out to be profitable on a bigger scale, but that possibility is not studied here.
Furthermore, the timespan of 10 years has been chosen as it is a good balance for the different investments and their respective depreciation period. At the end of the 10 years, the investments in the light workboat (lifetime 10 years) and the active sea gear (lifetime 5 years) have entirely lost their initial value (active sea gear is bought again on year 6). The structural sea gear theoretically has some residual value left, but the salvage value for this item is still set at 0. This is because the value of lines and anchors having spent a decade underwater would be very low, if not negative (removal and recycling costs). The farming licence could also theoretically be re-sold at the end of the 10-year period and therefore hold some value, but the demand for such an item is unknown, and the salvage value for this item is therefore set to 0 as well. On the other hand, the land infrastructure (lifetime 30 years) still has a substantial residual value at the end of

the 10-year period. For this reason, the salvage value of this investment is accounted as a revenue at the end of year 10 and included in the calculation of the NPV.

3 Results and discussion

The financial performance of the 6 scenarios selected are summarized in Table 18. Some values are highlighted using a colour scale, from green to red to visually present the best performing scenarios in bright green. The complete Income statements and balance sheets of all those scenarios are available in section 5.4 of the Appendix.

Table 18 Indicators for all scenarios

Financial indicators	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Net Present Value	- 2 851 530	- 2 399 070	1 016 312	- 1 028 716	- 111 527 172	1 513 561
Internal Rate of Return			23,31%	-3,13%		28,67%
Debt	2 500 000	2 900 000	3 800 000	4 200 000	21 300 000	3 800 000
Yield	16 000	25 000	75 000	75 000	87 940	67 500
Breakeven yield	29 585	35 066	57 972	74 980	810 508	45 747
Breakeven price	46,23	35,07	19,32	24,99	230,42	16,94
Cumulated P&L after taxes	- 3 396 251	- 2 516 390	3 320 457	- 11 041	- 180 642 057	4 241 832

The scenario 1 is the one requiring the least capital to start the activity, at NOK 2 500 000 in total. It is also the one that does not require heavy deadweights or the need of a heavy workboat at any step of the production process. However, this scenario is suffering heavy losses, with a NPV of NOK – 2 851 530. The main reason behind this low financial performance seems to be due to a low density of growlines in the farm area, only 3 200m leading to a yield of 16t of wet weight, which is the lowest yield of all the scenarios studied. Considering the fixed costs such as the legal expenses, the light workboat, the land infrastructures or the labour costs throughout the year are the same as the other scenarios, it is not surprising to find that this scenario is performing poorly compared to the other ones.

Scenario 2 is also not profitable, with a NPV of NOK – 2 399 070. However, this scenario is not performing as poorly as scenario 1. It can be concluded that for the same farm area of 9 hectares, installing deadweights with a rented heavy workboat is more profitable in the long run than using fluke anchors, due to a better use of the sea space available. Therefore fluke anchors are abandoned and deadweights are used in the rest of the analysis.

Scenario 3, by using a lower spacing of 4m between growlines and thus allowing to have 15 000m of growlines in the farm, is the first scenario studied to generate profits, with a NPV of

NOK 1 016 312. All the other options are set to minimise costs. Especially, the harvest is still done using a light workboat. For harvesting 15 000m of lines, it would then take 10 days for the full harvest, considering a light workboat harvests 1 500m of growline per day. The harvest needs to be done with calm weather, possibly extending the harvest period beyond those 10 days in case of unfavourable weather and consequently negatively impacting the revenues. To understand how a long harvesting period could induce lower revenues, it should be specified that throughout the growing period, the yield increases while the quality decreases as soon as biofouling starts to take hold on the seaweed. Therefore, the harvest is decided at the optimal point between quantity and quality. Having a long harvest period could prevent the seaweed to be harvested at this optimal period, and therefore this loss of revenues could be originating from a lower yield if the harvest is started early, or a loss in revenue due to a lower quality if the harvest is started late. This is why in the next scenario, the option of using a rented workboat for harvesting is studied.

Even if the harvesting period falls to two days instead of 10 days, using a rented workboat for harvest substantially decreases the profits in scenario 4. The NPV reaches a negative value of NOK – 1 028 716 after 10 years. However, looking at the cumulated profit and losses (P&L) of this scenario, one could see that the scenario 4 is almost at breakeven point. The breakeven price for this scenario is NOK 24,99 while a market price of NOK 25,00 is adopted in this study. It is not surprising to find a negative NPV however, considering that the discount rate is set at 10%, making any project with financial performance lower than 10% a bad investment decision. The financial performance of scenario 4 in term of profits and loses is close to 0%.

The takeout of this result is twofold. First, it shows that scenario 3 did not display high enough profits to compensate for the use of a heavy workboat for harvesting, as is chosen in scenario 4. Secondly, it shows that the cost of renting a heavy workboat is having a considerable impact on finances. The set-up, as a step requiring the use of a heavy workboat, does not impact the profits extensively considering this task is done only once in the 10 years period. However, renting a heavy workboat every year costing NOK 250 000 per day proves to be quite unsustainable for the financial health of a seaweed farm. Using a light workboat is then recommended for smaller farms having a length of growlines to harvest below 15 000m. Above that, harvesting might prove too time consuming for the quality or quantity of the seaweed landed.

Scenario 5 is testing the layout introduced in the Faroes by Ocean Rainforest (Bak, Mols-Mortensen and Gregersen, 2018). This scenario, based on vertical lines, is unequivocally not profitable, with yearly losses exceeding NOK 18 000 000 and a NPV of NOK – 111 527 172. This is due in main part to the harvesting (NOK 8 750 000 per year) and the seeding of the growlines (NOK 8 750 000 per year). In other word, the time required to handle multiple growlines makes the layout unprofitable through higher operation costs. Using a light boat for those steps is not feasible as it would take 228 days to seed or harvest 25 000m of vertical growlines based on the estimations chosen. Until a better handling of lines is found, it can be concluded with confidence that the vertical lines do not have a positive impact on profitability, and this layout is to be avoided. It can be observed that the daily cost of a heavy workboat, set at NOK 250 000 and sourced from a seaweed farm in Norway (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022) is a major drive to bring the profitability at such low levels. For such a farm, investing in a heavy workboat would without a doubt prove to be a preferable solution, but this possibility is not tested in this model.

In addition to vertical growlines, the experiment in the Faroes also tested partial harvesting and this harvesting technique is analyzed in scenario 6. This scenario is an adaptation of scenario 3 with the inclusion of partial harvesting, it is then based on a single line layout with 4m spacing. And from the results of scenario 6, it can be concluded that partial harvesting is clearly improving the profitability of the model. Scenario 6 is the best performing scenario of the 6 tested with a NPV of NOK 1 513 561, reaching an increase of about NOK 500 000 in NPV compared to scenario 3 which uses full harvesting. This result is not surprising considering that based on the parameters chosen, using partial harvesting allows to save on seed supply and seeding every 2 years, for a moderate effect on yield (10% reduction). This pattern is observable on the profit and losses over the period, where seeding years have a lesser profitability than non-seeding years.

Considering scenario 6 displays the highest profitability, this scenario is going to be tested further through a sensitivity analysis to observe the effect of different factors on the profitability of this scenario. First, let's explore some slightly different iteration of this scenario.

Installing the farm in a sheltered area allows to reduce sea gear use (layout 5) and lower the costs on structural sea gear. This indeed improve profitability a little further, with a NPV of NOK 1 724 608. This represents an increase of about NOK 159 000 from base scenario, which is a relatively contained increase.

But sea gear is not the only material investment in the farm. So far, the low-cost options have been selected both for the workboat and the land infrastructures on all scenario tested. Taking scenario 6 as a base while using a high-cost workboat and a high-cost land infrastructures, it can be observed that the NPV turns negative, with a value of NOK – 843 110. Therefore, both the workboat and land infrastructure investments need to be as contained as possible to allow the farm to generate profits. Any spending on those items which would stray too far higher than the values selected for the low-cost options would threaten the profitability of the project. However, while the NPV is negative in this case (NOK – 843 110), the cumulated P&L is on the other hand positive at NOK 2 285 732.

The last slight change to scenario 6 is related to the harvest boat. The use of a rented heavy workboat for harvesting instead of the light workboat selected so far has a substantial effect on profitability, with a NPV turning negative at NOK – 657 463. This confirms what has been observed before, that renting a heavy workboat at NOK 250 000 per day for harvesting or seeding is proving to be an expense hardly feasible for a seaweed farm, and that the use of a much cheaper light workboat must be privileged whenever possible.

Therefore, the results from the sensitivity analysis performed on the farming costs only are showing that a small increase in operating expenses can quickly compromise the general profitability of the project. The level of profitability still allows some risk mitigation in case revenues would be lower than expected, considering the possibility of external events affecting the profitability. A risk associated with seaweed aquaculture (or even agriculture in general) is the loss of a year's harvest. Scenario 6 generates about NOK 400 000 of profits per year, and the revenues per year are equal to NOK 1 687 500. Therefore, a total loss of yield could be compensated by about 4 years of full harvest. This is a valuable result considering the loss of a year harvest is not uncommon in seaweed farming. For example, it has happened to at least one Norwegian farm due to a low quality of seeds (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). The failure of the structural sea gear could be another cause, due to natural phenomenon (storm) or artificial (traffic). It occurred in the US, when a floating structure drifting in the farm area caused the seaweed harvest to be lost (The Guardian, 2020).

This observation tends to be consolidated if the sensitivity analysis is performed on other variables. The changes made to explore the robustness of scenario 6 in its ability to generate profits were only based on the costs necessary to operate the farm. As described in Figure 12, the profitability is an outcome of 3 main factors: the operating costs of the farm, the yield and the selling price. Therefore, the sensitivity analysis is now focusing on the yield and the market price, two variables which can have substantial impact on the profitability.

The NPV of the project is analysed when those two variables are modified on a scope ranging from -50% to +50%. The results are showed in Figure 16, which is generated using the values presented in Table 27 in the appendix (page 86).

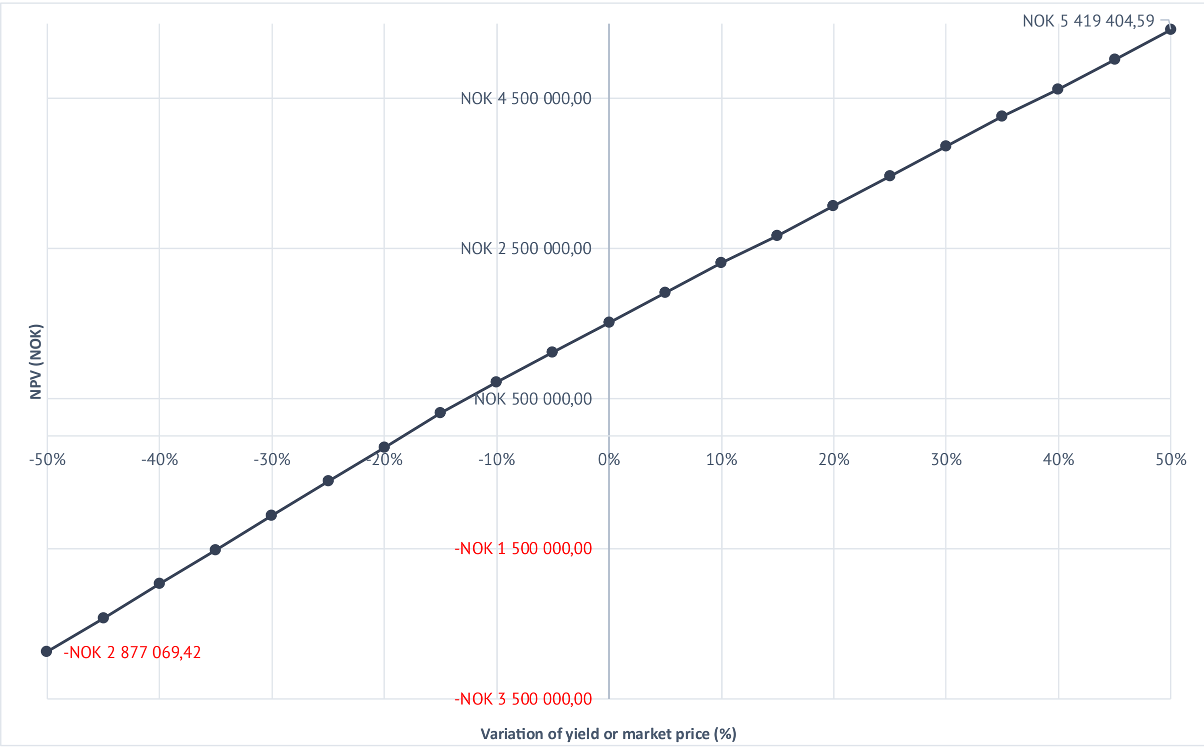

Figure 16 Sensitivity analysis on yield and market price

While the sensitivity analysis is performed on two variables, yield and market price, only one series is visible in Figure 16. This is because, as seen in Table 27, those 2 series are perfectly identical. A variation of +10% would generate the same NPV of NOK 2 306 163 for the project after 10 years, whether this variation is applied on the yield (5,5kg/m/y) or on the market price (27,5 NOK/kg). This is explained by the method used to define the cost of harvesting, which is calculated using the length of growline harvested, the boat used and the layout chosen. The yield is not impacting this calculation and therefore the cost of harvesting is similar whether the yield is 2,5kg/m/y (-50%) or 7,5kg/m/y (+50%). This calculation has been determined based on the data available, and the variation of harvesting cost related to a variation of the quantity of seaweed harvested is not part of this data.

More importantly, what this sensitivity analysis shows is that a decrease of -19% to either the yield or the market price while the other variable stays at nominal value would bring the NPV of

this project to a value close to 0. Similarly, if both variables are decreasing by 9% (yield = 4,55kg/m/y, price = 22,75 NOK/kg), this would make the project hardly worth investing in, with a NPV of NOK 107 666 after 10 years. In term of P&L, the project would get close to breaking even if both variables decrease by -15%, with a cumulated P&L of NOK 412 187 after 10 years.
What those results show is that the project is financially exposed to variation of yield or market price, and a relatively small variation of those variables could easily threaten the profitability of the whole project. This is especially important for the yield. As mentioned in section 2.2.7.1, the yield can vary tremendously from one location to another, potentially bringing the yield below the -19% decrease from the nominal value, at which point the NPV of the project is becoming negative.

Finally, the sensitivity analysis can be extended to the discount rate, which has been set to 10% in this feasibility study. The results are showed in Figure 17 using the NPV values presented in Table 28 in the appendix (page 87).

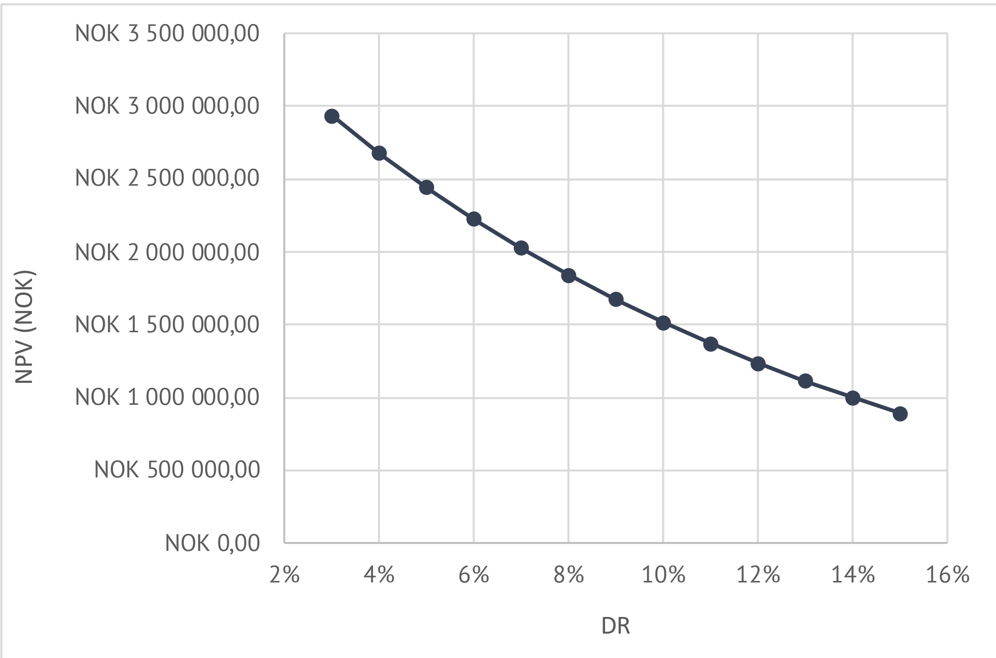

Figure 17 Sensitivity analysis on discount rate

It can be observed that the NPV of scenario 6 remains positive even if the discount rate is increased to as high as 15%. But generally speaking, the sensitivity analyses tend to indicate that even if seaweed farming could be profitable in Norway, the level of risk towards unexpected events or higher expenses is still quite high.

Sensitivity analyses offer valuable insights into the effect of some financial variables on the profitability, however, not all factors which could impact profitability are financial. Expanding the results of this study also means considering the effect of scaling up the production, with a larger farm. And indeed, increasing the farm area while maintaining some costs such as land infrastructures or light workboat would theoretically improve profitability. For example, expanding the farm area of scenario 1 from 9 hectares to 27 hectares (x3) would theoretically have the potential to bring the NPV from NOK - 2 851 530 to NOK – 442 077. But these results need to be taken lightly, considering such farm area is not the focus of this study, and some other costs might come into play with a wider farm (licence costs, investments, etc).

In the same logic, other factors not considered in this study could impact the profitability of a seaweed farm. For example, the method of multi-harvesting as experimented by Ocean rainforest in the Faroes is not included in the scenarios because it does not impact costs as much as it is affecting other factors. Multi harvesting (more than one full harvest or partial harvest per year) could allow a rationalization of the post-production processing facilities or allow to have a good quality to quantity ratio of the harvest while using a light workboat for harvest.

Also, it is important to highlight the difference of how those results could be interpreted depending on whether they are read from an investor or from a potential farmer. Some scenarios, which are barely breaking even and have a negative NPV would be assessed as unworthy investments from the point of view of investors. However, a farmer could decide to create a seaweed farm even in the case of poor profitability because it creates for themselves a job as a farmer. Even without generating large profits, this would be enough of a motivation for some to engage in such a venture.

The discussion can be extended to include the results of other studies and compare it to what results were found here. Especially, an important contributor of this study is the paper describing the experiment ran in the Faroe Islands (Bak, Mols-Mortensen and Gregersen, 2018). Even if partial harvesting was indeed proven to be beneficial based on the results found, vertical lines and multiple harvesting were not. Therefore, it is surprising to find that Ocean Rainforest is considering those three farming and harvesting methods to be positive, while the results from this study (see scenario 5) shows choosing those options is far from yielding the best results. Looking at the financial data, there is a strong difference in the CAPEX/OPEX structure when taking the costs related to 2 500m of growlines

Table 19 CAPEX/OPEX structure between Faroes experiment and current study for 2 500m of growlines

	Current study	Bak et al., 2018
CAPEX	NOK 13 108,57	NOK 217 000,00
OPEX	NOK 1 870 875,00	NOK 47 000,00

Details about the calculations performed to obtain these values are available in appendix (section 5.3.1)

The CAPEX difference could be explained by several factors. First, the farm in the Faroes is located offshore, in a very exposed area, with a considerable higher depth than the one chosen as a base for this study. The Faroes experiments mentions a depth between 50m and 200m, while the depth is set at 20m in this study. Therefore, there is a higher need for structural sea gear than what is considered here. Furthermore, the lifetime of active sea gear in the Faroes is set at 3 years, while it is set at 5 years in this study, for the same reason of exposition to elements. Those 2 factors could explain the higher CAPEX found in the Faroes experiment compared to the current study. However, the substantial difference in OPEX is not as easily explained. The heavy workboat is owned in the Faroes, leading to lower operating costs than renting one for a high price in Norway, causing an increase of CAPEX and decrease of OPEX. Labour costs would also favour the Faroes considering the lower GDP per capita in the Faroes than in Norway (CIA, 2014, 2018). However, those factors alone are not explaining why the difference is so high. Monitoring of the farm using a heavy workboat while the farm is located further offshore would cause higher fuel and labor costs. Seeding and harvesting 2 500m of growlines, an operation which requires a heavy workboat and a crew of about 4 people for a week at sea, would effortlessly bring the operating costs higher than NOK 47 000, at least in a Norwegian perspective. Not much information is given to explain this low OPEX value of NOK 47 000 and therefore the reason cannot be determined. One possible explanation could be that the OPEX found in the current feasibility study is overestimated, at least partially. However, another economic feasibility realized in 2016 tend to point that the results from Bak et al might possibly be overly positive.

The paper mentioned was written by van den Burg et al. (2016) and is an economic feasibility of seaweed production in the North Sea in combination with offshore wind generation (van den Burg *et al.*, 2016). Various seaweed species were tested, including sugar kelp. The conditions of the study are therefore quite similar to the ones tested by Bak et al. (2018). However, the conclusion of van den Burg et al. (2016) is that offshore seaweed production in the North Sea is not economically feasible, and sensitivity analyses show that either price or yield should improve by 300% in order for offshore seaweed farming to be profitable. Furthermore, comparing those results with other studies, van den Burg et al found that there is high uncertainty and little consensus on the costs of seaweed farming, with some costs varying by a factor of 100 between studies, with some publications sketching an excessively positive picture of the costs of seaweed production (van den Burg *et al.*, 2016). This is consistent with another economic feasibility study for offshore seaweed cultivation conducted in Northern Chile on another species of kelp (*Macrocystis pyrifera*), which also concluded that cultivation is not profitable in the long term. This study, incidentally, is also based on vertical growlines (Zuniga-Jara, Marín-Riffo and Bulboa-Contador, 2016).

Those results are given for offshore cultivation, while the current study was focused on coastal farming, but this still gives an valuable insight and another perspective on the findings of Bak et al. (2018). Considering offshore cultivation is characterized by higher costs than coastal farming, those two economic feasibility studies are not contredicting the findings of the current study.

In addition to the subject of profitability, seaweed farming is also concerned by other threats and opportunities which could either favour or hinder the industry. In term of threats for the future of the industry, one could mention the possible genetic interaction between farmed and wild seaweeds, the impact that seaweed farming could have on nearby ecosystems such as benthic organisms, the possible emergence of diseases in seaweed farms, the conflicts in marine spatial planning or the threat from climate change (Stévant, Rebours and Chapman, 2017). Even if profitability is secured for seaweed farming projects, the industry will probably face some of those challenges in the future. However, at least one major opportunity, especially for Norway, could favour seaweed farming and help raise profitability. Integrated multi-trophic aquaculture, which is the joint farming in the same area of finfish and seaweed or other low-trophic species is considered to have significant potential in Norway (Stévant, Rebours and Chapman, 2017). The uptake of dissolved inorganic nitrogen by the seaweed would not only reduce the discharge from salmon farms in Norway, it would also increase the yield of nearby seaweed being farmed, and therefore positively impact profitability of the activity (Broch *et al.*, 2013). The impact of these factors on profitability will get progressively defined as the industry develops.

4 Conclusion

Using a bioeconomic model of a 9-hectare sugar kelp farm on the coast on Norway, this feasibility study found that small-scale seaweed farming can be a profitable activity in Norway, even if not highly profitable. This was determined using a selling price of 25 NOK/kg of wet sugar kelp and a yield of 5kg per meter of growline. Not all model of farms studied are profitable however, and the right set of farming techniques and methods must be implemented in order for a farm to generate an adequate level of profits. A Norwegian small-scale seaweed farm profitability would for example be sensitive to an unexpected reduction of yield or market price of seaweed.
The assessment conducted in this study, by focusing on coastal and small-scale seaweed farms, increased the confidence in the possibility for Norway to host a seaweed industry comprised of self-employed seaweed farmers. Those results are however theoretical and more empirical results from seaweed farms in Norway would prove valuable to investigate how the sector could further improve its profitability.

5 Appendix

5.1 Number of scenarios

The number of different scenarios has been determined using the following formula:

Number_of_scenarios =
*number_of_options_in_step_1 * number_of_options_in_substep_2.1 **
*number_of_options_in_substep_2.2 * number_of_options_in_substep_2.3 **
*number_of_options_in_step_3 * number_of_options_in_step_4 * number_of_options_in_step_5*
** number_of_options_in_substep_6.1 * number_of_options_in_substep_6.2 **
number_of_options_in_substep_6.3
*⟺ 2 * 2 * 6 * 2 * 1 * 2 * 2 * 2 * 2 = 768*

5.2 Details of options and expenses

5.2.1 Light workboat

The light workboat can be bought under different options. Typically, it would be a boat around 8m, with a cabin, an open aft deck equipped with a winch. The low-cost option could be a repurposed fishing boat belonging to the category of under 8m. Those boats (Malo, Myra, Tobias, etc) are sold second hand at about 250 000kr or lower. The lifetime of such a boat would be an additional 10 years from the purchase date, considering the less demanding working conditions of a seaweed coastal farm. A Norwegian farm (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022) indicated that it costed them 230 000kr for such light boat (Polarcirkel type), and they are planning to use it during 10 years. The high-cost options could be aquaculture workboats bought new. For example the OXpro AL8 SC from Hatløy Maritime sold at about 750 000NOK (NauticExpo, 2022) with an expected lifetime of 15 years. Therefore, the depreciation cost for the low-cost option is equal to NOK 25 000 while the high-cost option annual depreciation cost is NOK 50 000 following the calculation below, and considering the salvage value is considered null at the end of the lifetime for each boat.

Acquisition cost / years of service = Annual depreciation cost

For both the low-cost and high-cost options, the annual maintenance cost is estimated at NOK 5 000.

5.2.2 Land infrastructures

No precise information was found in order to determine the cost of the land infrastructures. Therefore, an estimation based on the price of real estate in Norway led to the creation of 2 options in this step:

1. A high-cost option estimated at NOK 3 000 000, usable for 30 years (annual depreciation of NOK 100 000) and an annual maintenance cost of NOK 5 000.
2. A low-cost option estimated at NOK 1 000 000, usable for 30 years (annual depreciation of NOK 33 333) and an annual maintenance cost of NOK 5 000.

The depreciation costs were calculated following the formula below:

Acquisition cost / years of service = Annual depreciation cost

Despite being an estimation, these 2 options cover a wide range of possibilities that represent the costs to be expected for such facilities in Norway.

5.2.3 Sea gear

The sea gear is an important expense of a seaweed farm and the different elements needed are listed below. The availability, selling place and price for each element is expected to fluctuate in the future. However, prices will remain in the same range and it is unlikely that a future evolution of price of one element will substantially change the conclusion of the financial analysis.

5.2.3.1 Growline, retrieval buoy line and growline flotation buoy line

The growline is the line around which the seeds are laid. They are put in the water and attached to the structural sea gear to allow the seaweed to grow. The section and type of line needed have been determined using the farming design tool supplied by the organization GreenWave (GreenWave, 2022), and the cost is based on the retail price from the maritime shop Frøystad (Frøystad, 2022).

- Material: polyester
- Section: 10mm
- Price: 3,30 NOK/m
- Lifetime for growline and growline flotation buoy line: 5 years (active sea gear)
- Lifetime for retrieval buoy line: 15 years (structural sea gear)

5.2.3.2 Anchor line

The anchor lines are joining the anchors to the growline and are fixing the whole structure in the water column. The section and type of line needed have been determined using the farming design tool supplied by the organization GreenWave (GreenWave, 2022), and the cost is based on the retail price from the maritime shop Frøystad (Frøystad, 2022).

- Material: polyester
- Section: 12mm
- Price: 4,40 NOK/m
- Lifetime: 15 years (structural sea gear)

5.2.3.3 Anchor line buoy

The anchor line buoy is attached at the junction between the end of a growline and the anchor line. They prevent this junction, under the weight of the anchor line and its downward pull to sink. The size and type of buoy needed have been determined using the farming design tool supplied by the organization GreenWave (GreenWave, 2022), and the cost is based on the retail price from the maritime shop Nofi (Nofi, 2022).

- Type: A3
- Diameter: 575mm
- Price: NOK 528,00 (NOK 704,00 with VAT)
- Lifetime: 15 years (structural sea gear)

5.2.3.4 Retrieval buoy

The retrieval buoys are attached to the anchors and floating vertically above them. They are not having any role in the structure of the farm and are used only in case the anchors need to be retrieved and located. They are therefore not compulsory. The size and type of buoy needed have been determined using the farming design tool supplied by the organization GreenWave (GreenWave, 2022), and the cost is based on the retail price from the maritime shop Nofi (Nofi, 2022).

- Diameter: 380mm
- Price: NOK 55,50 (NOK 74,00 with VAT)
- Lifetime: 15 years (structural sea gear)

5.2.3.5 Growline flotation buoy

In order to prevent the growline to sink at depth where the growth would not be optimal due to a lack of light, the growline flotation buoys are attached at regular intervals on the growline and make sure it stays at a stable depth. The size and type of buoy needed have been determined using the farming design tool supplied by the organization GreenWave (GreenWave, 2022), and the cost is based on the retail price from the maritime shop WaveInn (WaveInn, 2022)

- Diameter: 295mm
- Price: NOK 55,50 (NOK 74,00 with VAT)
- Lifetime: 5 years (active sea gear)

5.2.3.6 Tension buoy

Current and tides could provoke some slacking in the structure. The tension buoys are attached directly along the anchor line underwater to keep an adequate tension and prevent any slacking. The size and type of buoy needed have been determined using the farming design tool supplied by the organization GreenWave (GreenWave, 2022), and the cost is based on the retail price from Biltema (Biltema, 2022).

- Diameter: 155mm
- Price: NOK 52,43 (NOK 69,90 with VAT)
- Lifetime: 15 years (structural sea gear)

5.2.3.7 Fluke anchor

The fluke anchors are keeping the whole farm fixed in relation to the seabed. They are attached to the anchor lines. The size of the anchor needed have been determined using the farming design tool supplied by the organization GreenWave (GreenWave, 2022), and the cost is based on the retail price from the maritime shop Nofi (Nofi, 2022).

- Weight: 35 kgs
- Price: NOK 1 181,25 (NOK 1 575,00 with VAT)
- Lifetime: 15 years (structural sea gear)

5.2.3.8 Deadweight 1

The necessary weight for each deadweight is set at 1200kg, corresponding to 0,5m^3 of concrete. This is an estimation made using recommendations for deadweights used for mooring ships. The layout requires 75 deadweights, so 38m^3 of concrete. Based on the price catalogue of a Norwegian concrete company (Verde AS, 2021), the concrete itself costs NOK 64 000 (NOK 1 700 per m^3) with a shipping cost of NOK 20 000 (3 trucks of 11m^3 each, 3h delivery time). By adding an estimated NOK 5 000 for labour costs and NOK 10 000 for extra materials, the total cost of the 75 deadweigths is NOK 99 000, so NOK 1 320 for each, rounded up to NOK 1 500.

5.2.3.9 Deadweight 2

The same calculations than the ones used for deadweight 1 are performed to find the cost of this model of deadweight. Considering deadweight 2 is half as heavy as deadweight 1 for a use in sheltered areas, the volume of concrete needed is decreased from 0,5m^3 to 0,25m^3. In total, the necessary volume of concrete is:

$$0{,}25 * 75 = 18{,}75\text{m}^3$$

This represents a cost of NOK 31 875kr on concrete, NOK 15 000 on transport, with still NOK 5 000 labour and NOK 10 000 for material.

31 875 + 15 000 + 5 000 + 10 000 = 61 875 NOK

61 875 / 75 = 825 NOK

The total cost for the 75 deadweigths is then NOK 61 875, so NOK 825 per deadweight, rounded up to NOK 900 per unit.

5.2.4 Layouts

5.2.4.1 Layout 1 Single line layout with fluke anchors

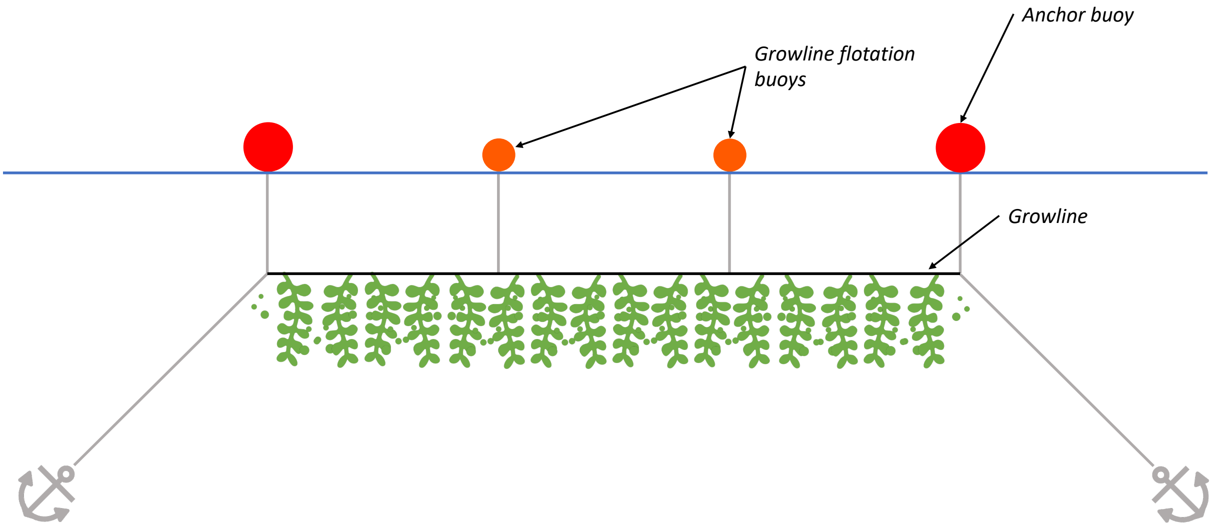

Figure 18 Example of a single line layout with fluke anchors, side view

This layout consists of two fluke anchors set on each side, with an anchor line joining the anchor buoy and the start of the growline. Several growline flotation buoys are maintaining the growline at a constant depth. The growlines, the flotation buoys line and the flotation buoys are active sea gear with a lifetime of 5 years, while the fluke anchors, the anchor buoys and the anchor lines are structural sea gear, with a lifetime of 15 years.

The total area of the farm is a square of 300m by 300m, for a total of 9 hectares. The growlines are set following a single array method, which means each growline is independent and attached on each side by an anchor. The fluke anchors are about 35 kgs each and can be installed by the farmer with a light workboat. Fluke anchors require a 5 to 1 ration between the length of the anchor line to the depth. Considering a depth of 20m and a width of the farm of 300m, the anchor line occupies 86m of the farm on each side, for a total of 172m, which allows for a 128m growline in between. The spacing between each growline is 12m to allow an easy handling of the lines, which allows for 25 growlines, so a total of 3 200m of growlines for the entire farm. A growline with a length of 128m growline requires 6 growline flotation buoys, so a flotation buoy every 16m, each end being buoyed by the anchor buoys. The spacing of growlines in the farm space and the spacing of growline flotation buoys were determined using the Greenwave seaweed farm simulator (GreenWave, 2022). The top view of the 300m by 300m filled with this layout is presented in Figure 19.

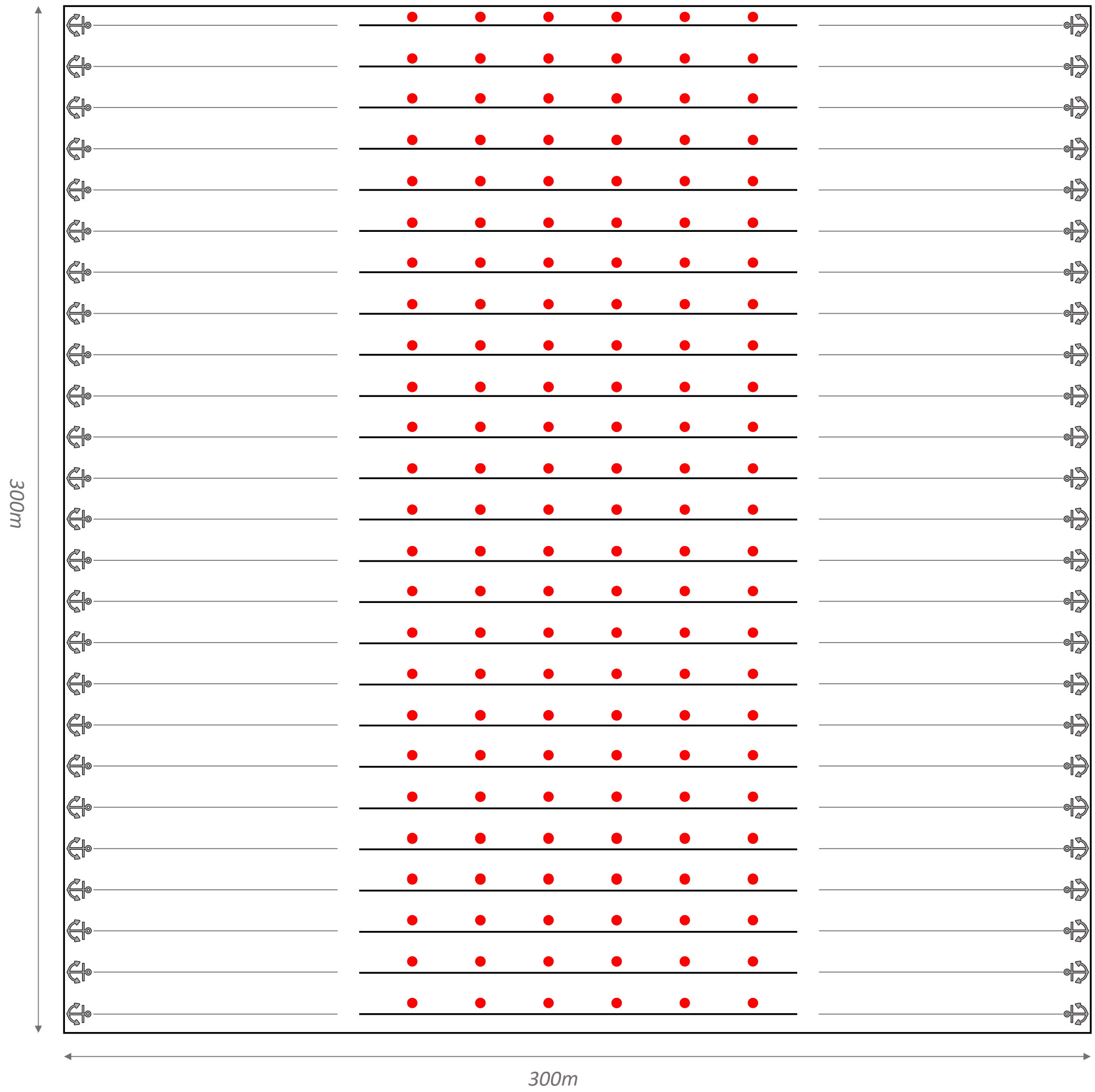

Figure 19 Farm layout – Single line layout with fluke anchors, top view

The details of costs and sea gear is visible in Table 20.

Table 20 Option 2.3.1 - Single line layout with fluke anchors (detailled)

2.3.1 Layout 1 - Single line layout with fluke anchors		
Growline - Length	m	128,00
Growlines - Number		25,00
Growline - Length total	m	3 200,00
Growline - Total cost	NOK	10 560,00
Anchor line - Length per growline	m	200,00
Anchor line - Length total	m	5 000,00
Anchor line - Total cost	NOK	22 000,00
Retrieval buoy line - Length per growline	m	40,00
Retrieval buoy line - Length total	m	1 000,00
Retrieval buoy line - Total cost	NOK	3 300,00
Growline flotation buoy line - Length per growline	m	18,00
Growline flotation buoy line - Length total	m	450,00
Growline flotation buoy line - Total cost	NOK	1 485,00
Anchor line buoy - Number per growline		2,00
Anchor line buoy - Number total		50,00
Anchor line buoy - Total cost	NOK	26 400,00
Retrieval buoy - Number per growline		2,00
Retrieval buoy - Number total		50,00
Retrieval buoy - Total cost	NOK	2 775,00
Growline flotation buoy - Number per growline		6,00
Growline flotation buoy - Number total		150,00
Growline flotation buoy - Total cost	NOK	8 325,00
Tension buoy - Number per growline		12,00
Tension buoy - Number total		300,00
Tension buoy - Total cost	NOK	15 729,00
Anchor - Number per growline		2,00
Anchor - Number total		50,00
Anchor - Total cost	NOK	59 062,50
Total structural sea gear	NOK	129 266,50
Total active sea gear	NOK	20 370,00
Yearly cost of sea gear per meter of growline	NOK/y	3,97

5.2.4.2 Layout 2 - Single line layout with deadweigths

This layout is based on layout 1 but is anchored with deadweigths instead of fluke anchors. Deadweights are effective with a lower ratio between length of line and depth, and a length of anchor line of 30m is set for a depth of 20m, using 22m on the surface. Therefore, instead of one growline measuring 128m like in the previous scenario, the layout is made of two growlines of 100m per row, over 25 rows using a 12m spacing between growlines.

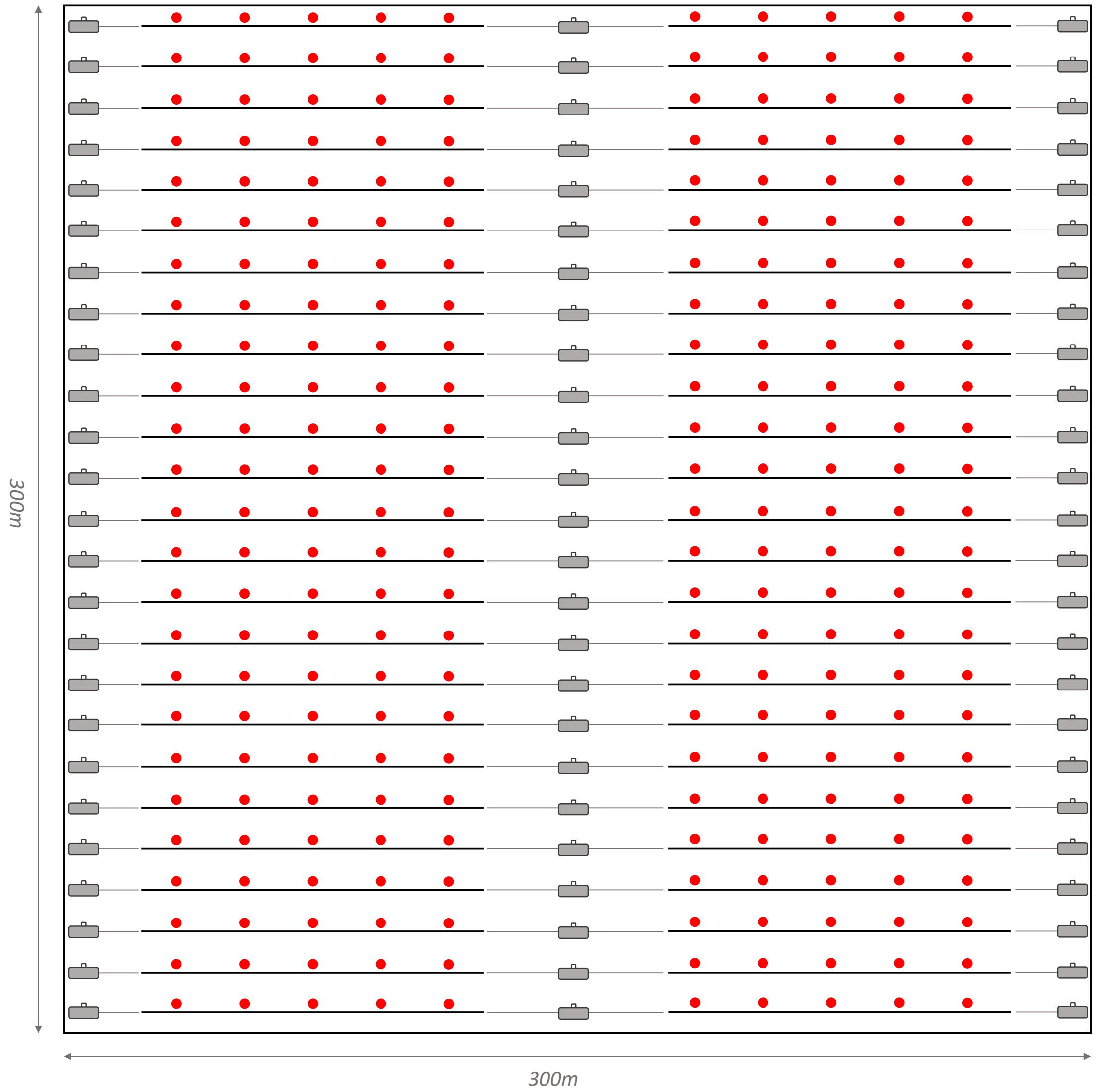

Figure 20 Farm layout - Single line layout with deadweigths, top view

By using deadweigths, the total growline length is therefore equal to 100 * 50 = 5 000m, around 50% increase from the single line layout with fluke anchors.

Table 21 Option 2.3.3 - Single line layout with deadweights (detailed)

2.3.2 Layout 2 - Single line layout with deadweigths		
Growline - Length	m	100,00
Growlines - Number		50,00
Growline - Length total	m	5 000,00
Growline - Total cost	NOK	16 500,00
Anchor line - Length per growline	m	64,00
Anchor line - Length total	m	3 200,00
Anchor line - Total cost	NOK	14 080,00
Retrieval buoy line - Length per growline	m	30,00
Retrieval buoy line - Length total	m	1 500,00
Retrieval buoy line - Total cost	NOK	4 950,00
Growline flotation buoy line - Length per growline	m	15,00
Growline flotation buoy line - Length total	m	750,00
Growline flotation buoy line - Total cost	NOK	2 475,00
Anchor line buoy - Number per growline		1,50
Anchor line buoy - Number total		75,00
Anchor line buoy - Total cost	NOK	39 600,00
Retrieval buoy - Number per growline		1,50
Retrieval buoy - Number total		75,00
Retrieval buoy - Total cost	NOK	4 162,50
Growline flotation buoy - Number per growline		5,00
Growline flotation buoy - Number total		250,00
Growline flotation buoy - Total cost	NOK	13 875,00
Tension buoy - Number per growline		2,00
Tension buoy - Number total		100,00
Tension buoy - Total cost	NOK	5 243,00
Deadweigth 1 - Number per growline		1,50
Deadweigth 1 - Number total		75,00
Deadweigth 1 - Total cost	NOK	112 500,00
Total structural sea gear	NOK	180 535,50
Total active sea gear	NOK	32 850,00
Yearly cost of sea gear per meter of growline	NOK/y	3,72

5.2.4.3 Layout 3 - Single line layout with deadweigths, low sea gear use

Layout 3 is adapted from layout 2, with a reduction of the sea gear to accommodate for a less exposed farm location.

The adaptations include a removal of retrieval buoys, which were directly floating above the deadweigths. The anchor line buoys, which were A3 buoy models with a high buoyancy are replaced with the same model used for growline flotation buoys. Therefore, anchor line buoys are removed, and instead of having 5 growline flotation buoys as in layout 2, the number of growline flotation buoys per growline is raised to 7. More importantly, the weight of deadweigths is halved from 1 200 kgs (deadweight 1 in layout 2) to 600 kgs (deadweight 2 in layout 3), leading to a unit price of NOK 900. Details about the calculations performed to obtain this result are in section 5.2.3.9 of the appendix.

Table 22 Option 2.3.3 - Single line layout with deadweigths, low sea gear use (detailed)

2.3.3 Layout 3 - Single line layout with deadweigths, low sea gear use		
Growline - Length	m	100,00
Growlines - Number		50,00
Growline - Length total	m	5 000,00
Growline - Total cost	NOK	16 500,00
Anchor line - Length per growline	m	64,00
Anchor line - Length total	m	3 200,00
Anchor line - Total cost	NOK	14 080,00
Growline flotation buoy line - Length per growline	m	13,50
Growline flotation buoy line - Length total	m	675,00
Growline flotation buoy line - Total cost	NOK	2 227,50
Anchor line buoy - Number per growline		1,50
Anchor line buoy - Number total		75,00
Anchor line buoy - Total cost	NOK	39 600,00
Growline flotation buoy - Number per growline		3,00
Growline flotation buoy - Number total		150,00
Growline flotation buoy - Total cost	NOK	8 325,00
Tension buoy - Number per growline		2,00
Tension buoy - Number total		100,00
Tension buoy - Total cost	NOK	5 243,00
Deadweigth 2 - Number per growline		1,50
Deadweigth 2 - Number total		75,00
Deadweigth 2 - Total cost	NOK	67 500,00
Total structural sea gear	NOK	126 423,00
Total active sea gear	NOK	27 052,50
Yearly cost of sea gear per meter of growline	NOK/y	2,77

5.2.4.4 Layout 4 - Single line layout with deadweigths, 4m width between growlines

Spacing between growlines is reduced from 12m to 4m.

Calculation of the number of growlines in the layout 4:

length_of_farm_area / distance_between_each_growline = number_of_rows

*number_of_rows * 2 = number_of_growlines*

⇔

300 / 4 = 75

*75 * 2 = 150*

Apart from the difference in spacing, the growlines are similar than in layouts 2 and 3. Therefore, the layout 4 contains a total of 15 000m.

*total_length_growlines = number_of_growlines * length_growline*

⇔

*150 * 100 = 15 000*

Table 23 Option 2.3.4 - Single line layout with deadweigths, 4m width between growlines (detailed)

2.3.4 Layout 4 - Single line layout with deadweigths, 4m width between growlines		
Growline - Length	m	100,00
Growlines - Number		150,00
Growline - Length total	m	15 000,00
Growline - Total cost	NOK	49 500,00
Anchor line - Length per growline	m	64,00
Anchor line - Length total	m	9 600,00
Anchor line - Total cost	NOK	42 240,00
Retrieval buoy line - Length per growline	m	30,00
Retrieval buoy line - Length total	m	4 500,00
Retrieval buoy line - Total cost	NOK	14 850,00
Growline flotation buoy line - Length per growline	m	15,00
Growline flotation buoy line - Length total	m	2 250,00
Growline flotation buoy line - Total cost	NOK	7 425,00
Anchor line buoy - Number per growline		1,50
Anchor line buoy - Number total		225,00
Anchor line buoy - Total cost	NOK	118 800,00
Retrieval buoy - Number per growline		1,50
Retrieval buoy - Number total		225,00
Retrieval buoy - Total cost	NOK	12 487,50
Growline flotation buoy - Number per growline		5,00
Growline flotation buoy - Number total		750,00
Growline flotation buoy - Total cost	NOK	41 625,00
Tension buoy - Number per growline		2,00
Tension buoy - Number total		300,00
Tension buoy - Total cost	NOK	15 729,00
Deadweigth 1 - Number per growline		1,50
Deadweigth 1 - Number total		225,00
Deadweigth 1 - Total cost	NOK	337 500,00
Total structural sea gear	NOK	541 606,50
Total active sea gear	NOK	98 550,00
Yearly cost of sea gear per meter of growline	NOK/y	3,72

5.2.4.5 Layout 5 - Single line layout with deadweigths, low sea gear use, 4m between growlines

The modifications made to adapt layout 4 into layout 5 are similar as the ones between layout 2 and layout 3:

- Suppression of retrieval buoys
- Anchor line buoys are replaced with growline flotation buoys
- The weight of each deadweight is halved, from 1 200 kgs to 600 kgs

The rest of the characteristics in unchanged from layout 4.

Table 24 Option 2.3.5 - Single line layout with deadweigths, low sea gear use, 4m between growlines

2.3.5 Layout 5 - Single line layout with deadweigths, low sea gear use, 4m between growlines		
Growline - Length	m	100,00
Growlines - Number		150,00
Growline - Length total	m	15 000,00
Growline - Total cost	NOK	49 500,00
Anchor line - Length per growline	m	64,00
Anchor line - Length total	m	9 600,00
Anchor line - Total cost	NOK	42 240,00
Growline flotation buoy line - Length per growline	m	13,50
Growline flotation buoy line - Length total	m	2 025,00
Growline flotation buoy line - Total cost	NOK	6 682,50
Anchor line buoy - Number per growline		1,50
Anchor line buoy - Number total		225,00
Anchor line buoy - Total cost	NOK	118 800,00
Growline flotation buoy - Number per growline		3,00
Growline flotation buoy - Number total		450,00
Growline flotation buoy - Total cost	NOK	24 975,00
Tension buoy - Number per growline		2,00
Tension buoy - Number total		300,00
Tension buoy - Total cost	NOK	15 729,00
Deadweigth 2 - Number per growline		1,50
Deadweigth 2 - Number total		225,00
Deadweigth 2 - Total cost	NOK	202 500,00
Total structural sea gear	NOK	379 269,00
Total active sea gear	NOK	81 157,50
Yearly cost of sea gear per meter of growline	NOK/y	2,77

5.2.4.6 Layout 6 - Vertical growlines layout with deadweigths

This layout is based on the layout used in the Faroes Islands by the company Ocean Rainforest (Bak, Mols-Mortensen and Gregersen, 2018). The structural sea gear consists of an anchored horizontal fix line at about 10m deep, on which multiple vertical growlines are attached and float towards the surface, with a buoy on the top end. The growlines are spaced every 2m on the fix line.

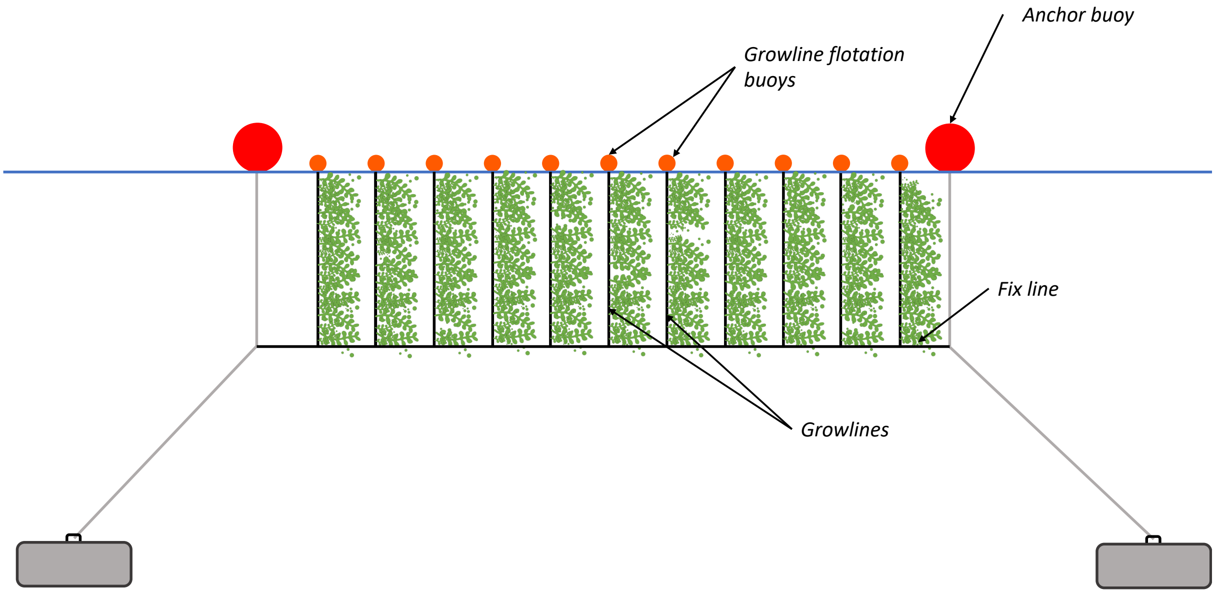

Figure 21 Example of a vertical line layout with deadweights, side view

In the case documented in the Faroes Islands, the structural sea gear is dimensioned for offshore cultivation in deep waters. In this financial analysis the layout of the active sea gear is kept, while adapting the structure to our needs of shallower and more protected waters. The distance between each fix line is given at about 10m in the Faroes. The layout 1,2 and 3 uses a 12m spacing, so the same basis is kept for the placing of the fix lines. Each fix line is 10m deep, therefore the growlines are 10m long each, spaced every 2m. Therefore, this layout contains 2 500 growlines of 10m each, so a total of 25 000m of growline spread over 50 fix lines of 100m each.

length_of_farm_area / distance_between_each_fix_line = number_of_rows
⇔ 300 / 12 = 25

*number_of_rows * 2 = number_of_fix_line*

*⇔ 25 * 2 = 50*

length_fix_line / spacing_between_growlines = number_of_growlines_per_fix_line
⇔ 100 / 2 = 50

*length growline * number_of_growlines_per_fix_line * number_of_fix_line = total_length_growline*
*⇔ 10 * 50 * 50 = 25 000*

This vertical line layout has the characteristic of having much more length of growline per unit of space than the single line layout. With the same spacing, structural gear and the same sea area, the layout 6 with vertical lines has 5 times more length of growline deployed than the layout 2 with a horizontal single line (25 000m versus 5 000m).

However, higher density of growlines and complexity comes at a cost, and the choice of layout has a high impact on the cost of harvesting. The study conducted in the Faroes Islands by the company Ocean Rainforest reports that it took them at first 6,25 days to harvest one fix line of 500m, which contains 2 500m of growlines (Bak, Mols-Mortensen and Gregersen, 2018). According to the footage available online that they posted about this operation, the boat used is a multipurposed vessel equipped with a crane, therefore a similar vessel to the ones needed for harvesting of single line layouts and described in the section of this analysis about harvesting (2.2.6 Step 6 – Harvest). After improvements of the vessel, they harvested the same length in 3,5 days, which equals to 715m of growline harvested per day (Bak, Mols-Mortensen and Gregersen, 2018). To put this number in perspective, a harvest boat can allegedly harvest 10 000m of an horizontal growline layout per day (layouts 1 to 5) (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). The efficiency of harvesting is rounded up to a ratio of 10 to 1 between vertical growline layout and horizontal growline layout in the rest of this study. This difference is used in the step 6 of this analysis to calculate the cost of the harvesting phase, which is then highly dependent on the layout chosen at the step 2 of the production process.

In addition to the higher cost of harvesting, having a denser layout with more length of growlines in the same area of water also induces a lower UV exposure for the seaweed, leading to a lower yield per meter of growline. As found in the experiment ran in the Faroes Islands, the yield applied if the vertical layout is chosen is 3,5176 kgs/m per year. More explanation about UV exposure is determined as the factor for a lower yield, hence dependent on the layout, is given is the section 2.2.6.2 about Harvesting method).

*Table 25 Option 2.3.6 - Vertical growlines layout with deadweigths (detailed_*

2.3.6 Layout 6 - Vertical growlines layout with deadweigths		
Growline - Length	m	10,00
Growline - Number		2 500,00
Growline - Length total	m	25 000,00
Growline - Total cost	NOK	82 500,00
Fix line - Length	m	100,00
Fix line - Number		50,00
Fix line - Length total	m	5 000,00
Fix line - Total cost	NOK	22 000,00
Anchor line - Length per fix line	m	64,00
Anchor line - Length total	m	3 200,00
Anchor line - Total cost	NOK	14 080,00
Retrieval buoy line - Length per fix line	m	30,00
Retrieval buoy line - Length total	m	1 500,00
Retrieval buoy line - Total cost	NOK	4 950,00
Anchor line buoy - Number per fix line		1,50
Anchor line buoy - Number total		75,00
Anchor line buoy - Total cost	NOK	39 600,00
Retrieval buoy - Number per fix line		1,50
Retrieval buoy - Number total		75,00
Retrieval buoy - Total cost	NOK	4 162,50
Growline flotation buoy - Number per growline		1,00
Growline flotation buoy - Number total		2 500,00
Growline flotation buoy - Total cost	NOK	138 750,00
Tension buoy - Number per fix line		2,00
Tension buoy - Number total		100,00
Tension buoy - Total cost	NOK	5 243,00
Deadweigth 1 - Number per fix line		1,50
Deadweigth 1 - Number total		75,00
Deadweigth 1 - Total cost	NOK	112 500,00
Total structural sea gear	NOK	202 535,50
Total active sea gear	NOK	221 250,00
Yearly cost of sea gear per meter of growline	NOK/y	2,31

5.2.5 Seed supply

5.2.5.1 Supplier 1 - Hortimare

The cost of seeded lines is calculated using the pricelist supplied directly by Hortimare, an hatchery located in the Netherlands (Hortimare, 2022). This company offers both seeding material (to be glued on growlines) and already seeded twine, to be wrapped around the growlines. Considering the wrapping of seeded twine appears to be a popular seeding technique in Norway, only this option is selected.

The pricelist from Hortimare can be seen in Figure 22. As indicated by this pricelist, the cost is decreasing with the length of twine ordered. For this study, only 2 categories of prices are kept, based on the length of growlines from each of the layout:

- Length of growlines between 3 000m and 8 000m
- Length of growlines over 8 000m

Between 3 000m and 8 000m

*(cost_per_meter_under_1000 * 1000 + cost_per_meter_under_3000 * 2000) / 3000*
*⇔ (4,0 * 1000 + 3,75 * 2000) / 3000 = 3,833 EUR/m*

Considering all scenarios have a higher total growline length than 3 000m, this result is rounded downwards to EUR 3,80/m. Using a generic conversion rate of EUR 1 = NOK 10, the meter of seeded twine for a total growline length between 3 000m and 8 000m is NOK 38,0.

Over 8 000m

*(cost_per_meter_under_1000 * 1000 + cost_per_meter_under_3000 * 2000) + cost_per_meter_under_8000 * 5000) / 8000*
*⇔ (4,0 * 1000 + 3,75 * 2000 + 3,5 * 5000) / 8000 = 3,625 EUR/m*

Using a generic conversion rate of EUR 1 = NOK 10, the meter of seeded twine for a total growline length superior to 8 000m is NOK 36,25.

The cost of shipping of approximately NOK 15 000, communicated by Hortimare for a delivery in Norway is fixed for all length of twine ordered and added to the cost of twine to obtain the final cost for the supply of seeds.

Pricing 2021 (Europe) Direct Seeding, Seed for Twine and Twine

Amount of Direct Seeding material and Seed for Twine - per meter -	Price per meter (cumulative pricing*)	Small order costs
0 – 1.000	€ 1,50	€ 500,00
1.000 – 3.000	€ 1,50	€ 250,00
3.000 – 10.000	€ 1,50	Not applicable
10.000 – 25.000	€ 1,40	Not applicable
25.000 – 50.000	€ 1,25	Not applicable
50.000 – 75.000	€ 1,00	Not applicable
75.000 – 100.000	€ 0,90	Not applicable
100.000 – 150.000	€ 0,80	Not applicable
150.000 – 200.000	€ 0,70	Not applicable
200.000 – 250.000	€ 0,60	Not applicable
250.000 – 350.000	€ 0,50	Not applicable

Amount of Twine - per meter -	Price per meter (cumulative pricing*)	Small order costs
0 – 500	€ 4,00	€ 500,00
500 – 1.000	€ 4,00	€ 250,00
1.000 – 3.000	€ 3,75	Not applicable
3.000 – 8.000	€ 3,50	Not applicable
8.000 – 12.000	€ 3,25	Not applicable
> 12.000	to be offered by Hortimare and agreed by client	Not applicable

Transportation of the material is ExWorks from The Netherlands to your location; transportation costs are **not included** and will always be invoiced additionally. Estimated costs will be communicated to you beforehand and will be invoiced after shipment based upon the invoice of the carrier. You may also arrange transport yourself at your own risk or we would be able to ship out on e.g. your DHL account if desired.

* Pricing is cumulative; in case you would purchase 35.000 meters, you will pay 10.000 x € 1,50 + 15.000 x € 1,40 + 10.000 x € 1,25.

Small order costs are not cumulative and will only be charged once. The amount of small order costs is based upon the total amount of meters purchased per offer.

Invoicing will be handled by Hortimare BV in Euro's.

General Terms & Conditions apply and can be found on: https://www.hortimare.com/terms/

Figure 22 Pricelist Hortimare

5.2.6 Seeding

The seeding phase describe the wrapping of seeded twine around the growline, as can be seen in Figure 23. This step contains 2 options.

Figure 23 Wrapping of seeded twine around a growline. Source: Ocean Rainforest Instagram @oceanforest_norway

5.2.6.1 Seeding using heavy workboat (rented)

The length of growline harvested per day using a heavy workboat is different dependent on whether the layout uses horizontal or vertical growlines. The difference between each layout is given though the experiment conducted in the Faroes (Bak, Mols-Mortensen and Gregersen, 2018). In this experiment, a heavy workboat is able to harvest 715m per day, while the length is about 10 000m for a horizontal layout (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022). This makes horizontal lines 14 times faster to harvest than vertical lines. This ratio is kept to calculate the difference between vertical and horizontal layouts. Those number are given for harvesting, but considering the handling of line is similar between harvesting and seeding, harvesting is used as a model to estimate the time needed for seeding. Therefore, a heavy workboat is able to seed 10 000m of growlines per day in a horizontal layout, and 715m in a vertical layout. Renting a heavy workboat is NOK 250 000 per day (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022).

The final cost of seeding is therefore not only depending on the workboat chosen at this step, but also dependent on the layout chosen in step 2. A calculation based on the cost of boat rental per day, the length of growline harvested per day with the workboat chosen and the total length of growline in the layout chosen is giving the total cost of seeding in the result section.

> *Total_cost_of_seeding = cost_of_boat_rental_per_day * (total_length_of_growline / length_of_growline_seeded_per_day)*

5.2.6.2 Seeding using light workboat (owned)

The calculations made to determine the cost of seeding with a light workboat are similar to the ones performed to find the cost of seeding with a heavy workboat. However, no data was collected to precisely determine the efficiency of a light workboat for this task, and how much meters of growline it could seed per day. This variable is therefore estimated.

First of all, the possibility of seeding in a light workboat is assumed to be possible, with a high level of confidence. Seeding does not require heavy machinery or the transportation of big loads as is the case for harvesting, therefore the use of a light workboat for this step is feasible. Manual operation of the lines (tying and untying the active sea gear on the structural sea gear and the seeded twine onto the growlines) is part of the seeding process, and this would take a similar time whether performed from a light workboat or a heavy workboat. However, a heavy workboat would allow to gain in efficiency due to the use of a crane and a steadier handling of the lines. Therefore, the light workboat is estimated to be 4 times slower than a heavy workboat to perform this operation. In term of length of growline, this translates to 2 500m of growlines seeded per day, instead of 10 000m when using a heavy workboat. Those number are given for a horizontal layout. This basis is then used using the time difference ratio observed between a horizontal layout and a vertical layout during the harvesting phase using a heavy workboat. The application of the same reduction of efficiency ratio determined in section 5.2.6.1 gives a length of 715m of vertical growlines seeded per day.

This estimation is unfortunately not backed by accurate data to increase the confidence in those findings. However, the consequences of an inaccurate estimation are mitigated by the low importance this step has in the total operational costs of the farm for most scenarios. For the scenario 6, the costs associated with seeding represent under 4% of the total operational costs per year.

5.2.7 Harvest

5.2.7.1 Harvest boat

Figure 24 Heavy operation boat used in the Ocean Rainforest farm (Faroes Islands). Source: Ocean Rainforest Instagram

Figure 25 Heavy operation boat used in the Lerøy Ocean Forest farm (Norway). The boat is used both for harvesting and post-processing (fermentation). Source: Ocean Forest Instagram

Figure 26 Light workboat used for harvesting (from Seaweed Solutions Instagram @seaweed_solutions)

5.2.7.2 Harvesting method

The options of using partial harvesting or full harvesting is based on the study conducted in the Faroes by Ocean Rainforest (Bak, Mols-Mortensen and Gregersen, 2018). In this experiment, several innovative farming techniques were introduced without control lines. Therefore, the benefits of partial harvesting have first to be isolated from the other parameters of the study. In addition to partial harvesting, Ocean Rainforest used multiple harvesting per year and a vertical lines layout, so in total 3 novel options in the production process. Unfortunately, no control lines were set to evaluate the benefits of each option. The single line layout was not controlled alongside vertical lines, neither was single harvesting or no harvesting. Therefore, the performance of those options is deducted from the data available in the study and from the data available from other studies.

Ocean rainforest is partially harvesting the same lines twice a year (Bak, Mols-Mortensen and Gregersen, 2018). The question is whether this multiple partial harvesting is beneficial in term of yield. First, let's calculate the yield of the Ocean Forest farm. The yield from the Ocean rainforest study is given *as dry yield per fix line per year*, which must be converted in the unit used in this financial analysis, which is *wet yield per meter of growline per year.* The productivity of one fix line is given as 879,4 kgs of dry weight per year, which equals to 8 794 kgs of wet weight per year, using a 10 to 1 ratio between wet weight and dry weight (Bak, Mols-Mortensen and Gregersen, 2018). One fix line is 500m, and holds 2 500m of growline, for a total of 3,5176 kgs of wet sugar kelp harvested per meter of growline.

Yield_per_meter_of_growline = yield_per_fix_line / total length growline
⟺ 8 794 / 2 500 = 3,5176

In comparison, a single line growing sugar kelp and harvested once a year is expected to yield approximately 5 kgs of food-grade wet weight per meter. This is supported by both data coming from a farm in Norway growing sugar kelp (*Interview with a Norwegian seaweed farmer (anonymous)*, 2022), as well as the result from a study focused on the yield of sugar kelp on the coast of Norway (Matsson, Christie and Fieler, 2019). This difference of yield could be explained by multiple possible factors:

- Number of harvests (bi-annual vs annual)
- Harvesting technique (partial vs full)

- Location (Faroes vs Norway)
- Farm layout (vertical vs horizontal growlines)
- Exposure (offshore vs semi-offshore or fjord ecosystem)

The absence of control growth in the experiment ran in the Faroes make it more difficult to determine how much those factors are influencing the lower yield. In order to do so, the results of a study conducted on the variation of yield of sugar kelp from different locations and depths in Norway is used (Matsson, Christie and Fieler, 2019). It found the following results.

Table 26 Variation of yield of sugar kelp at 3m and 8m depth. Yield is expressed in kg/m of growline. Data from Matsson et al., 2019

	Yield at 3m depth (kg/m)	Yield at 8m depth (kg/m)	∆Yield (yield_8m / yield_3m)
Inshore	11	6	55%
Fjord	13	6	46%
Semi-offshore	24	18	75%
Average	48	30	63%

Those results show how yield is dependent on depth. On average, the difference of yield between 3m and 8m depth is equal to 63%. This is due to the lowest exposure to UV at lower depth, on which the sugar kelp is dependent for its growth. Farms in Norway which are using a variation of the single line layout tend to lay their lines at less than 3m depth, providing a higher yield than deeper waters. Vertical growlines are ranging from 10m depth to the surface, therefore they are on average positioned at deeper waters and with lower exposure to UV than a single line positioned closer to the surface. On average, it could be considered that the growlines in a vertical layout are about 5m deeper than the growlines in a horizontal layout. In addition, it has been showed how vertical layouts are denser than single line layout (25 000m of growline in vertical layout 6 compared to 15 000m in horizontal layout 4). Higher density also negatively impacts the sunlight received by each strand of seaweed. It can then be concluded that it is probable that the main factor explaining the reduction of yield observed in the Faroes Islands is due to a lower UV exposure because of the vertical layout chosen. The variation of yield between the Ocean Rainforest farm (3,5176 kg/m) and the data from Norwegian experiments (5 kg/m) is equal to 70%. This is close to the average yield difference of 63% found between 3m and 8m depth in Norway, for a similar depth variation than between a horizontal and vertical layout (5m). The other factors are then considered to have a negligeable effect on the yield for the rest of this study. This assumption would need to be tested with other experiment and data in order to be validated, nonetheless the rest of this financial analysis will be based on this assumption. What it means is that multiple partial harvesting is not influencing the yield, and that the financial benefits of using partial harvesting only occur before the growing season, by saving on seed supply and seeding.

The calculation of this financial benefit of partial harvesting is based on the experiment conducted in the Faroes, where they did 4 partial harvests of sugar kelp without the need for reseeding (Bak, Mols-Mortensen and Gregersen, 2018). They were doing bi-annual harvests, so in their case 4 harvests equal to 2 growing seasons. In this current financial analysis, multiple harvests per year is decorrelated from the partial harvesting method, opening possibilities to study other scenarios such as partial harvesting + single harvest per year, a possibility not explored in the Faroes. Therefore, using partial harvesting means that seeding happens only once every 2 years, instead of once a year for full harvesting. Also, to account for the part of the seaweed left on the line and not harvested in a case of a partial harvesting, a reduction of 10% on the yield is applied if partial harvesting is selected.

5.3 Details of discussion

5.3.1 CAPEX/OPEX difference between the Faroes experiment and the current study

The CAPEX and OPEX numbers are given in the paper describing the experiment conducted in the Faroe (Bak, Mols-Mortensen and Gregersen, 2018). Those number are given in EUR per set of 2 500m of growline per year. They are converted to NOK with a conversion rate of EUR 1 = NOK 10. The case of one harvest per year is selected for the calculation.

About the numbers from the current study, scenario 5 is used for the OPEX/CAPEX calculations as it is the closest to the experiment from the Faroe. For the CAPEX, the sum of all maintenance costs and depreciations is calculated. For the OPEX, the cost of seeds, seeding, harvesting, fuel and labor costs are summed. This scenario, using layout 6, contains 25 000m of growlines, therefore the OPEX and CAPEX for the whole scenario are divided by 10 to be compared with the results from the Faroes which are given for 2 500m only. The cost of license and setup, only occurring on year one, are not included in the calculation of Capex and OPEX.

5.3.2 Sensitivity analysis on yield and market price

Table 27 Sensitivity analysis on yield and market price – NPV values

Percentage	Yield	Selling price	NPV (yield)	NPV (selling price)
-50%	2,5	12,5	-NOK 2 877 069,42	-NOK 2 877 069,42
-45%	2,75	13,75	-NOK 2 422 217,84	-NOK 2 422 217,84
-40%	3	15	-NOK 1 967 366,26	-NOK 1 967 366,26
-35%	3,25	16,25	-NOK 1 512 514,68	-NOK 1 512 514,68
-30%	3,5	17,5	-NOK 1 057 663,10	-NOK 1 057 663,10
-25%	3,75	18,75	-NOK 602 811,52	-NOK 602 811,52
-20%	4	20	-NOK 147 959,94	-NOK 147 959,94
-15%	4,25	21,25	NOK 304 713,43	NOK 304 713,43
-10%	4,5	22,5	NOK 717 552,47	NOK 717 552,47
-5%	4,75	23,75	NOK 1 117 259,09	NOK 1 117 259,09
0%	5	25	NOK 1 513 560,63	NOK 1 513 560,63
5%	5,25	26,25	NOK 1 909 862,16	NOK 1 909 862,16
10%	5,5	27,5	NOK 2 306 163,70	NOK 2 306 163,70
15%	5,75	28,75	NOK 2 673 879,53	NOK 2 673 879,53
20%	6	30	NOK 3 070 181,07	NOK 3 070 181,07
25%	6,25	31,25	NOK 3 466 482,61	NOK 3 466 482,61
30%	6,5	32,5	NOK 3 862 784,14	NOK 3 862 784,14
35%	6,75	33,75	NOK 4 259 085,68	NOK 4 259 085,68
40%	7	35	NOK 4 626 801,51	NOK 4 626 801,51
45%	7,25	36,25	NOK 5 023 103,05	NOK 5 023 103,05
50%	7,5	37,5	NOK 5 419 404,59	NOK 5 419 404,59

5.3.3 Sensitivity analysis on discount rate

Table 28 Sensitivity analysis on discount rate – NPV values

DR	NPV
3%	NOK 2 934 189,35
4%	NOK 2 676 556,12
5%	NOK 2 440 158,66
6%	NOK 2 222 995,79
7%	NOK 2 023 277,32
8%	NOK 1 839 399,71
9%	NOK 1 669 924,70
10%	NOK 1 513 560,63
11%	NOK 1 369 145,97
12%	NOK 1 235 634,96
13%	NOK 1 112 084,91
14%	NOK 997 644,98
15%	NOK 891 546,31

5.4 Income statements and balance sheets

5.4.1 Scenario 1

Table 29 Scenario 1 - Income statement and balance sheet

Year	1	2	3	4	5	6	7	8	9	10
Income statement										
Operating expenses										
2 Infrastructure expenses										
Workoat depreciation	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00
Workboat maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Dock for harvest	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Land infrastructure depreciation	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33
Land infrastructures maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Structural sea gear depreciation	8 617,77	8 617,77	8 617,77	8 617,77	8 617,77	8 617,77	8 617,77	8 617,77	8 617,77	8 617,77
Active sea gear depreciation	4 074,00	4 074,00	4 074,00	4 074,00	4 074,00	4 074,00	4 074,00	4 074,00	4 074,00	4 074,00
3 Set up										
Set up	20 000,00	-	-	-	-	-	-	-	-	-
4 Seed supply										
Seed supply	121 600,00	121 600,00	121 600,00	121 600,00	121 600,00	121 600,00	121 600,00	121 600,00	121 600,00	121 600,00
5 Seeding										
Seeding	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00
6 Harvesting										
Harvesting	30 000,00	30 000,00	30 000,00	30 000,00	30 000,00	30 000,00	30 000,00	30 000,00	30 000,00	30 000,00
Other operating expenses										
Fuel	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00
Employees	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00
Total operating expenses	580 125,10	560 125,10	560 125,10	560 125,10	560 125,10	560 125,10	560 125,10	560 125,10	560 125,10	560 125,10
Other expenses										
Insurance	8 000,00	8 000,00	8 000,00	8 000,00	8 000,00	8 000,00	8 000,00	8 000,00	8 000,00	8 000,00
Interest loan	-	175 000,00	175 000,00	175 000,00	175 000,00	175 000,00	175 000,00	175 000,00	175 000,00	175 000,00
Environmental and MSP study	120 000,00	-	-	-	-	-	-	-	-	-
Total other expenses	128 000,00	183 000,00	183 000,00	183 000,00	183 000,00	183 000,00	183 000,00	183 000,00	183 000,00	183 000,00
Total expenses	708 125,10	743 125,10	743 125,10	743 125,10	743 125,10	743 125,10	743 125,10	743 125,10	743 125,10	743 125,10
Operating revenue										
Sales	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00
Total revenues	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00	400 000,00
Income before tax	- 308 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10
Net Income	- 308 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10
Balance sheet										
Liabilities and shareholders' equitiy										
Debt	2 500 000,00	2 500 000,00	2 500 000,00	2 500 000,00	2 500 000,00	2 500 000,00	2 500 000,00	2 500 000,00	2 500 000,00	2 500 000,00
Loss and profits	- 308 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10	- 343 125,10
Total	2 191 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90
Assets										
Licence	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00
Cash	660 263,50	696 288,60	767 313,70	838 338,80	909 363,90	960 019,00	1 031 044,10	1 102 069,20	1 173 094,30	1 910 786,07
Structural sea gear	120 648,73	112 030,97	103 413,20	94 795,43	86 177,67	77 559,90	68 942,13	60 324,37	51 706,60	43 088,83
Active sea gear	16 296,00	12 222,00	8 148,00	4 074,00	-	16 296,00	12 222,00	8 148,00	4 074,00	-
Workboat	225 000,00	200 000,00	175 000,00	150 000,00	125 000,00	100 000,00	75 000,00	50 000,00	25 000,00	-
Land infrastructure	966 666,67	933 333,33	900 000,00	866 666,67	833 333,33	800 000,00	766 666,67	733 333,33	700 000,00	-
Total	2 191 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90	2 156 874,90
Grand total	-	-	-	-	-	-	-	-	-	-

5.4.2 Scenario 2

Table 30 Scenario 2 - Income statement and balance sheet

Year	1	2	3	4	5	6	7	8	9	10
Income statement										
Operating expenses										
2 Infrastructure expenses										
Workoat depreciation	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00
Workboat maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Dock for harvest	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Land infrastructure depreciation	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33
Land infrastructures maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Structural sea gear depreciation	12 035,70	12 035,70	12 035,70	12 035,70	12 035,70	12 035,70	12 035,70	12 035,70	12 035,70	12 035,70
Active sea gear depreciation	6 570,00	6 570,00	6 570,00	6 570,00	6 570,00	6 570,00	6 570,00	6 570,00	6 570,00	6 570,00
3 Set up										
Set up	250 000,00	-	-	-	-	-	-	-	-	-
4 Seed supply										
Seed supply	190 000,00	190 000,00	190 000,00	190 000,00	190 000,00	190 000,00	190 000,00	190 000,00	190 000,00	190 000,00
5 Seeding										
Seeding	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00	20 000,00
6 Harvesting										
Harvesting	40 000,00	40 000,00	40 000,00	40 000,00	40 000,00	40 000,00	40 000,00	40 000,00	40 000,00	40 000,00
Other operating expenses										
Fuel	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00
Employees	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00
Total operating expenses	894 439,03	644 439,03	644 439,03	644 439,03	644 439,03	644 439,03	644 439,03	644 439,03	644 439,03	644 439,03
Other expenses										
Insurance	12 500,00	12 500,00	12 500,00	12 500,00	12 500,00	12 500,00	12 500,00	12 500,00	12 500,00	12 500,00
Interest loan	-	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00
Environmental and MSP study	120 000,00	-	-	-	-	-	-	-	-	-
Total other expenses	132 500,00	215 500,00	215 500,00	215 500,00	215 500,00	215 500,00	215 500,00	215 500,00	215 500,00	215 500,00
Total expenses	1 026 939,03	859 939,03	859 939,03	859 939,03	859 939,03	859 939,03	859 939,03	859 939,03	859 939,03	859 939,03
Operating revenue										
Sales	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00
Total revenues	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00	625 000,00
Income before tax	- 401 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03
Net Income	- 401 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03
Balance sheet										
Liabilities and shareholders' equitiy										
Debt	2 900 000,00	2 900 000,00	2 900 000,00	2 900 000,00	2 900 000,00	2 900 000,00	2 900 000,00	2 900 000,00	2 900 000,00	2 900 000,00
Loss and profits	- 401 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03	- 234 939,03
Total	2 498 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97
Assets										
Licence	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00
Cash	908 614,50	1 152 553,53	1 229 492,57	1 306 431,60	1 383 370,63	1 427 459,67	1 504 398,70	1 581 337,73	1 658 276,77	2 401 882,47
Structural sea gear	168 499,80	156 464,10	144 428,40	132 392,70	120 357,00	108 321,30	96 285,60	84 249,90	72 214,20	60 178,50
Active sea gear	26 280,00	19 710,00	13 140,00	6 570,00	-	26 280,00	19 710,00	13 140,00	6 570,00	-
Workboat	225 000,00	200 000,00	175 000,00	150 000,00	125 000,00	100 000,00	75 000,00	50 000,00	25 000,00	-
Land infrastructure	966 666,67	933 333,33	900 000,00	866 666,67	833 333,33	800 000,00	766 666,67	733 333,33	700 000,00	-
Total	2 498 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97	2 665 060,97
Grand total	-	-	-	-	-	-	-	-	-	-

5.4.3 Scenario 3

Table 31 Scenario 3 - Income statement and balance sheet

Year	1	2	3	4	5	6	7	8	9	10
Income statement										
Operating expenses										
2 Infrastructure expenses										
Workoat depreciation	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00
Workboat maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Dock for harvest	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Land infrastructure depreciation	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33
Land infrastructures maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Structural sea gear depreciation	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10
Active sea gear depreciation	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00
3 Set up										
Set up	250 000,00	-	-	-	-	-	-	-	-	-
4 Seed supply										
Seed supply	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00
5 Seeding										
Seeding	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00
6 Harvesting										
Harvesting	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00
Other operating expenses										
Fuel	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00
Employees	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00
Total operating expenses	1 385 400,43	1 135 400,43	1 135 400,43	1 135 400,43	1 135 400,43	1 135 400,43	1 135 400,43	1 135 400,43	1 135 400,43	1 135 400,43
Other expenses										
Insurance	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00
Interest loan	-	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00
Environmental and MSP study	120 000,00	-	-	-	-	-	-	-	-	-
Total other expenses	157 500,00	303 500,00	303 500,00	303 500,00	303 500,00	303 500,00	303 500,00	303 500,00	303 500,00	303 500,00
Total expenses	1 542 900,43	1 438 900,43	1 438 900,43	1 438 900,43	1 438 900,43	1 438 900,43	1 438 900,43	1 438 900,43	1 438 900,43	1 438 900,43
Operating revenue										
Sales	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00
Total revenues	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00
Income before tax	332 099,57	436 099,57	436 099,57	436 099,57	436 099,57	436 099,57	436 099,57	436 099,57	436 099,57	436 099,57
Net Income	259 037,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66
Balance sheet										
Liabilities and shareholders' equitiy										
Debt	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00
Loss and profits	259 037,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66	340 157,66
Total	4 059 037,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66
Assets										
Licence	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00
Cash	2 080 031,60	2 275 302,03	2 389 452,46	2 503 602,90	2 617 753,33	2 633 353,76	2 747 504,20	2 861 654,63	2 975 805,06	3 756 622,16
Structural sea gear	505 499,40	469 392,30	433 285,20	397 178,10	361 071,00	324 963,90	288 856,80	252 749,70	216 642,60	180 535,50
Active sea gear	78 840,00	59 130,00	39 420,00	19 710,00	-	78 840,00	59 130,00	39 420,00	19 710,00	-
Workboat	225 000,00	200 000,00	175 000,00	150 000,00	125 000,00	100 000,00	75 000,00	50 000,00	25 000,00	-
Land infrastructure	966 666,67	933 333,33	900 000,00	866 666,67	833 333,33	800 000,00	766 666,67	733 333,33	700 000,00	-
Total	4 059 037,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66	4 140 157,66
Grand total	-	-	-	-	-	-	-	-	-	-

5.4.4 Scenario 4

Table 32 Scenario 4 - Income statement and balance sheet

Year	1	2	3	4	5	6	7	8	9	10
Income statement										
Operating expenses										
2 Infrastructure expenses										
Workoat depreciation	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00
Workboat maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Dock for harvest	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Land infrastructure depreciation	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33
Land infrastructures maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Structural sea gear depreciation	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10
Active sea gear depreciation	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00
3 Set up										
Set up	250 000,00	-	-	-	-	-	-	-	-	-
4 Seed supply										
Seed supply	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00	543 750,00
5 Seeding										
Seeding	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00	60 000,00
6 Harvesting										
Harvesting	500 000,00	500 000,00	500 000,00	500 000,00	500 000,00	500 000,00	500 000,00	500 000,00	500 000,00	500 000,00
Other operating expenses										
Fuel	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00
Employees	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00
Total operating expenses	1 785 400,43	1 535 400,43	1 535 400,43	1 535 400,43	1 535 400,43	1 535 400,43	1 535 400,43	1 535 400,43	1 535 400,43	1 535 400,43
Other expenses										
Insurance	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00	37 500,00
Interest loan	-	294 000,00	294 000,00	294 000,00	294 000,00	294 000,00	294 000,00	294 000,00	294 000,00	294 000,00
Environmental and MSP study	120 000,00	-	-	-	-	-	-	-	-	-
Total other expenses	157 500,00	331 500,00	331 500,00	331 500,00	331 500,00	331 500,00	331 500,00	331 500,00	331 500,00	331 500,00
Total expenses	1 942 900,43	1 866 900,43	1 866 900,43	1 866 900,43	1 866 900,43	1 866 900,43	1 866 900,43	1 866 900,43	1 866 900,43	1 866 900,43
Operating revenue										
Sales	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00
Total revenues	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00	1 875 000,00
Income before tax	- 67 900,43	8 099,57	8 099,57	8 099,57	8 099,57	8 099,57	8 099,57	8 099,57	8 099,57	8 099,57
Net Income	- 67 900,43	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66
Balance sheet										
Liabilities and shareholders' equitiy										
Debt	4 200 000,00	4 200 000,00	4 200 000,00	4 200 000,00	4 200 000,00	4 200 000,00	4 200 000,00	4 200 000,00	4 200 000,00	4 200 000,00
Loss and profits	- 67 900,43	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66	6 317,66
Total	4 132 099,57	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66
Assets										
Licence	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00
Cash	2 153 093,50	2 341 462,03	2 455 612,46	2 569 762,90	2 683 913,33	2 699 513,76	2 813 664,20	2 927 814,63	3 041 965,06	3 822 782,16
Structural sea gear	505 499,40	469 392,30	433 285,20	397 178,10	361 071,00	324 963,90	288 856,80	252 749,70	216 642,60	180 535,50
Active sea gear	78 840,00	59 130,00	39 420,00	19 710,00	-	78 840,00	59 130,00	39 420,00	19 710,00	-
Workboat	225 000,00	200 000,00	175 000,00	150 000,00	125 000,00	100 000,00	75 000,00	50 000,00	25 000,00	-
Land infrastructure	966 666,67	933 333,33	900 000,00	866 666,67	833 333,33	800 000,00	766 666,67	733 333,33	700 000,00	-
Total	4 132 099,57	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66	4 206 317,66
Grand total	-	-	-	-	-	-	-	-	-	-

5.4.5 Scenario 5

Table 33 Scenario 5 - Income statement and balance sheet

Year	1	2	3	4	5	6	7	8	9	10
Income statement										
Operating expenses										
2 Infrastructure expenses										
Workoat depreciation	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00
Workboat maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Dock for harvest	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Land infrastructure depreciation	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33
Land infrastructures maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Structural sea gear depreciation	13 502,37	13 502,37	13 502,37	13 502,37	13 502,37	13 502,37	13 502,37	13 502,37	13 502,37	13 502,37
Active sea gear depreciation	44 250,00	44 250,00	44 250,00	44 250,00	44 250,00	44 250,00	44 250,00	44 250,00	44 250,00	44 250,00
3 Set up										
Set up	250 000,00	-	-	-	-	-	-	-	-	-
4 Seed supply										
Seed supply	906 250,00	906 250,00	906 250,00	906 250,00	906 250,00	906 250,00	906 250,00	906 250,00	906 250,00	906 250,00
5 Seeding										
Seeding	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00
6 Harvesting										
Harvesting	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00	8 750 000,00
Other operating expenses										
Fuel	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00
Employees	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00
Total operating expenses	19 089 835,70	18 839 835,70	18 839 835,70	18 839 835,70	18 839 835,70	18 839 835,70	18 839 835,70	18 839 835,70	18 839 835,70	18 839 835,70
Other expenses										
Insurance	43 970,00	43 970,00	43 970,00	43 970,00	43 970,00	43 970,00	43 970,00	43 970,00	43 970,00	43 970,00
Interest loan	-	1 491 000,00	1 491 000,00	1 491 000,00	1 491 000,00	1 491 000,00	1 491 000,00	1 491 000,00	1 491 000,00	1 491 000,00
Environmental and MSP study	120 000,00	-	-	-	-	-	-	-	-	-
Total other expenses	163 970,00	1 534 970,00	1 534 970,00	1 534 970,00	1 534 970,00	1 534 970,00	1 534 970,00	1 534 970,00	1 534 970,00	1 534 970,00
Total expenses	19 253 805,70	20 374 805,70	20 374 805,70	20 374 805,70	20 374 805,70	20 374 805,70	20 374 805,70	20 374 805,70	20 374 805,70	20 374 805,70
Operating revenue										
Sales	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00
Total revenues	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00	2 198 500,00
Income before tax	- 17 055 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70
Net Income	- 17 055 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70
Balance sheet										
Liabilities and shareholders' equitiy										
Debt	21 300 000,00	21 300 000,00	21 300 000,00	21 300 000,00	21 300 000,00	21 300 000,00	21 300 000,00	21 300 000,00	21 300 000,00	21 300 000,00
Loss and profits	- 17 055 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70	- 18 176 305,70
Total	4 244 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30
Assets										
Licence	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00
Cash	2 483 994,50	1 479 080,20	1 595 165,90	1 711 251,60	1 827 337,30	1 722 173,00	1 838 258,70	1 954 344,40	2 070 430,10	2 853 182,47
Structural sea gear	189 033,13	175 530,77	162 028,40	148 526,03	135 023,67	121 521,30	108 018,93	94 516,57	81 014,20	67 511,83
Active sea gear	177 000,00	132 750,00	88 500,00	44 250,00	-	177 000,00	132 750,00	88 500,00	44 250,00	-
Workboat	225 000,00	200 000,00	175 000,00	150 000,00	125 000,00	100 000,00	75 000,00	50 000,00	25 000,00	-
Land infrastructure	966 666,67	933 333,33	900 000,00	866 666,67	833 333,33	800 000,00	766 666,67	733 333,33	700 000,00	-
Total	4 244 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30	3 123 694,30
Grand total	-	-	-	-	- 0,00	- 0,00	- 0,00	- 0,00	- 0,00	- 0,00

5.4.6 Scenario 6

Table 34 Scenario 6 - Income statement and balance sheet

Year	1	2	3	4	5	6	7	8	9	10
Income statement										
Operating expenses										
2 Infrastructure expenses										
Workoat depreciation	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00	25 000,00
Workboat maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Dock for harvest	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Land infrastructure depreciation	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33	33 333,33
Land infrastructures maintenance	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00	5 000,00
Structural sea gear depreciation	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10	36 107,10
Active sea gear depreciation	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00	19 710,00
3 Set up										
Set up	250 000,00	-	-	-	-	-	-	-	-	-
4 Seed supply										
Seed supply	543 750,00	-	543 750,00	-	543 750,00	-	543 750,00	-	543 750,00	-
5 Seeding										
Seeding	60 000,00	-	60 000,00	-	60 000,00	-	60 000,00	-	60 000,00	-
6 Harvesting										
Harvesting	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00	100 000,00
Other operating expenses										
Fuel	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00	2 500,00
Employees	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00	300 000,00
Total operating expenses	1 385 400,43	531 650,43	1 135 400,43	531 650,43	1 135 400,43	531 650,43	1 135 400,43	531 650,43	1 135 400,43	531 650,43
Other expenses										
Insurance	33 750,00	33 750,00	33 750,00	33 750,00	33 750,00	33 750,00	33 750,00	33 750,00	33 750,00	33 750,00
Interest loan	-	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00	266 000,00
Environmental and MSP study	120 000,00	-	-	-	-	-	-	-	-	-
Total other expenses	153 750,00	299 750,00	299 750,00	299 750,00	299 750,00	299 750,00	299 750,00	299 750,00	299 750,00	299 750,00
Total expenses	1 539 150,43	831 400,43	1 435 150,43	831 400,43	1 435 150,43	831 400,43	1 435 150,43	831 400,43	1 435 150,43	831 400,43
Operating revenue										
Sales	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00
Total revenues	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00	1 687 500,00
Income before tax	148 349,57	856 099,57	252 349,57	856 099,57	252 349,57	856 099,57	252 349,57	856 099,57	252 349,57	856 099,57
Net Income	115 712,66	667 757,66	196 832,66	667 757,66	196 832,66	667 757,66	196 832,66	667 757,66	196 832,66	667 757,66
Balance sheet										
Liabilities and shareholders' equitiy										
Debt	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00	3 800 000,00
Loss and profits	115 712,66	667 757,66	196 832,66	667 757,66	196 832,66	667 757,66	196 832,66	667 757,66	196 832,66	667 757,66
Total	3 915 712,66	4 467 757,66	3 996 832,66	4 467 757,66	3 996 832,66	4 467 757,66	3 996 832,66	4 467 757,66	3 996 832,66	4 467 757,66
Assets										
Licence	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00	203 000,00
Cash	1 936 706,60	2 602 902,03	2 246 127,46	2 831 202,90	2 474 428,33	2 960 953,76	2 604 179,20	3 189 254,63	2 832 480,06	4 084 222,16
Structural sea gear	505 499,40	469 392,30	433 285,20	397 178,10	361 071,00	324 963,90	288 856,80	252 749,70	216 642,60	180 535,50
Active sea gear	78 840,00	59 130,00	39 420,00	19 710,00	-	78 840,00	59 130,00	39 420,00	19 710,00	-
Workboat	225 000,00	200 000,00	175 000,00	150 000,00	125 000,00	100 000,00	75 000,00	50 000,00	25 000,00	-
Land infrastructure	966 666,67	933 333,33	900 000,00	866 666,67	833 333,33	800 000,00	766 666,67	733 333,33	700 000,00	-
Total	3 915 712,66	4 467 757,66	3 996 832,66	4 467 757,66	3 996 832,66	4 467 757,66	3 996 832,66	4 467 757,66	3 996 832,66	4 467 757,66
Grand total	-	-	-	-	-	-	-	-	-	-

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